Strategic National Risk Assessment 2015

Technical Appendix

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Homeland Security

PRE-DECISIONAL DRAFT

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Section 1: New & Updated National-Level Risks in 2015

In 2015, SNRA partners reviewed the publicly disseminated findings from the 2011 SNRA for accuracy and relevancy. The review focused on updating data for existing threats and hazards, which would change 2011 findings; and identifying new national-level risks. The list of updated and new risks identified by SNRA partners in 2015 is listed in Table 1 below.

Table 1: New and Updated National-Level Risks for 2015

Quantitatively Assessed Threats and Hazards	Qualitative Narratives Supporting Threat and Hazard Identification
▪ Drought ▪ Human Pandemic Outbreak ▪ Space Weather ▪ Winter Storm ▪ Combustible/Flammable Cargo Accident (Rail) ▪ Transportation System Failure ▪ Aircraft as a Weapon ▪ Armed Assault ▪ Explosives Terrorism Attack ▪ Physical Attack on the Electric Grid	▪ Antibiotic resistance, super bugs ▪ Emerging infectious Diseases other than influenza ▪ Heat Wave ▪ Plant Disease ▪ Industrial Accidents/Explosions ▪ Mass Migration/Migrant Surge ▪ Oil Spills ▪ Pipeline Failure ▪ Cyber Attack ▪ Electric Grid Failure (Natural/Accidental) (Cross-Cutting) ▪ Urban Fire/Urban Conflagration (Cross-Cutting) ▪ Evolving Threats ▪ Climate Change

The SNRA project team and partners implemented a similar methodology as the SNRA development in 2011. The SNRA project team analyzed quantitative data to update existing threat and hazard data and associated 2011 SNRA findings, and qualitatively identified new threats and hazards.

To accomplish the 2015 SNRA, the project team conducted research and analysis on data sets, including the National Preparedness Reports and associated data calls; Threat and Hazard Identification and Risk Assessment data, and other data sets as appropriate. This enabled SNRA partners to develop a baseline understanding of which national-level threats and hazards pose the greatest concern to the nation.

Section 2: Limitations of the Analytical Approach

Significant portions of the quantitative SNRA methodology, including but not limited to its measurement of psychological and social impacts, were newly developed for the 2011 SNRA and have not received full peer and stakeholder (public) review. For all but the specific uses for which the SNRA was commissioned in 2011 and 2015, the methodology, analysis, and findings of the SNRA remain provisional pending this review, and should be treated as such.

- Information about the frequency and impacts of the events included in the SNRA is at varying stages of maturity, with additional work required in some areas to ensure that event data can be appropriately compared. Where substantial additional research is warranted, events are discussed qualitatively and are not compared with other events.
- The SNRA methodology does not explicitly model the dynamic nature of some of the included hazards. For example, terrorists' evolving tactics in response to changes in defensive posture are not included.
- For national-level events where historic data was used as the basis of analysis, the risk from low-likelihood, high-impact incidents may not be adequately captured. This is particularly true for technological/accidental hazards. Further study is needed to better characterize these risks at the national strategic level.
- The SNRA measure of social displacement (the number of people forced to leave their home for a period of two days or longer) does not differentiate between temporary or short-term evacuation, and displacement that lasts for a long period or is permanent. While experts consulted for the 2011 SNRA advised that this measure of displacement may be a reasonable first proxy for many additional social impact metrics, they also stressed the importance of accounting for the time dimension in displacement and the need for additional research to further develop the SNRA measures to reflect this dimension.
- Experts consulted about psychological consequences emphasized caution in the application of the SNRA's measure of psychological distress, and stressed the need for additional research. The SNRA measure represents a first approximation of psychological impact based upon other impact measures in the SNRA, and does not take into account additional psychosocial factors such as income or education recognized as significant determinants of resilience in individuals, families, and communities, and at the societal level. The U.S. Department of Homeland Security and its partner organizations leveraged previously funded social and behavioral research to develop the measure used in the SNRA in 2011. This research continues today, and is a high priority for the Department and for FEMA.
- Experts and agencies across the Federal Government contributing to the 2011 SNRA generally participated on the assumption that it was intended as a rapid initial survey for the specific and limited purpose of informing the 2011 National Preparedness Goal, which would be substantially revised and developed in subsequent iterations. Many of these rapidly developed contributions have been retained in the 2015 SNRA without revision due to factors unrelated to the original 2011 project plan. Because of this use beyond the purpose and timescale for which they were contributed, they should not be taken as reflective of the rigor of the work the original contributors would have provided for a work of greater

permanence and wider impact than the 2011 SNRA as originally contemplated. **Their inclusion is the sole responsibility of the SNRA 2015 project team.**

For its comparative quantitative analysis, the 2015 SNRA retains the methodology developed for the 2011 SNRA without substantial modification.

- Many apparent limitations of this methodology were recognized by the Department at the time of the first iteration of the SNRA, and additional limitations have been identified from reviews by Federal partners since 2011. However, these reviews have been limited to a very small portion of those partners with sufficient clearances to see the SNRA methodology, data, and findings as a whole. They do not include the U.S. risk technical community, or the vast majority of the SNRA's stakeholders and their elected representatives in Congress and state, local, tribal, and territorial governments. As critical review by these communities constitutes the basis of the legitimacy of the SNRA as a scientific assessment and as a national risk assessment, the SNRA project team determined that it did not have the scientific authority to make substantive changes to the 2011 methodology without the authoritative guidance of the feedback that only this broad review can provide.
- The 2015 SNRA does include multiple extensions, improvements, and enhancements; however, these are presented as proposals as opposed to unilaterally decided changes to the 2011 methodology. The findings derived from these were used to inform the 2015 revisions to the Goal. For other purposes, however, like the rest of the SNRA the findings derived from these extensions should be considered as provisional pending full peer and stakeholder review.

Section 3: Thresholds in the SNRA

To inform homeland security preparedness and resilience activities, the SNRA evaluated the risk from known threats and hazards that have the potential to significantly impact the Nation's homeland security. These included natural hazards, technological/accidental hazards, and adversarial, human-caused threats/hazards.

For assessment in the initial SNRA, participating stakeholders – including Federal agencies, DHS Components, and the intelligence community, among others – developed these threats and hazards into a list of ***national-level events*** having the potential to test the Nation's preparedness.

For the purposes of the assessment, DHS analysts identified thresholds of consequence necessary to create a national-level event. These thresholds were informed by subject matter expertise and available data, and are provided below.

The selection of appropriate thresholds for each event was among the most significant challenges for the SNRA project.

- As the Nation's preparedness may be challenged by events having impacts across any or all of the consequence categories of the SNRA, it is not possible to identify any one generic consequence threshold capable of adequately capturing this distinction for all the hazards in the SNRA.
- Wherever possible, common thresholds across multiple events were sought to minimize the total number of different threshold criteria needed to define the set of national-level events as a whole. However, the unique impacts of each event, and in many cases data availability, precluded the assignment of every event to a larger, harmonized-threshold class.

Since there is no one objective or context-independent answer to this question, these determinations ultimately came down to the best, but human, judgment of the SNRA project team.

- For some events, economic consequences were used as thresholds. For others, fatalities or injuries/illnesses were deemed more appropriate as the threshold to determine a national-level incident.
- In no case, however, were economic and casualty thresholds treated as equivalent to one another (i.e., dollar values were not assigned to fatalities).

Event descriptions in Tables 1-3 of the *2015 SNRA Findings* that do not explicitly identify a threshold signify that no minimum consequence threshold was employed.

2011 SNRA Thresholds

- Natural hazards: $100 million direct economic loss
  - Exceptions:
    - Animal Disease: FMD outbreak
    - Pandemic: Influenza pandemic outbreak
    - Space weather, tsunami, volcano: Qualitative

- Accidents: mixed
  - Dam Failure: 1+ fatalities
  - Chemical Substance Spill or Release: 1+ ‘public’ fatalities, or any fatality resulting in evacuation/shelter-in-place order
  - Radiological Substance Release: Reactor core breach resulting in radiation release
  - Biological Food Contamination [accidental]: 100 hospitalizations + multi-state response
- Malevolent acts: mixed
  - Armed Assault, Explosives Terrorism Attack: 1+ injuries or fatalities
  - CBRN attacks: Any [non-state actor] release or use of CBRN agent
  - Aircraft as a Weapon: Any attack
  - Cyber Attack against Data: $1 billion economic loss
  - Cyber Attack against Physical Infrastructure: Either 1+ fatalities, or $100 million economic loss

2015 SNRA Thresholds (new or changed)

- Natural hazards:
  - Space Weather: $1 billion direct economic loss
  - Drought: $1 billion of direct economic loss
  - Winter Storm: $1 billion direct economic loss
- Accidents:
  - Transportation System Failure: 1+ fatalities
  - Combustible/Flammable Cargo Accident (Rail): 1+ fatalities
- Malevolent acts:
  - Aircraft as a Weapon: 1+ fatality or injury other than the attacker
  - Armed Assault: 1+ fatality or injury other than the attacker
  - Explosives Terrorism Attack: Any attack[1]
  - Physical Attack on the Power Grid: Loss of power to one or more metropolitan areas for 3 or more hours
  - Cyber Attack: Qualitatively treated [additionally, substantially expanded taxonomy from SNRA 2011]

[1] Limited to terrorist attacks only (as with Aircraft as a Weapon, Armed Assault)

Section 4: Data Sources in the SNRA

The SNRA project team used the data sources presented in Table 2 below during the development of the 2011 SNRA, and the update in 2015.

Table 2: SNRA Data Sources

<table>
<tr><th>Threat/Hazard</th><th>Frequency</th><th>Fatalities and Injuries/Illnesses</th><th>Direct Economic Loss</th><th>Social Displacement</th></tr>
<tr><td>Animal Disease</td><td colspan="3">USDA Economic Research Service modeling & DHS/OHA and DHS/S&T subject matter expertise</td><td>Subject matter expert estimates via DHS Centers of Excellence</td></tr>
<tr><td>Drought</td><td colspan="3">Historic data compiled from NOAA National Climactic Data Center (NCDC)</td><td>SNRA project team assumption of zero displaced</td></tr>
<tr><td>Earthquake</td><td colspan="3">Historic data compiled from the Center for Science and Technology Policy Research at University of Colorado-Boulder & FEMA HAZUS modeling</td><td>Historic data from EM-DAT disaster database</td></tr>
<tr><td>Flood</td><td colspan="3">Historic data compiled from NOAA National Climactic Data Center (NCDC) and FEMA HAZUS modeling</td><td>Historic data from EM-DAT disaster database</td></tr>
<tr><td>Human Pandemic Outbreak</td><td>CDC analysis of historic record</td><td>CDC subject matter expertise</td><td>SNRA project analysis using CDC modeling</td><td>SNRA project team assumption of zero displaced</td></tr>
<tr><td>Hurricane</td><td colspan="3">Historic data compiled from NOAA, the Center for Science and Technology Policy Research at University of Colorado-Boulder & FEMA HAZUS modeling</td><td>Historic data from EM-DAT disaster database</td></tr>
<tr><td>Space Weather</td><td>Expert estimates from the literature (range)</td><td>Epidemiological studies of 2003 East Coast Blackout</td><td>Expert estimates from the literature (range)</td><td>Subject matter expert estimates via DHS Centers of Excellence</td></tr>
<tr><td>Tornado</td><td colspan="3">Historic data compiled from the NOAA/National Weather Service (NWS) Storm Prediction Center (SPC)</td><td>Not assessed</td></tr>
<tr><td>Wildfire</td><td colspan="3">Historic data compiled from Spatial Hazard Events and Losses Database for the United States (SHELDUS) – University of South Carolina</td><td>Historic data from EM-DAT international disaster database</td></tr>
<tr><td>Winter Storm</td><td colspan="3">Historic data compiled from NOAA National Climactic Data Center (NCDC)</td><td>Not assessed</td></tr>
<tr><td>Biological Food Contamination</td><td colspan="2">CDC Foodborne Outbreak Online Database (FOOD) and FDA / USDA subject matter expertise</td><td>Open source historic examples</td><td>Subject matter expert estimates via DHS Centers of Excellence</td></tr>
<tr><td>Chemical Substance Spill or Release</td><td colspan="4">DOT Pipeline & Hazardous Materials Safety Administration (PHMSA) and EPA Risk Management Program (RMP) incident databases</td></tr>
<tr><td>Combustible/ Flammable Cargo Accident (Rail)</td><td colspan="4">DOT Pipeline & Hazardous Materials Safety Administration (PHMSA) incident database</td></tr>
<tr><td>Dam Failure</td><td colspan="2">Historic data compiled by DHS Dams Sector</td><td>U.S. Bureau of Reclamation modeling</td><td>Subject matter expert estimates via DHS Centers of Excellence</td></tr>
<tr><td>Radiological Substance Release</td><td colspan="3">U.S. Nuclear Regulatory Commission (NRC) license renewal applications</td><td>Subject matter expert estimates via DHS Centers of Excellence</td></tr>
<tr><td>Transportation System Failure</td><td colspan="3">Historic data compiled by Structures Group, Cambridge University Department of Engineering</td><td>SNRA project team assumption of zero displaced</td></tr>
<tr><td>CBRN Terrorism Attacks</td><td colspan="3">DHS/S&T Integrated Terrorism Risk Assessment (ITRA)</td><td>Subject matter expert estimates via DHS Centers of Excellence</td></tr>
<tr><td>Armed Assault</td><td colspan="2">Historic data published by FBI</td><td>SNRA project team analysis based upon historic data</td><td>SNRA project team assumption of zero displaced</td></tr>
</table>

Threat/Hazard	Frequency	Fatalities and Injuries/Illnesses	Direct Economic Loss	Social Displacement
Aircraft-as-a-Weapon	Historic data published by FBI	Open source historic data (Planes hitting buildings or crowds)	Historic data and insurance models	Open source historic data
Explosives Terrorism Attack	Historic data published by FBI	FBI historic data and DHS/NPPD analysis of historic 'near-miss' incidents	Insurance models and SNRA project team analysis	Open source historic data
Physical Attack on the Power Grid	Published power industry incident reports	Epidemiological studies of 2003 East Coast Blackout	DHS/NPPD analysis for SNRA project	Not assessed for all estimates

Impact Type	Impact Specific Subject Matter Expert Data Sources (All Provided 2011)
Social Displacement	▪ University of Maryland, National Consortium for the Study of Terrorism & Responses to Terrorism (START) (2011) ▪ Institute for Alternative Futures (2011) ▪ University of Pittsburgh Medical Center, Center for Biosecurity (2011)
Psychological Distress	▪ National Center for Disaster Mental Health Research (2011) ▪ University of California-Irvine, Department of Psychology and Social Behavior (2011) ▪ Carnegie Mellon University, Dept. of Social & Decision Sciences, Dept. of Engineering & Public Policy (2011) ▪ University of Maryland, START (2011) ▪ DHS/S&T Human Factors Division (2011)[2]
Environmental Impacts	▪ Environmental Protection Agency (2011)

[2] DHS/S&T Resilient Systems Division (RSD) is the organizational successor to Human Factors Division. The 2015 SNRA did not perform new elicitations for the psychological distress metric.

Section 5: Analysis & Detailed Findings

Analytic Approach

The quantitative analysis of the SNRA drew data and information from a variety of sources, including existing U.S. Government models and assessments, historical records, structured analysis, and judgments of experts from different disciplines. The information was used to assess the risk of identified incidents as a function of frequency[3] and impacts. More specifically, the SNRA asks:

- With what frequency is it estimated that an event will occur?
- What are the impacts of the event(s) if it does occur?

The SNRA examined the risks associated with six categories of harm: loss of life, injuries and illnesses, direct economic costs, social displacement, psychological distress, and environmental impact. Each impact, when combined with the frequency of the national-level event, produces a different type of risk, such as fatality risk, injury and illness risk, and direct economic risk. This multi-faceted view of potential impacts draws attention to the broad and often interdependent effects of incidents that require whole-of-community preparation and cooperation across the homeland security enterprise. For instance, community resilience relates to both mitigating human and economic impacts and addressing the psychological and social distress caused by the incident within the community. Similarly, other types of resilience involve withstanding environmental and infrastructure degradations to ensure essential services continue to be delivered.

The SNRA relied on the best available quantitative estimates of frequency and impacts from existing Government models and assessments, peer-reviewed literature, and expert judgment. Where sufficient quantitative information was not available or additional research is warranted, events were assessed semi-quantitatively or qualitatively. The estimates of the frequency and impacts for each of the events were compared where appropriate.

The SNRA used the following approaches to estimate frequency and impact:

Frequency

In order to apply a consistent methodology across all SNRA event types, frequency was selected as a metric for the likelihood of event occurrence. Frequency was estimated as the potential number of occurrences or attacks, per year, which met or exceeded the established threshold[4] for the event. For the majority of events, frequency estimates were based on statistical analysis of historic data, or directly from historical data where extensive records were available.[5] For the 2015 SNRA, these included new unclassified analyses of the conventional (non-CBRN and non-

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[3] Frequency was used in the SNRA to capture likelihood because some events have the potential to occur more than once a year.

[4] When interpreting the frequency results, it is important to consider that the frequency data in the SNRA is directly related to the threshold included in each national-level event definition. For example, the results for floods indicate that floods causing greater than $100 million in direct economic losses are estimated to occur with a frequency between once every two years and ten times per year, with a best estimate of four times per year.

[5] SNRA analysts examined the data sets for a particular event and identified how many incidents within the scope of the event occurred at or above the established threshold per year.

cyber) terrorist attack events of the 2011 SNRA, together with a new adversarial event, Physical Attack on the Power Grid. Chemical/biological/radiological/nuclear (CBRN) adversarial/human-caused frequencies were estimated primarily using elicitation from subject matter experts.[6]

Fatalities

For events that have occurred in the past, the expected number of fatalities was estimated primarily from the historical record. For events that have never occurred (primarily in terrorism), impacts were estimated using data from previous government risk assessments, which rely on models and simulations.

Injuries and Illnesses

Injuries and illnesses were estimated similarly to fatalities. However, this category mixed permanent debilitating injuries (such as those resulting from chemical accidents) with temporary illnesses (such as those resulting from pandemic influenza). Therefore, the injury and illness impacts should be considered in context with the types of injuries and illnesses likely to result from each hazard.

Direct Economic Loss

Direct economic losses were estimated similarly to fatalities. Direct economic losses were defined to include decontamination, disposal, and physical destruction costs, lost spending due to fatalities, medical costs, and business interruptions. Due to constraints on the time available to execute the SNRA and the community's lack of a broadly agreed upon method for calculating indirect and induced economic impacts, these impacts, which are often larger than direct losses, are not included in this assessment.

Attempts were made to assess direct economic losses as comparably as possible across the range of event types in the SNRA; however, data availability made this challenging. The comparability of economic impact estimates in the SNRA is an important area for future study.

Social Displacement

The number of people forced to leave their home for a period of two days or longer was used as a measure of social displacement. Estimates of displacement were obtained from open source social science literature and emergency management databases for historical events and from relevant models for events with limited historic precedence. The measure of social displacement used in the SNRA does not capture the significant differences between short-term evacuation and long-term permanent relocation, which is a limitation of the current analysis.

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[6] Subject matter expert (SME) elicitation was a component of modeling frequency in the Terrorism Risk Assessments, the DHS/Directorate of Science & Technology (S&T) models leveraged for the classified CBRN risk information in the SNRA. The outputs from these models were converted to equivalent units of successful events per year for comparison to the frequencies of natural and technological hazards drawn from the historical record.

SME estimation of the frequency of rare, adversarial/human-caused events is challenging, and SME frequency judgments in the SNRA reflect significant uncertainty. As with all data in the SNRA, these SME frequency judgments should be interpreted as order of magnitude estimates for the purposes of comparison.

Psychological Distress

Experts in the psychosocial impacts of disasters consulted for the SNRA recommended that significant and/or prolonged psychological distress caused by national-level events would be the most meaningful psychological metric for strategic capabilities planning and national preparedness. These experts recommended a methodology to assess significant distress which reflected empirical findings indicating that the psychological impacts of a disaster may follow from the other types of impacts being assessed in the SNRA. Specifically, the experts recommended a consequence index which was a function of the SNRA estimates for deaths, injuries, and displacement related to each national-level event. This approach represents the first attempt to include psychological impacts in a DHS strategic, national-level risk assessment. Additional analysis is required to verify and validate the approach used, and experts consulted about psychological impacts emphasized caution in the application of the SNRA's measure of psychological distress and the need for additional research.

Environmental Impact

For the purposes of the SNRA, environmental risk was defined as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources. Environmental effects within urban areas and all human health effects were not included within the scope of this environmental risk assessment, because these impacts were already addressed separately in the other impact analyses for the SNRA. In 2011, an *ad hoc* group of experts from the Environmental Protection Agency (EPA) judged the relative environmental impact of each national-level event by selecting one of four categories of severity: *de minimus* (or minimal), low, moderate, and high. In doing so, the experts considered the areal extent of the impact, the potential for adverse impacts, and the severity of adverse impacts.

Documentation

All sources and estimates were documented to promote credibility, defensibility, and transparency within the assessment. Additional information on data sources and methods for frequency and impacts is available in the footnotes and data sources section of this appendix, and in the methodology appendices to the SNRA 2011 Unclassified Documentation of Findings.

Table 3: Comparative Risk in the SNRA - Non-CBRN Attack Events

Threat/Hazard	Best Estimate Risk: Fatality	Injury/Illness	Direct Economic	Social Displacement	Psychological Distress	Environmental
Animal Disease Outbreak			X			
Drought			X			▒
Earthquake			X			
Flood			X	X		X
Human Pandemic Outbreak	X	X	X		X	
Hurricane			X	X	X	X
Space Weather*			X	X		
Tornado			X	▒	▒	▒
Wildfire			X	X		
Winter Storm			X	▒	▒	▒
Biological Food Contamination			▒			
Chemical Substance Spill or Release						X
Combustible/Flammable Cargo Acc. (Rail)						▒
Dam Failure			▒			
Radiological Substance Release						
Transportation Systems Failure						▒
Aircraft as a Weapon						
Armed Assault						
Explosives Terrorism Attack						▒
Physical Attack on the Power Grid					▒	▒

*Upper estimates represented (no best estimate impacts)

How to read this table:

- Natural Hazards
- Accidents (Unintentional failures of human systems)
- Adversarial (Human-caused with malevolent intent)

Best estimate risk is assessed to fall within or bound the top order of magnitude of fatality, injury/illness, direct economic, social displacement, or psychological distress risk or the two diagonally highest occupied risk bins (Figure 8) of best estimate environmental risk among the natural and accidental hazard events in the SNRA. The relative magnitude (on a linear scale) of the quantitatively based best estimate risks is indicated by background shading in each cell. The color is specific to each impact type – health and safety (pink/red), economic (green), social (blue), psychological (grey), and environmental (salmon).

Insufficient quantitative risk data to support comparisons with other events.

In this approach, the relative risk on each impact axis is considered in isolation, rather than combined. Relative weightings between different impact measures are subjective value judgments that may vary by decision context and decision maker.

The best estimate of risk for each SNRA event is used to identify top-tiered risks. However, there is considerable uncertainty, varying data quality, and substantial overlap in the risk estimates of the SNRA events, making it difficult to generate a rank-ordered list of events based solely on the SNRA risk results.

Insufficient quantitative data to support comparisons to other events
Antibiotic Resistance
Emerging Infectious Disease (non-Influenza)
Heat Wave
Plant Disease
Tsunami
Volcanic Eruption
Industrial Accident (Explosion)
Migrant Surge/Mass Migration
Oil Spill
Pipeline Failure
Cyber Attacks

Risk estimates are classified
Biological Terrorism Attack (non-food)
Chemical Terrorism Attack (non-food)
Chemical/Biological Food Terrorism Attack
Nuclear Terrorism Attack
Radiological Terrorism Attack

Detailed Findings

The results of the SNRA include a comparison of risks for potential incidents in terms of the likelihood (estimated as a frequency, i.e., number of events per year) and impacts of threats and hazards, as well as an analysis of the uncertainty associated with those incidents.

The assessment finds that a wide range of threats and hazards pose a significant risk to the Nation, affirming the need for an all threats/hazards, capability-based approach to preparedness planning. Many events are estimated to have the potential to happen more than once every 10 years, meaning that it is likely that the Nation's preparedness will be tested in this decade.

Key findings are discussed below.

High Risk Events

Of the non-CBRN attack[7] events, the national-level events that are estimated to have generally high risk across many impact categories in the SNRA are pandemic influenza outbreaks and hurricanes (see Table 3 above). Space weather may pose comparable or greater risk to hurricanes on some impact axes, but this is highly uncertain.

To identify these high risk events, the results for each type of risk (estimated as an annualized loss) were considered independently and not aggregated. Events which were estimated to have high risk in each impact category, taking into account uncertainty and the quality of the underlying data, were identified. The events identified above are those which were identified as high risk across the majority of impact types.

- Pandemic influenza is estimated to be the highest risk event of all the non-adversarial events in the SNRA for fatality, illness/injury, and psychological distress risk, and is near the top for direct economic risk. At the best estimate, it has more fatality and injury/illness risk than every other natural hazard or accident in the SNRA combined. It is estimated to have no social displacement risk and relatively low environmental risk.
- Hurricanes are the highest direct economic risk at the best estimate, with the possible exception of space weather. Hurricanes also present the highest social displacement risks to the Nation of all the non-adversarial events included in the SNRA, coupled with relatively high psychological distress and environmental risks. Though not amongst the largest fatality and injury/illness risks within this set, hurricanes do carry some risk in these dimensions.
- The risks to the Nation posed by space weather are clouded with uncertainty.[8] However, the SNRA cannot rule out the possibility that space weather may rank with hurricanes in the top tier of direct economic and social displacement risks to the Nation.

When considering the high risk events listed above, it is important to consider that many hazards have the potential to be catastrophic, and many additional natural and accidental hazard national-level events in the SNRA pose significant risk to the Nation.

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[7] Classified data and analyses suitable for the comparison of chemical, biological, radiological, and nuclear (CBRN) terrorist attack threats within the fully quantitative framework of the SNRA may be found in the classified SNRA Technical Report.

[8] Technical experts are strongly divided between experts who believe that a severe solar storm would most likely shut down the electric grid for days, and others who believe that it would most likely shut down large portions of the grid for months to years. As there is little middle ground between them, low and high impact estimates for this event in the SNRA represent not the endpoints of a range bounding a best estimate, but two alternate best estimates with the uncertainty being over which set of experts is correct. See the Space Weather risk summary sheet.

It is also important to note that this identification process considered each type of risk equally (i.e., fatality and economic risks are equally important to flagging events as "high risk" in this process); however, decision-makers may weigh each type of risk differently, depending on their risk tolerances and the decision context. Further, risk is not the only consideration for capability development and prioritization, and events identified here as high risk are not necessarily those for which the risks are most easily or inexpensively mitigated; additional information about the cost of preparedness capabilities and their effectiveness at reducing risk is necessary for making resource allocation prioritization decisions.

Additional findings specific to each risk type are discussed below. Supplementary information about the data sources and methods used to estimate frequencies and impacts is provided in the event risk summary sheets.

Human Pandemic Influenza Outbreaks Present Risk to the U.S.

The most salient finding identified within the SNRA is the dominance of the fatality risk and injury/illness risk associated with a human pandemic influenza outbreak, when compared with every other natural and accidental hazard and non-CBRN[9] adversarial threat not only individually, but also in sum. *The pandemic influenza outbreak event considered in the SNRA has more fatality risk and injury/illness risk, at the best estimate, than every other measured natural, unintentional, or non-CBRN adversarial hazard event in the SNRA combined.*

- The SNRA considers a pandemic influenza outbreak with a 25% gross clinical attack rate[10] and a case fatality rate of up to 0.5%, similar to the 1957 flu pandemic.[11] A pandemic of this type is expected to occur once every 10 to 60 years and cause more than a hundred thousand fatalities. For comparison, deaths in the United States from annual seasonal influenza are on the order of 40,000 each year.

The pandemic influenza scenario and data sources were determined in collaboration with the Centers for Disease Control and Prevention (CDC). The pandemic scenario selected for the SNRA is moderate relative to the characteristics of recent influenza pandemics. For example, the three major influenza pandemics of the 20th century (1918, 1957, and 1968) had gross clinical attack rates (adjusted to current population) of 24% to 34% of the population; therefore, the 25% attack rate assumed for the SNRA scenario is conservative. Further, the 1957 flu pandemic had a relatively low case fatality rate of less than 0.5%, in contrast to the 1918 Spanish influenza which had a much higher case fatality rate of between 2.5% and 10%.[12]

Figure 1 illustrates the relative amount of fatality risk and illness/injury risk, at the best estimate, associated with the SNRA human pandemic influenza outbreak event relative to other natural hazard and accident events in the SNRA. The area of the shapes in the figure represents the relative amount of risk.

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[9] Classified data and analyses suitable for the comparison of chemical, biological, radiological, and nuclear (CBRN) terrorist attack threats within the fully quantitative framework of the SNRA may be found in the classified SNRA Technical Report.

[10] The gross clinical attack rate is the fraction of a population that becomes clinically ill from influenza during the pandemic.

[11] Reed et al (2013, January). Novel framework for assessing epidemiologic effects of influenza epidemics and pandemics; and Technical Appendix. *Emerging Infectious Diseases* 19(1) 85–91, at http://wwwnc.cdc.gov/eid/article/19/1/12-0124_article; Technical Appendix at http://wwwnc.cdc.gov/eid/article/19/1/12-0124-techapp1.

[12] Reed et al (2013), *op cit*.

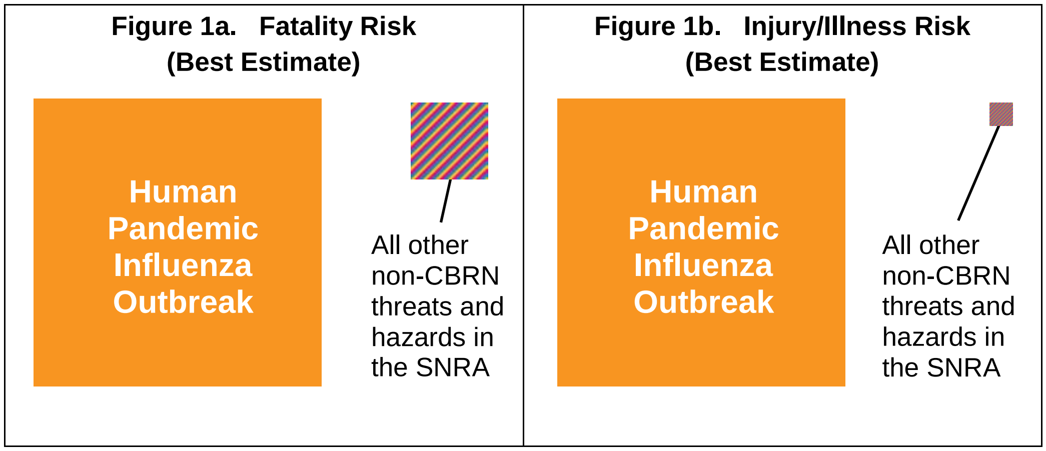


Figure 1: Dominance of Human Pandemic Influenza Outbreak Over All Other Non-CBRN Hazards - Fatality Risk and Injury/Illness Risk

Figure 2 depicts the best estimates of the fatality and direct economic risk for the SNRA's quantitatively assessed natural hazards and accidents, as measured by the product of the best estimates of frequency and fatalities given occurrence (Figure 2a, fatality risk) or the product of the best estimates of frequency and direct economic impacts given occurrence (Figure 2b, direct economic risk). Although it is not the one largest or dominant contributor to direct economic risk among national-level events as it is for human fatality and illness/injury risk, the pandemic influenza outbreak scenario ranks with the most catastrophic natural disaster events assessed in the SNRA.

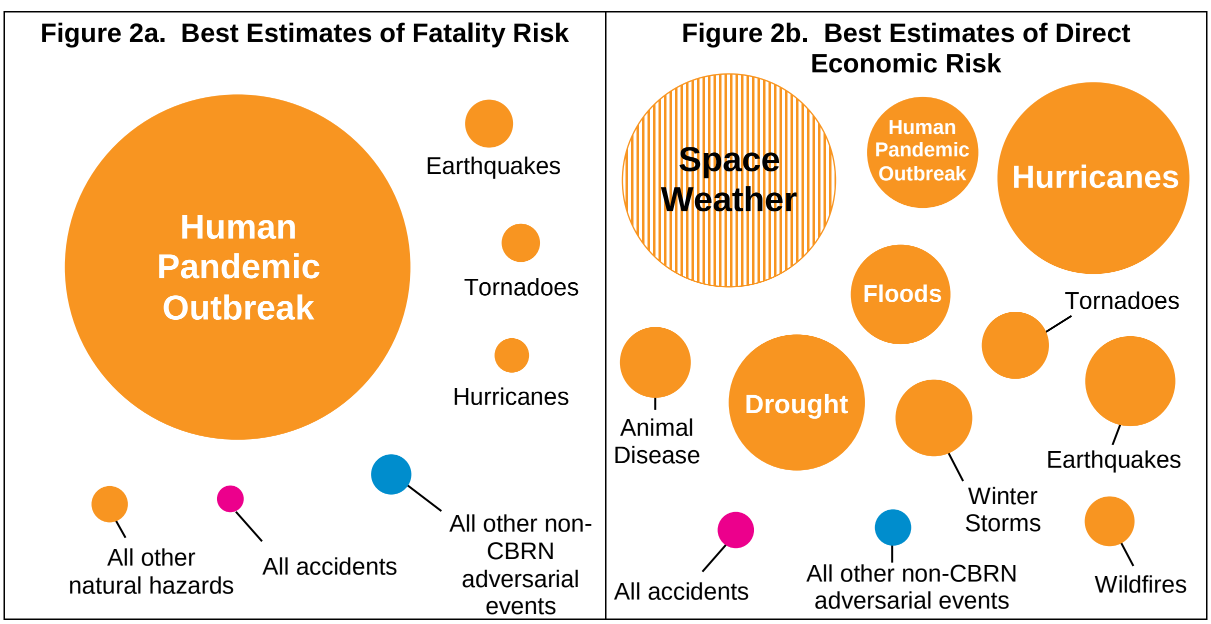


Figure 2: Best Estimates of Risk in the Unclassified SNRA Events

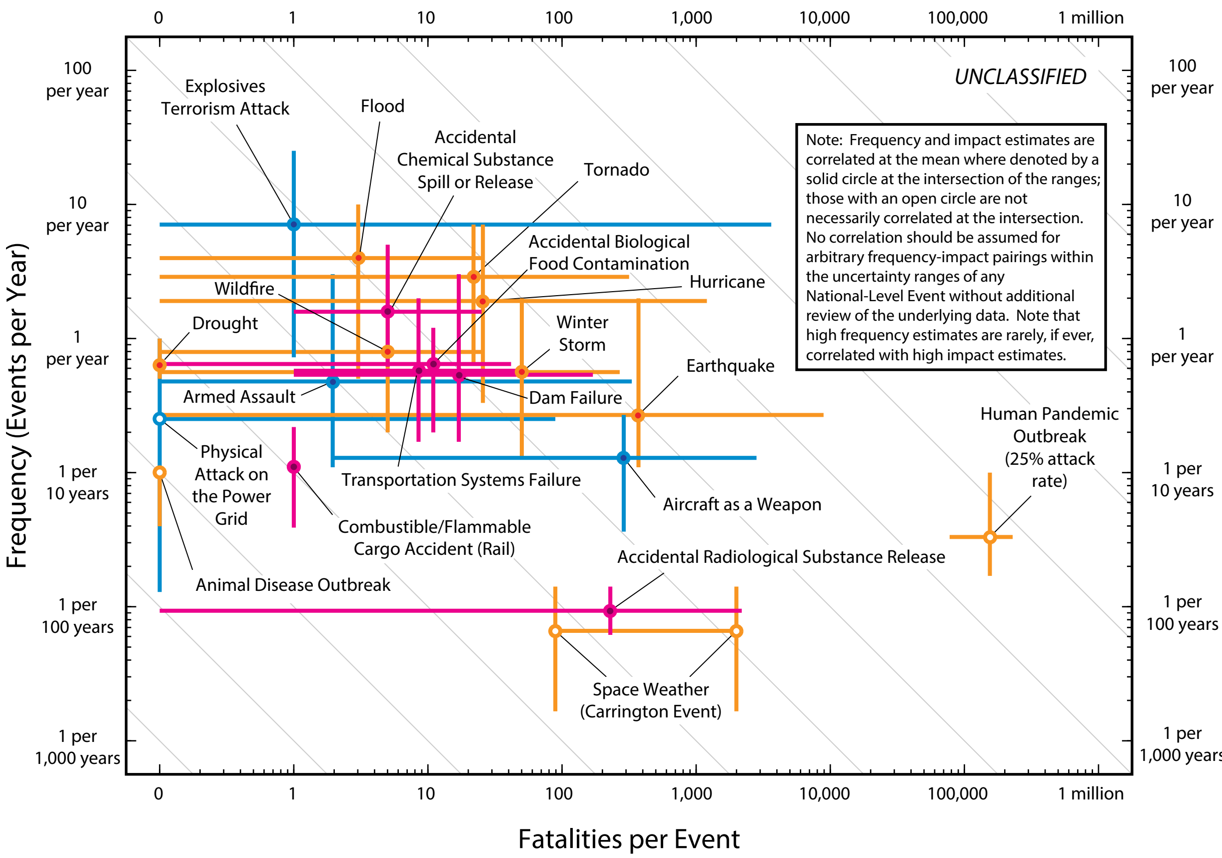
When interpreting Figure 2, it is important to remember that there is significant uncertainty in the frequencies and impacts associated with many events assessed in the SNRA.

Significant Risks May Be Masked By Limited Data

In the course of conducting the SNRA, a number of events were not assessed because of limited quantitative data availability. The SNRA is therefore unable to comment on the relative risk associated with these events, some of which are qualitatively believed to have potential for significant impact. These are seen in tables 2 and 3 of the 2015 SNRA Findings document.

Fatality Risk

Fatality risk was estimated for each national-level event by multiplying the best estimate of the frequency by the best estimate of the resulting injuries/illnesses given occurrence. Figure 3 presents a visual depiction of fatality risk across the SNRA-assessed accidental, natural, and non-CBRN adversarial hazard events.



Legend:
Natural Hazards
Technological Hazards
Adversarial Threats

Events Not Displayed:

- Cyber Attacks
- Antibiotic Resistance
- Oil Spill
- Heat Wave
- CBRN Terrorism Attacks
- Non-Influenza Human Diseases
- Industrial Accident (Fire/Explosion)
- Migrant Surge/Mass Migration
- Tsunami
- Plant Disease
- Pipeline Failure
- Volcanic Eruption

Figure 3: Fatality Risk

Note that all comparative statements are made within the set of natural and accidental hazards, and conventional-attack adversarial threats, which were analyzed at an unclassified level for the 2015 SNRA. Classified data and analyses suitable for the comparison of chemical, biological, radiological, and nuclear (CBRN) terrorist attack threats within the fully quantitative framework of the SNRA may be found in the classified SNRA Technical Report.

As discussed above, the pandemic influenza outbreak event considered in the SNRA has greater fatality risk, at the best estimate, than every other measured natural or technological hazard in the SNRA combined.

- The SNRA considers a pandemic influenza outbreak with a 25 percent gross clinical attack rate[13] and similar case fatality rate to the 1957 flu pandemic. A pandemic of this type is expected to occur once every 10 to 60 years and cause more than a hundred thousand fatalities.[14] For comparison, deaths in the United States from annual seasonal flu are on the order of 40,000 each year.

Compared with hazards such as hurricanes or floods, pandemic influenza is a higher consequence, lower likelihood event. In other words, pandemic influenza is driven to be a high fatality risk by its significant expected impacts given occurrence, rather than its frequency.

At the best estimate, earthquakes, tornadoes, and hurricanes, closely followed by large winter storms, are estimated to pose less fatality risk than a pandemic influenza outbreak by a factor of a hundred or more, but may nonetheless pose relatively high risk when uncertainty is taken into account. Aircraft-as-a-weapon attacks also fall within an order of magnitude of fatality risk, although the uncertainty of the effects of a successful attack are dominated by uncertainty in models and assumptions; as compared to natural hazards with detailed historical records.

The other natural, accidental, and adversarial threats and hazards considered in the 2015 SNRA ranked behind these hazards. However, in many cases this result is strongly conditioned on the data and assumptions which the SNRA relied upon to model the risk of these events in the next 3-5 years. These include the majority of the accidental and technological hazards.

Substantial uncertainty also attaches to the health impacts of long-term (weeks to months, or years) electric power outages covering large regions. This uncertainty is relevant to the fatality risk from a catastrophic space weather incident or a physical attack on the electric grid which result in such outages. The SNRA estimates for the fatality (and illness/injury) impacts of these events are deliberately selected to be modest, because of the paucity of peer-reviewed studies of long-term grid outage health effects from any cause which would be needed to support higher estimates.

By comparison with pandemic influenza and every other natural and technological hazard quantitatively assessed by the SNRA, foot-and-mouth disease has considerably less fatality risk than other types of events in the SNRA. Although an outbreak of foot-and-mouth disease in the United States has the potential to have considerable impact on livestock and the agricultural economy, it poses little health risk to humans. By definition, the SNRA Drought hazard event

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[13] The gross clinical attack rate is the fraction of a population that becomes clinically ill from influenza during the pandemic.

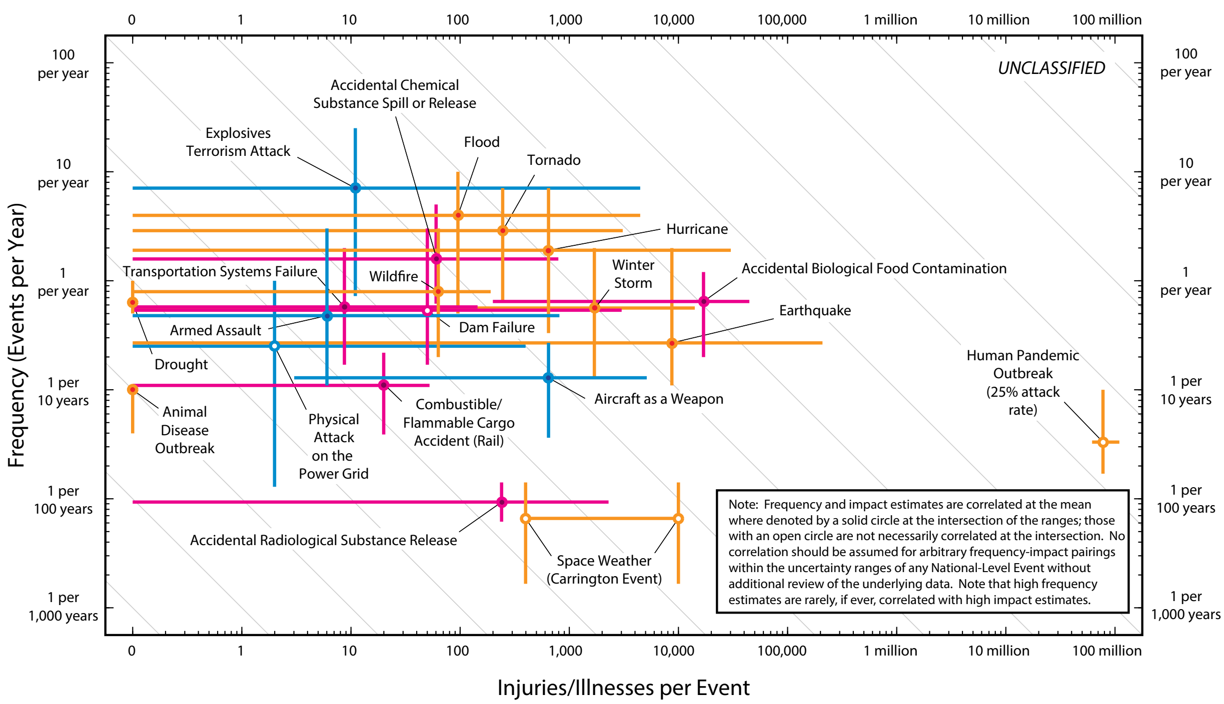
[14] Reed et al (2013, January). Novel framework for assessing epidemiologic effects of influenza epidemics and pandemics; and Technical Appendix. *Emerging Infectious Diseases* 19(1) 85–91, at http://wwwnc.cdc.gov/eid/article/19/1/12-0124_article; Technical Appendix at http://wwwnc.cdc.gov/eid/article/19/1/12-0124-techapp1.

also has zero human health and safety impacts, as these are considered within the scope of the SNRA Heat Wave event.[15]

Insufficient data (immediately capable of meaningful comparison with the other SNRA threats and hazards in the manner above) about the fatality risk associated with cyber attacks, tsunamis, volcanoes, antibiotic resistance, emerging infectious diseases other than influenza, plant disease, heat waves, industrial accidents, mass migration events, oil spills, or pipeline failures was collected during the SNRA to support quantitative comparisons to other national-level events. For this reason, these events are not displayed in Figure 3.

Injury/Illness Risk

Note that all comparative statements are made within the set of natural and accidental hazards, and conventional-attack adversarial threats, which were analyzed at an unclassified level for the 2015 SNRA. Classified data and analyses suitable for the comparison of chemical, biological, radiological, and nuclear (CBRN) terrorist attack threats within the fully quantitative framework of the SNRA may be found in the classified SNRA Technical Report.



Legend:

Natural Hazards
Technological Hazards
Adversarial Threats

Events Not Displayed:

- Cyber Attacks
- Antibiotic Resistance
- Oil Spill
- Heat Wave
- CBRN Terrorism Attacks
- Non-Influenza Human Diseases
- Industrial Accident (Fire/Explosion)
- Migrant Surge/Mass Migration
- Tsunami
- Plant Disease
- Pipeline Failure
- Volcanic Eruption

Figure 4: Injury/Illness Risk

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[15] The Heat Wave hazard is currently addressed with a qualitative treatment in the SNRA (SNRA Working Papers). However, substantial quantitative research has been completed (see working paper) and it is expected to be added to the quantitative data set of the SNRA before the next full iteration of the SNRA.

Injury/illness risk was estimated for each national-level event by multiplying the best estimate of the frequency by the best estimate of the resulting injuries/illnesses given occurrence. Figure 4 presents a visual depiction of injury/illness risk across SNRA-assessed events.

A pandemic influenza outbreak with a 25 percent gross clinical attack rate and similar case fatality rate to the 1957 flu pandemic has vastly more injury and illness risk, at the best estimate, than every other measured natural or technological hazard in the SNRA combined (see Figure 4). However, pandemic influenza illnesses are different than most of the other injuries and illnesses in the SNRA, in that most victims who become ill but do not die are likely to recover fully and have no lasting physical impact on their lives.

After pandemic influenza, there are several events that cluster together with a factor of 100 to 1,000 times smaller injury/illness risk than pandemic, but which also are estimated to pose significant illness/injury risk relative to other non-adversarial events in the SNRA, at the best estimate. These events include accidental biological food contamination, earthquakes, hurricanes, winter storms, and tornadoes. In contrast to pandemic influenza, many of those injured or struck ill by these events may face chronic health problems for years after the initial event.

Floods are estimated to pose less illness/injury risk, at the best estimate, than the events listed above, but may pose relatively high risk when uncertainty is taken into account. Explosives attacks, aircraft as a weapon, chemical accidents, dam failures, and wildfires also pose injury risks comparable with floods.

Foot-and-mouth disease poses little to no health risk to humans.[16]

Insufficient data (immediately capable of meaningful comparison with the other SNRA threats and hazards in the manner above) about the injury/illness risk associated with cyber attacks, tsunamis, volcanoes, antibiotic resistance, emerging infectious diseases other than influenza, plant disease, heat waves, industrial accidents, mass migration events, oil spills, or pipeline failures was collected during the SNRA to support quantitative comparisons to other national-level events. For this reason, these events are not displayed in Figure 4.

Direct Economic Risk

Note that all comparative statements are made within the set of natural and accidental hazards, and conventional-attack adversarial threats, which were analyzed at an unclassified level for the 2015 SNRA. Classified data and analyses suitable for the comparison of chemical, biological, radiological, and nuclear (CBRN) terrorist attack threats within the fully quantitative framework of the SNRA may be found in the classified SNRA Technical Report.

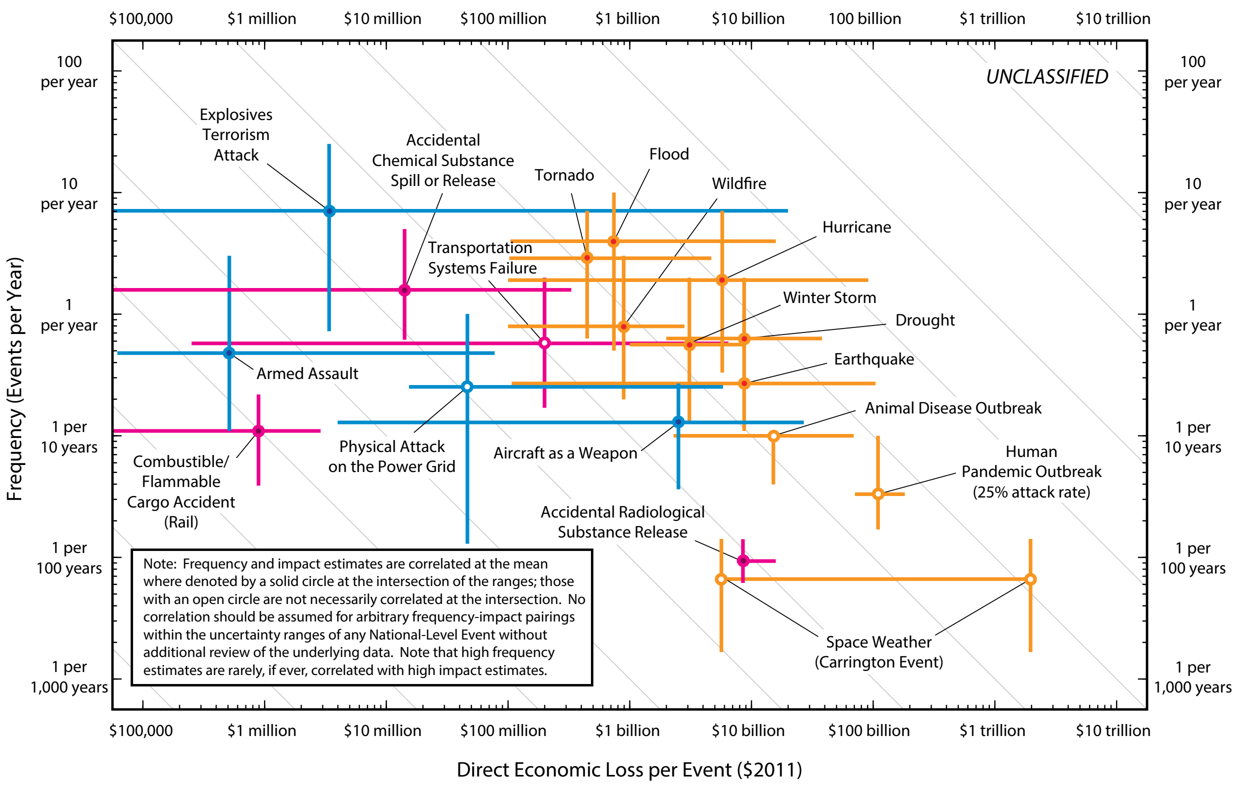
Direct economic risk was estimated for each national-level event by multiplying the best estimate of the frequency times the best estimate of the resulting direct economic losses given occurrence.

No single national-level event dominates direct economic risk among the natural and technological hazards of the SNRA to the extent that pandemic influenza outbreaks dominate the

[16] As noted above, injury and illness impacts of drought/heat events are considered within the scope of the SNRA heat wave event, currently under analysis for a planned inter-revision addition to the SNRA data set.

fatality and injury/illness risk. However, of the natural, accidental, and non-CBRN adversarial hazards considered in the 2015 SNRA, natural hazards as a whole dominate direct economic risk. Every one of the natural hazard events ranks above each of the accidental and non-CBRN adversarial threats and hazards considered in the SNRA, at the best estimate.

The risks to the Nation posed by space weather are clouded with great uncertainty. This question is a polarizing topic among technical experts in the space weather risk community: there is a stronger divergence of expert opinion regarding this risk than for any other accidental or natural hazard treated in the SNRA. For this reason, the SNRA does not present a best estimate of direct economic impact.



Legend:

Natural Hazards
Technological Hazards
Adversarial Threats

Events Not Displayed:

- Cyber Attacks
- Antibiotic Resistance
- Oil Spill
- Heat Wave
- Dam Failure
- CBRN Terrorism Attacks
- Non-Influenza Human Diseases
- Industrial Accident (Fire/Explosion)
- Migrant Surge/Mass Migration
- Biological Food Contamination
- Tsunami
- Plant Disease
- Pipeline Failure
- Volcanic Eruption

Figure 5: Direct Economic Risk

As the SNRA does report a best estimate of likelihood – the 1 in 150 year frequency (1/600 – 1/70 year range) which experts of both opinions agree upon for the likelihood of a 'Carrington event' (despite their disagreement over the likely impacts of such a storm) – it is possible to estimate direct economic risk for each of these possible magnitudes of impact. For these most rare and severe events which all experts agree are capable of causing direct economic loss to the U.S. in the billions of dollars or more,[17] experts believe that a rare space weather event will either cause catastrophic economic loss exceeding $1 trillion dollars; or it will cause slightly above average economic loss as compared to the other natural hazards studied in the SNRA (Figure 5).

- The low estimate for economic loss ($6 billion) would rank space weather among the lowest direct economic risks among the natural hazards in the SNRA.

The high estimate for economic loss ($2 trillion) would rank space weather among the highest direct economic risks among the natural hazards in the SNRA. Part of the purpose of the SNRA is to help planners and emergency managers prioritize among different threats and hazards, each of possibly catastrophic potential, by resolving some of the uncertainty about the relative likelihood of catastrophic outcomes. Having some likelihood information allows planners to 'reasonably rule out' a large number of possible but extremely unlikely catastrophic hazard scenarios in order to focus on the much smaller subset of catastrophic hazard scenarios which, however uncertain, cannot be so 'reasonably ruled out' as extremely unlikely. The SNRA cannot rule out the possibility that space weather may actually pose a very small direct economic risk, in comparison with other threats and hazards. However, this Assessment also cannot rule out the possibility that space weather may rank with the highest direct economic risks of all the unclassified threats and hazards in the SNRA.

Of hazards possessing an undisputed best estimate, hurricanes and drought pose the largest direct economic risk of natural and technological hazards in the SNRA at the best estimate, given the precision of the SNRA, although there is considerable uncertainty (see Figure 5).

Droughts meeting a threshold of $1 billion or more of direct economic loss were treated as a hazard event in the SNRA. The ubiquity of drought as a recurring and often normal condition of many U.S. climactic regions necessitated a higher threshold than most other natural disaster events (Section 3) to capture only those events which could be considered exceptions to the norm.[18]

Other SNRA events that pose the same order of magnitude of direct economic risk at the best estimate as hurricanes, drought, and possibly space weather are pandemic influenza outbreaks, foot-and-mouth disease, earthquakes, winter storms, tornadoes, and floods.

- For many high-consequence disasters such as hurricanes and floods, mitigation strategies resulting from advanced warning, such as advance evacuations from areas expected to be impacted, have reduced human health risks over time. However, the physical destruction from natural disasters, combined with their frequency, results in direct economic risk comparable to that of large-scale no-notice disasters such as earthquakes and tornadoes.
- Winter storms are an annually recurring natural hazard for many climactic regions of the Nation, but are no less costly for their regularity. As with drought and space weather, the SNRA set a $1 billion threshold for winter storms, differing from the $100 million threshold set for many other natural disasters, to capture only exceptionally destructive winter storm

[17] The 2015 Space Weather event is harmonized to the $1 billion threshold used for some other super-mundane natural hazards in the SNRA for this reason.

[18] The resulting set of historical drought incidents posed a mean direct economic loss equal to that of earthquakes, but this is a coincidental artefact of thresholds: earthquakes of $100 million or greater are considered in the SNRA. If only earthquakes meeting a $1 billion direct economic loss threshold were considered, the resulting best estimate (average) would be higher than that of the SNRA Drought hazard event. However, the difference in annualized direct economic risk would be similar.

incidents. However, the comparatively high frequency of even these major storm events – which the Nation experiences once every other year, on the average – place their direct economic risk in the top rank of the hazards considered in the SNRA.

- The direct economic risk associated with a foot-and-mouth disease (FMD) outbreak in the United States is driven by the immediate reduction in international trade which would occur given an outbreak as well as disease control and eradication efforts. Given the value placed on FMD-free status, a confirmed case of FMD in the U.S. would result in an immediate restriction of exports. The current control strategy in U.S. Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) regulations to regain FMD-free status is to cull all infected and susceptible animals.[19,20] The APHIS Administrator has discretion to examine other options based on the size of the outbreak.

Events which are assessed to pose relatively low direct economic risk in the SNRA, at the best estimate, in comparison with the other non-adversarial hazards include non-CBRN terrorism attacks and industrial/technological accidents of all kinds. Of these, aircraft as a weapon, explosives terrorism attacks, and accidental radiological substance releases (nuclear power plant accident) have the potential for very high direct economic impacts. However, for explosives terrorism attacks these high estimates are based upon insurance models of very catastrophic attacks, orders of magnitude above the historic average costs of explosives terrorism attacks in the U.S. For accidental radiological substance release, the direct economic impacts associated with an incident are highly dependent upon the assumed decontamination standard.

It is important to note that none of the above risk estimates include indirect or induced economic costs, which have the potential to be as large or greater than the direct economic impacts.

Social Displacement Risk

Note that all comparative statements are made within the set of natural and accidental hazards, and conventional-attack adversarial threats, which were analyzed at an unclassified level for the 2015 SNRA. Classified data and analyses suitable for the comparison of chemical, biological, radiological, and nuclear (CBRN) terrorist attack threats within the fully quantitative framework of the SNRA may be found in the classified SNRA Technical Report.

Low, best, and high estimates of social displacement conditional upon event occurrence are unclassified for all events in the SNRA. However, as social displacement *risk* represents the product of these impact measures with estimated frequencies of event occurrence which are classified for all adversarial SNRA events, only the natural, technological, and non-CBRN adversarial hazards are discussed below.

The social displacement metric was new to the 2011 SNRA. Because of this lack of prior use, many of the estimates gathered or assessed by the 2011 project were judged to be of comparably lower fidelity than the fatality, illness/injury, or direct economic impact data. However, more granular data obtained for the unclassified hazards, including adversarial threats having new unclassified analyses, was judged to provide a sufficient basis for the full quantitative treatment

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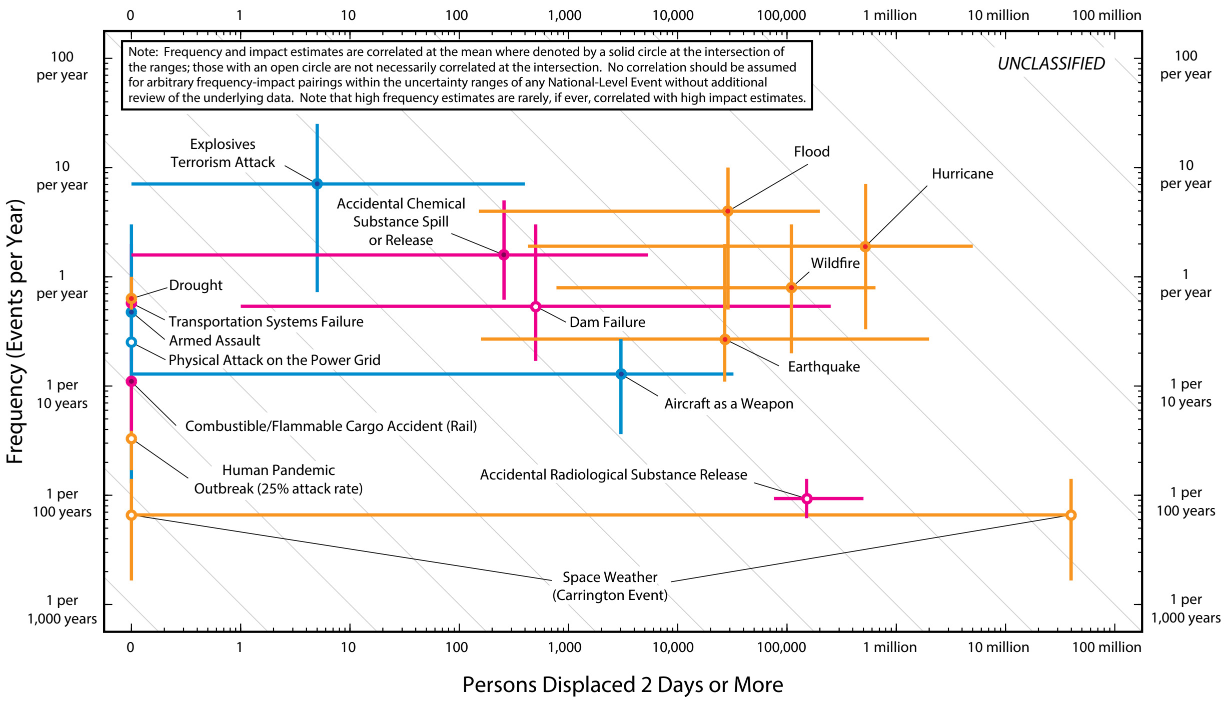
[19] U.S. Code of Federal Regulations (2011). Title 9, Section 53.4. *Destruction of animals.* Washington, DC: U.S Government Printing Office. Retrieved from http://www.gpo.gov/fdsys/pkg/CFR-2011-title9-vol1/pdf/CFR2011-title9-vol1-sec53-4.pdf.

[20] U.S. Government Accountability Office (2002, July). *Foot and mouth disease: To protect U.S. livestock, USDA must remain vigilant and resolve outstanding issues* (GAO-02-808). Retrieved from http://www.gao.gov/new.items/d02808.pdf.

of social displacement risk for the 2015 SNRA. It should be stressed that this is the judgment of the 2015 project team, and differs from that of the project team which designed and executed the 2011 SNRA.

SNRA threats and hazards show a much clearer striation of risk levels, when compared at the best estimate, for social displacement risk than for other impact axes (Figure 6).



Legend:

Natural Hazards
Technological Hazards
Adversarial Threats

Events Not Displayed:

- Cyber Attacks
- Antibiotic Resistance
- Oil Spill
- Heat Wave
- Tornado
- CBRN Terrorism Attacks
- Non-Influenza Human Diseases
- Industrial Accident (Fire/Explosion)
- Migrant Surge/Mass Migration
- Biological Food Contamination
- Tsunami
- Plant Disease
- Pipeline Failure
- Volcanic Eruption
- Winter Storm

Figure 6: Social Displacement Risk

Hurricanes dominate social displacement risk, among the natural, accidental, and non-CBRN attack hazards considered in this unclassified documentation of the SNRA. However, the high estimate for space weather[21] is within an order of magnitude of the best estimate for hurricanes.

Space weather displacement risk depends upon many unknowns, and is clouded with uncertainty. Expert opinions suggest the social displacement risk for space weather will either be catastrophic or negligible, depending on underlying assumptions and the effects of space weather to the Nation's power grid.

[21] There is a stronger divergence of expert opinion regarding the likely impacts of this risk than with any other accidental or natural hazard treated in the SNRA. Because of this, other than environmental impacts the SNRA makes no single best estimate for space weather on any impact measure.

Floods, wildfires, and possibly space weather pose social displacement risk an order of magnitude below hurricanes, at the best estimate. Earthquakes follow an order of magnitude below these three (i.e. 100 times less than hurricanes), at the best estimate.

Hurricanes, floods, and wildfires are relatively high frequency and result in moderate to high social displacement. These natural hazard events possess significant displacement risk in part because of advance warning of the event and evacuations to safer locations. Displacement from earthquakes represents people forced to leave their homes due to damage or destruction caused by the event: it is more likely to be longer term, or permanent.

Pandemic influenza outbreaks were estimated to pose minimal social displacement risk, because displacement due to hospitalizations was not included in the social displacement impact assessment. Drought, transportation systems (bridge) failure, armed assault, physical attacks on the power grid, and combustible/flammable cargo accident (rail) were also assessed to have zero displacement impacts, and hence zero displacement risk, at the best estimate.

Note that there is a significant difference between short-term evacuations up to a week and longer term permanent relocation – a distinction that is not made in the SNRA. As such, caution is advised when interpreting the social displacement risks in Figure 6.

Insufficient data about the social displacement risk associated with winter storms, tornadoes, cyber attacks, tsunamis, volcanoes, antibiotic resistance, emerging infectious diseases other than influenza, plant disease, heat waves, industrial accidents, mass migration events, oil spills, or pipeline failures was collected during the SNRA to support quantitative comparisons to other national-level events. For this reason, these events are not displayed in Figure 6.

Psychological Distress Risk

Note that all comparative statements are made within the set of natural and accidental hazards, and conventional-attack adversarial threats, which were analyzed at an unclassified level for the 2015 SNRA. Classified data and analyses suitable for the comparison of chemical, biological, radiological, and nuclear (CBRN) terrorist attack threats within the fully quantitative framework of the SNRA may be found in the classified SNRA Technical Report.

Psychological impacts for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as inputs.[22] More details regarding the SNRA psychological distress impact analysis and the limitations of this analysis are available in Appendix G of the SNRA 2011 Unclassified Documentation of Findings.

Psychological distress risk was estimated in a semi-quantitative manner using a risk matrix displayed in Figure 7 below. To our knowledge, the SNRA was the first systematic effort to compare psychological impacts and risks from national-level events; as such, additional research

[22] The index approach currently does not include a component for translating economic losses into psychological distress. If estimates of homes destroyed and jobs lost (rather than overall direct economic impacts) are obtained as impact estimates for various national-level events, it would be possible to capture financial loss as part of the equation for psychological distress in future iterations of the SNRA.

into the psychological impacts of disasters is required to improve the understanding of these impacts at a strategic, national level to permit better estimates of expected loss.

Frequency (Best Estimate, events per year)	Less than 500	Between 500 and 5,000	Between 5,000 and 50,000	Between 50,000 and 500,000	Between 500,000 and 5 million	Greater than 5 million
Greater than 1 per year	Accidental Chemical Substance Release Explosives Terrorism Attack		Flood	Hurricane		**Higher Risk**
Between 1 per year and 1 per 10 years	Dam Failure Transportation Systems Failure Combustible/ Flammable Cargo Accident (Rail) Armed Assault	Aircraft as a Weapon	Accidental Biological Food Contamination Earthquake	Wildfire		
Less than 1 per 10 years	**Lower Risk**			Accidental Radiological Substance Release	Space Weather	Pandemic Influenza

Psychological Distress

How to read this chart: This is a plot of psychological distress risk, as drawn from the best estimates of frequency and psychological distress. Higher risk national-level events tend toward the upper right of the chart, lower risk ones towards the lower left. One national-level event can be said to be higher risk than another when it is both higher frequency AND higher impact. The color coding of the national-level events corresponds to the hazard type: adversarial events, technological/accidental hazards, and natural disasters. Psychological distress likelihood and impacts for CBRN attacks are classified, and are not displayed on this chart. Drought had a psychological distress impact of zero, as it had no assessed fatality, injury/illness, or displacement impacts.

Figure 7: Psychological Distress Risk

Two events were estimated to have relatively high psychological distress risk compared with other non-terrorism related hazards: pandemic influenza outbreaks and hurricanes. These findings are driven by the underlying method used to estimate significant distress in the SNRA, which heavily weighted contributions from events' fatalities and injuries/illnesses, as well as social displacement to a lesser extent. As discussed above, pandemic influenza dominates the fatality and injury/illness risk, while hurricanes pose a significant social displacement risk. Because the equation used to represent significant distress considers each of these impact types, events that are high risk in these three categories will correspondingly pose relatively high psychological distress risk.

Other events that are not estimated to pose the highest psychological distress risks among the non-adversarial hazards, but which are still noteworthy, include floods and wildfires, and possibly space weather.

Drought had zero psychological distress impacts at the best estimate because of its zero human health and displacement impacts, and is not displayed in Figure 7.

Insufficient data about the psychological distress risk associated with winter storms, tornadoes, physical attacks on the power grid, cyber attacks, tsunamis, volcanoes, antibiotic resistance, emerging infectious diseases other than influenza, plant disease, heat waves, industrial explosions, mass migration events, oil spills, or pipeline failures was collected during the SNRA to support quantitative comparisons to other national-level events. For this reason, these events are not displayed in Figure 7.

Environmental Risk

Note that all comparative statements are made within the set of natural and accidental hazards, and conventional-attack adversarial threats, which were analyzed at an unclassified level for the 2015 SNRA. Classified data and analyses suitable for the comparison of chemical, biological, radiological, and nuclear (CBRN) terrorist attack threats within the fully quantitative framework of the SNRA may be found in the classified SNRA Technical Report.

Since environmental impacts are measured on a four-level ordinal scale (minimal, low, moderate, high), estimating environmental risk is not as straightforward as for other types of risk. While the environmental impact estimates themselves were provided by subject matter experts, analysts' judgments were used to choose events with high combinations of environmental impact and frequency. The lack of quantitative environmental risk estimates necessitates a subjective judgment of high risk events; this is an area of the SNRA recognized for future improvement.

- Estimates of environmental impacts conditional upon event occurrence are unclassified for all events in the SNRA, and may be found in Appendix H of the SNRA 2011 Unclassified Documentation of Findings. As environmental risk represents the product of these impact measures with estimated frequencies of event occurrence which are classified for CBRN adversarial SNRA events, only natural and technological hazards are discussed below. Comparative analysis among all SNRA events based on environmental impacts alone, independently of frequency of occurrence, is presented in Appendix H.

Three national-level events among the natural and technological hazards are estimated to have relatively high environmental risk due in part to their high frequency: floods, hurricanes, and accidental chemical substance releases (toxic inhalation hazards). These events were judged to be of high environmental risk because they were judged to result in the most significant environmental impacts (moderate, at the best estimate) of the events with the highest frequency estimates in the SNRA (greater than one event per year, at the best estimate).

No other natural, technological, or non-CBRN adversarial hazards were assessed to have a high environmental impact and hence high environmental risk at the best estimate, although some were assessed to have the potential to have high adverse impacts on the environment at the second best estimate (see SNRA 2011 Unclassified Documentation of Findings Appendix H for table).

Space weather was judged to have *de minimis* (minimal) environmental risk because of its assessed *de minimis* adverse environmental impact, at the best estimate. If a space weather event affecting physical infrastructure were to result in extended power outages, the potential for environmental impacts would increase to low/moderate as chemical and treatment plants failed.[23]

Frequency (Best Estimate, events per year)	De Minimus	Low	Moderate	High
Greater than 1 per year			Flood Hurricane Accidental Chemical Substance Release	Higher Risk
Between 1 per year and 1 per 10 years	Armed Assault	Aircraft as a Weapon Wildfire	Accidental Biological Food Contamination Dam Failure Earthquake	
Less than 1 per 10 years	Space Weather Lower Risk	Animal Disease Outbreak Pandemic Influenza	Accidental Radiological Substance Release	

	De Minimus	Low	Moderate	High
Impacts only (events for which frequencies are classified)	Radiological Terrorism Attack	Biological Terrorism Attack (non-food) Chemical/Biological Food Contamination Terrorism Attack	Chemical Terrorism Attack (non-food)	Nuclear Terrorism Attack

Environmental Impacts

How to read this chart: This is a plot of environmental risk, as drawn from the best estimates of frequency and environmental impact. Higher risk national-level events tend toward the upper right of the chart, lower risk ones towards the lower left. One national-level event can be said to be higher risk than another when it is both higher frequency AND higher impact. The color coding of the national-level events corresponds to the hazard type: adversarial events, technological/accidental hazards, and natural disasters. As the likelihoods and hence the environmental risk of adversarial events are classified, the unclassified environmental impacts of adversarial events are displayed without likelihood information.

Figure 8: Environmental Risk

Insufficient data about the environmental risk associated with winter storms, tornadoes, physical attacks on the power grid, cyber attacks, tsunamis, volcanoes, antibiotic resistance, emerging infectious diseases other than influenza, plant disease, heat waves, industrial accidents, mass migration events, oil spills, or pipeline failures was collected during the SNRA to support quantitative comparisons to other national-level events. In addition, the change in scope of the Explosives Terrorism Attack event made it unclear whether the Low/Moderate judgment of the

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[23] For the 2015 SNRA, these may more appropriately correspond to the low and high estimate scenarios respectively on other impact axes, resulting in a dual estimate situation as well for environmental impacts. However, as these estimates were previously elicited the 2015 project team chose not to make adjustments to their presentation as given in the 2011 SNRA.

2011 subject matter experts would still apply. For this reason, these events are not displayed in Figure 8.

Risks Requiring Additional Study

While the analysis of all events in the SNRA would benefit from additional research and deliberate, long-term study, the threats and hazards identified in tables 2 and 3 of the 2015 SNRA Findings document were judged to have insufficient quantifiable data to estimate frequency and impacts. The SNRA project team recommends these events for future study during the next iteration of the SNRA.

Highly Uncertain Risks

Cyber attacks were determined to be highly uncertain risks in the SNRA, as the risk from these events is difficult to quantify.[24] The 2015 iteration of the SNRA did not quantitatively assess cyber attacks. However, a detailed scoping analysis of the current space of cyber risk to the United States, undertaken by the DHS/National Protection and Programs Directorate (NPPD) Office of Cyber & Infrastructure Analysis (OCIA) for the 2015 SNRA, is provided in the accompanying SNRA documentation.

Frequency Chart

The following chart is intended to provide additional threat and hazard specific context, identifying frequency ranges utilized by the SNRA. As frequency is a conceptually more abstract concept than fatalities, injuries, or persons displaced, a presentation of frequencies in a chart by themselves may make them substantially easier to grasp for many readers.

The length of each bar denotes the range between the Low and High estimates, or the amount of uncertainty surrounding the Best Estimate. The vertical slide marker on each bar denotes that Best Estimate.

In order to apply a consistent methodology across all SNRA event types, frequency was selected as a metric for the likelihood of event occurrence. Frequency was estimated as the potential number of occurrences or attacks, per year, which met or exceeded the established threshold for the event.

- For the majority of events, frequency estimates were based on statistical analysis of historic data, or directly from historical data where extensive records were available.[25] For the 2015 SNRA, these included new unclassified analyses of the conventional (non-CBRN and non-cyber) terrorist attack events of the 2011 SNRA, as well as a new adversarial event (Physical Attack on the Power Grid).

[24] A major achievement of the 2011 SNRA was the determination of quantitative frequency distributions for cyber attacks against data systems and against physical infrastructure by subject matter expert elicitation under formal protocols (see Appendices B and M, SNRA 2011 Unclassified Documentation of Findings [unclassified methodology], and Appendix B of the classified SNRA Technical Report). However, quantified impacts [consequences] associated with these frequencies could not be determined.

[25] SNRA project analysts examined the data sets for a particular event and identified how many incidents within the scope of the event occurred at or above the established threshold per year.

- CBRN adversarial/human-caused frequencies were estimated primarily using elicitation from subject matter experts.[26]

When interpreting the frequency results, it is important to consider that the frequency data in the SNRA is directly related to the threshold included in each national-level event definition. For example, the results for floods indicate that floods causing greater than $100 million in direct economic losses are estimated to occur with a frequency between once every two years and ten times per year, with a best estimate of four times per year. For reference, the full threat and hazard definitions, including thresholds, can be found in Table 1 of the SNRA 2015 Findings.

Detailed Findings

Many events are estimated to have the potential to happen more than once every 10 years, meaning that it is likely that the Nation's preparedness will be tested in this decade.

The most frequent threat/hazard event in the 2015 SNRA is explosives terrorism attacks. This may seem surprising, at first. However, this frequency reflects the choice of threshold.

- For the 2015 SNRA, the threshold for explosives terrorism attacks was set to be the occurrence of an event (an explosives or incendiary attack, designated as terrorist by the U.S. Government[27]), similar to the CBRN events. Federal partner participants in the 2015 SNRA selected this threshold to capture the set of explosives and incendiary attack incidents most relevant to the planning and preparedness questions involved with the 2015 revision of the National Preparedness Goal.
- Bombings occur with a much higher frequency in the United States than may be generally realized, with more than a thousand every year in the last years that the FBI reported complete statistics (see Explosives Terrorism Attack risk summary sheet). As large as it may appear, the set of terrorism-designated incidents included in the primary data set leveraged by the 2015 SNRA represents only a tiny subset of these.[28]

By their best estimates, the most frequent natural and technological hazard events in the SNRA are floods, tornadoes, hurricanes, and accidental chemical substance releases (toxic inhalation hazards), which are expected to occur a few times per year. However, other events have the potential to occur at least this frequently, when uncertainty is considered.

Of the non-adversarial events with frequency data of sufficient quality upon which to base comparisons, the least frequent hazard, a very severe (Carrington level[29]) space weather event, has a best estimate of frequency of approximately 1 in 150 years. However, because of the

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[26] Subject matter expert (SME) elicitation was a component of modeling frequency in the Terrorism Risk Assessments, the DHS/Directorate of Science & Technology (S&T) models leveraged for the classified CBRN risk information in the SNRA. The outputs from these models were converted to equivalent units of successful events per year for comparison to the frequencies of natural and technological hazards drawn from the historical record.

SME estimation of the frequency of rare, adversarial/human-caused events is challenging, and SME frequency judgments in the SNRA reflect significant uncertainty. As with all data in the SNRA, these SME frequency judgments should be interpreted as order of magnitude estimates for the purposes of comparison.

[27] The terrorism designation is in part a constraint originating in the best available data, the FBI historical statistical reviews of terrorism in the United States (see the Explosives Terrorism Attack risk summary sheet).

[28] Note that in the case of explosives attacks, lowering the threshold does not substantially affect the risk on the metrics measured by the SNRA. For example, a much larger number of zero-injury attacks are captured, increasing the counted frequency: however, the average number of fatalities and injuries decrease in proportion, resulting in little or no change in injury or fatality risk.

[29] See Space Weather risk summary sheet, this Appendix.

limited observational evidence for solar storms of this magnitude, the uncertainties are very broad around this best estimate.

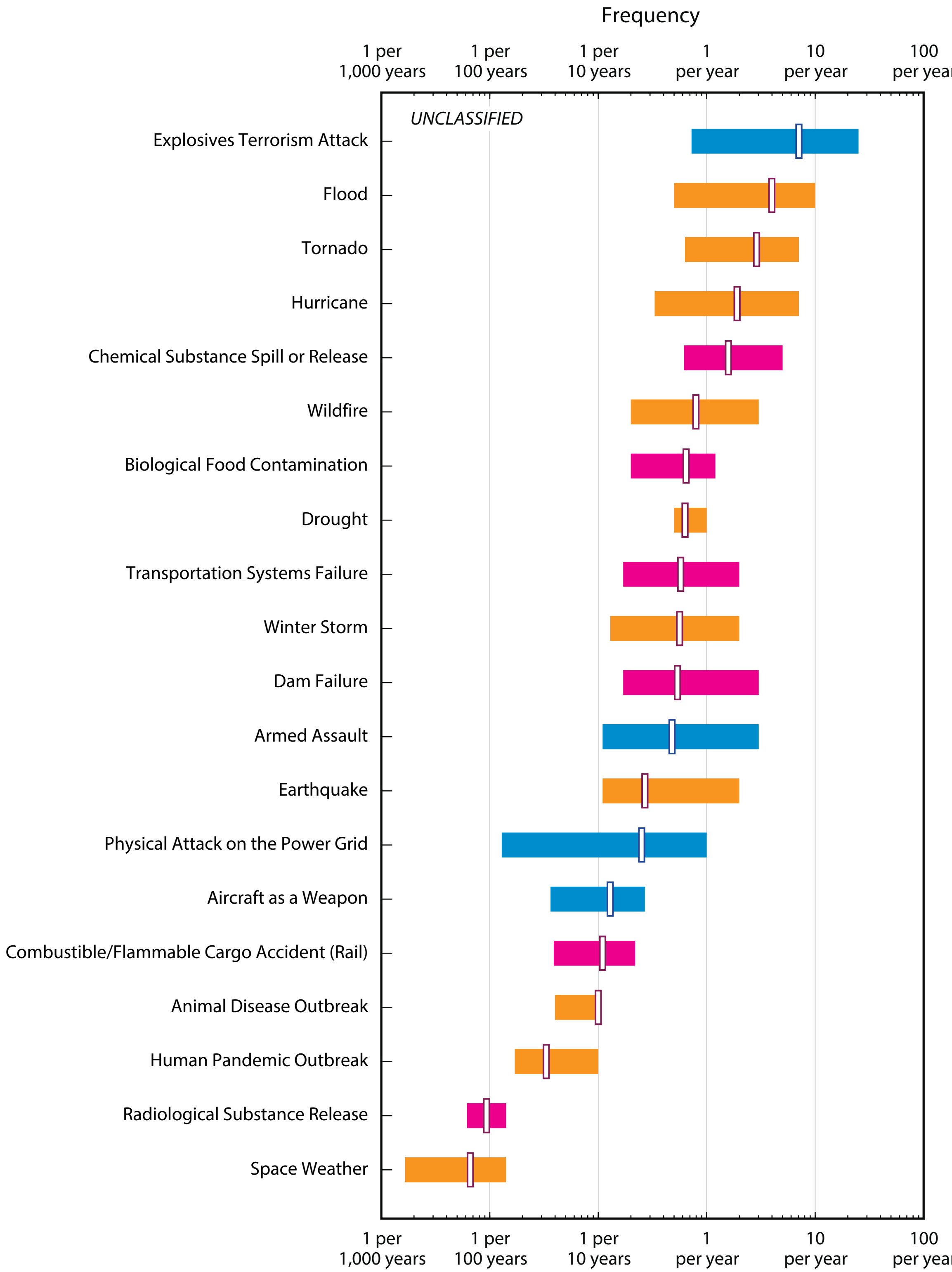

Figure 9: Frequency by Threat/Hazard Event

Section 6: New and/or Updated Risk Summary Sheets

Contents

For each national-level event, the research, assumptions, and data which were used to produce the low, best, and high estimates of likelihood and measures of impact were documented in an event-specific risk summary sheet by the SNRA project team. Summary sheets with common reporting formats to document staff research and analysis of individual hazards have been used by past comparative risk assessments, in part because of their utility in guiding research efforts to identify data capable of being expressed in terms of a predetermined set of measures designed to be comparable across all events.[30]

These risk summary sheets share a standardized data table format to facilitate the comparability and harmonization of estimates across diverse events. This table specifies the categories, types, and metrics which are to be used to measure likelihood and each type of impact.

[30] Lundberg, Russell (2013, September). Comparing homeland security risks using a deliberative risk ranking methodology. Dissertation, Pardee RAND Graduate School, RAND document RGSD319; at http://www.rand.org/about/people/l/lundberg_russell.html#publications. Willis et al (2012). Comparing security, accident, and disaster risks to guide DHS strategic planning. *Current Research Synopses* paper 43, RAND Corporation, and the National Center for Risk and Economic Analysis of Terrorism Events (CREATE), University of Southern California. Near-final draft versions of the ten risk summary sheets in the back of Dr Lundberg's dissertation were kindly provided to the SNRA project by RAND in early 2011 to assist in project formulation, and have been extensively leveraged by the SNRA 2015 project team to frame research questions and identify data sources.

The risk summary sheet documentation has been used in the past for comparative ecological risk assessments in particular: see Willis et al (2004, April), Ecological risk ranking: development and evaluation of a method for improving public participation in environmental decision making, *Risk Analysis* 24(2) 363-78; Florig et al (2001), A deliberative method for ranking risks (Parts I, II), *Risk Analysis* 21(5) 913-937; and Fisheries and Oceans Canada (2012), Terms of Reference, Risk-based Assessment of Climate Change Impacts and Risks on the Biological Systems and Infrastructure within Fisheries and Oceans Canada's Mandate: http://www.dfo-mpo-gc.ca/csas-ssca/Schedule-Horraire/2012/11_15-17-eng.html (electronic resource: retrieved July 2013). See Lundberg (2013) for additional discussion of risk summary sheets in comparative risk assessment.

Physical Attack on the Power Grid

A malicious actor causes physical damage to an aspect of the power grid, resulting in a loss of power in one or more metropolitan areas for three or more hours. [i]

Category	Description	Metric	Low[ii]	Best[iii]	High[iv]
Health and Safety	Fatalities	Number of Fatalities	0[v]	0[vi]	90[vii]
	Injuries and Illnesses	Number of Injuries or Illnesses	0[viii]	2[ix]	400[x]
Economic	Direct Economic Loss	U.S. Dollars	$15 million	$46 million	$5.7 billion
Social	Displacement	People Displaced from Homes ≥ 2 Days	0[xi]	0[xii]	0[xiii]
Psychological	Psychological Distress	Qualitative Bins	TBD	TBD	TBD
Environmental	Environmental Impact	Qualitative Bins	*De Minimus*[xiv]		
LIKELIHOOD	Frequency of Events[xv]	Number per Year	0.013[xvi]	1 every four years[xvii]	1 to 3 per year[xviii]

[i] Some studies have chosen to examine a nationwide or near-nationwide power outage in the continental United States for at least six months. However, experts differ on how realistic this scenario could be. Because of the uncertainty regarding feasibility of a nationwide power outage, the scenario included here is scoped to a significant but reasonable event.

[ii] For the Physical Attack on the Power Grid event, low, best, and high impact estimates are correlated across impact axes because they represent three physical scenarios (such correlation should not be assumed for other SNRA events). Note that the low, best, and high estimates of likelihood are not correlated to these scenarios: they represent the low estimate, best estimate, and high estimate of the overall frequency of any scenario within the scope of the event (any of the three impact scenarios defining the SNRA's reported range and any other scenario meeting the thresholds which define the scope of the Physical Attack on the Power Grid event).

The low impact estimates assume a successful attack on the grid infrastructure that causes physical damage, but which does not result in a power outage with significant impacts. This outcome could be because the grid is able to offload power and prevent a power outage or disruption, or because there is an outage of 3 or more hours which occurs at night (critical facilities and industries are assumed to have backup power sufficient for several hours).

[iii] The best impact estimates assume a successful attack on the grid infrastructure that causes physical damage and a power outage to a broad metropolitan area in the continental U.S. at daytime, with the power outage lasting 3 hours. The best estimate duration is based on the lengths of the accidental outages discussed in the Event Background section. In order to estimate the impacts of an outage for the best estimate scenario, this assessment assumes the size of the population affected is 2,138,460. This population size represents the median population size for the 50 largest metropolitan urban areas as captured in the 2010 census.

[iv] The high impact estimates assume a successful attack on the grid infrastructure that causes physical damage and a power outage to a broad metropolitan area in the continental U.S., similar to the best estimate. However, the outage lasts for one day, resulting in net impacts to the Nation similar to those of the Northeast Blackout in August 2003.

[v] Zero by assumption.

[vi] Scaled from high estimate in proportion to total person-days without power.

[vii] Injuries and fatalities from power grid failures generally result from heat stroke and respiratory ailments, which can occur when outages occur during the summer months. However, it is difficult, if not impossible, to directly tie heat stroke victims to a power outage. Determining the role of heat (versus other concurrent factors) in a death can be complicated, and different jurisdictions use different criteria for considering deaths heat related. For the high

estimate, the 90 deaths in New York City associated with the 2003 Northeast Blackout, as determined by [Anderson 2012], are used. This figure is likely to be inflated because of the city's population density; however, studies of the New York City-specific impacts from 2003 blackout remain the most defensible high estimate for the scenarios articulated in the Economic Impacts section of this paper.
[viii] Zero by assumption.
[ix] Scaled to the high estimate in proportion to total person-days without power.
[x] Mean estimate of excess hospitalizations for complications of respiratory illnesses in New York City for August 14-15 attributed to the loss of electric power in the 2003 Northeast Blackout [Lin 2011] minus the three fatalities due to respiratory illness found [Anderson 2012], on the assumption that these deaths were most likely pronounced in hospital. This epidemiological study examined hospitalizations for respiratory, cardiovascular, and renal diseases: only respiratory diseases showed statistically significant hospitalizations over prior year averages (from a subset with comparable temperature ranges) of the same days in August. Other studies have examined excess hospitalizations for severe diarrheal illnesses caused by eating spoiled meat products due to loss of refrigeration [Marx et al 2006] and other measures of increased burdens on emergency responders and the hospital system in New York City due to the blackout [Prezant et al 2005] but did not provide quantitative estimates which could be extracted for this summary sheet.
[xi] SNRA project team assumption.
[xii] SNRA project team assumption.
[xiii] The SNRA project team could not find defensible estimates of the number of people displaced from their homes due to the August 2003 blackout, for instance to cooling centers (temperatures were elevated in New York City, [Anderson 2012]), used as the physical model for the high impact estimates: it is likely this number is non-zero, though perhaps very small.
[xiv] Provisional estimate by the 2015 SNRA project team by analogy with the environmental impact estimate description for the Cyber Attack against Physical Infrastructure event, elicited from EPA experts in 2011. Note that this estimate has NOT been reviewed by the original subject matter experts. See Environmental Impacts section.
[xv] Based on data from Department of Energy's OE-417 Filings from 2011-2014 (most complete data for which physical attacks were tracked). Data are available at www.oe.netl.doe.gov/oe417.aspx. For over 100 incidents representing 1/3 of reported physical attacks, the impacts were listed as unknown. This analysis presumes that there were no impacts from these incidents.
[xvi] One incident in the United States [FBI 1982] pp 29-30, [Thomas 1981] in the 80 year period since 1936, chosen as the longest observation period where terror attacks causing blackouts in the United States have been a reasonable possibility. 1936 is sometimes used as a reference point for the maturation of the large-scale, integrated electric grid in the U.S.: it marked the first large scale accidental blackouts and the first appearance in popular culture of the suggestion that the electric grid could be a vulnerable target for terrorists in the Hitchcock film *Sabotage*. The first large scale deliberate blackouts occurred in the U.S. in 1939, when they were used by striking electrical workers as a tool to pressure employers: the power supply to Times Square and Broadway was shut off in 1941, and the entire city of Pittsburgh was shut down twice in 1946 by striking electrical workers including a month long blackout of the central business district. [Nye 2010] 2, 59-64, 70-72, 182.
[xvii] Assumes continuing average of one event every four years that causes a confirmed *and* measurable loss of power and effect on customers. Also assumes that these types of events have the potential to cascade into a blackout.
[xviii] Assumes continuing average of about one event with impact (defined as loss of power *or* an effect on customers) per year and that this type event holds the potential of cascading into a blackout.

Event Background

> *Utility executives and Federal energy officials have long worried that the electric grid is vulnerable to sabotage. That is in part because the grid, which is really three systems serving different areas of the U.S., [had failures impacting a large number of customers] when small problems such as trees hitting transmission lines created cascading blackouts. … Many of the system's most important components sit out in the open, often in remote locations, protected by little more than cameras and chain-link fences.*[31]

From 2011[32] to 2014[33], there were 322[34] reported incidents of alleged or confirmed sabotage, physical attack and vandalism[35] to different parts of U.S. utilities. These cases represented about 35 percent of all incidents[36] reported to the U.S. Department of Energy that posed a risk to the grid. Most had little effect,[37] but some resulted in measureable impacts. The well-known incident at the Pacific Gas & Electric (PG&E) Company's Metcalf Transmission Substation outside of San Jose, California, for example, had widely reported estimates of $15 million[38] in damages and the potential for more serious impacts because the PG&E Metcalf substation provides power to California's Silicon Valley.

In the U.S., there is no single interconnected national grid. Instead, the continental U.S. is served by three separate grids, which are largely not impacted by the failure or resiliency of the others. It is feasible for coordinated events to impact more than one of the grids within the U.S., but it is highly unlikely that an attack within one grid could cascade and impact the others.

The three separate networks are:

- The Western Interconnection, which serves those contiguous states west of the Rockies as well as their Canadian neighbors and portions of Northwestern Mexico.
- The Electric Reliability Council of Texas, which serves only the state of Texas.
- The Eastern and Quebec Interconnection which serves all states (and Canadian Provinces) east of the Rockies and south of the Great Lakes and New York. The Eastern Interconnection is actually made up of multiple interconnected but separately managed grids, allowing some cascading failures but also additional resiliencies within this large, heavily populated area.

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[31] [Smith Feb 2014]

[32] The first year the Department of Energy began collecting this information via OE-417 filings

[33] Most recent, complete year of data available from the Department of Energy's OE-417 filings

[34] OE-417 filings are considered emergency forms. Depending on the specific circumstances, they must be filed either within one hour or six hours of the incident.

[35] Due to similar definitions and timeframe for data submission by owners and operators, sabotage, physical attack and vandalism are all considered physical attacks for purposes of this analysis.

[36] Other incident types include weather and natural disasters, fuel supply deficiency, and operator actions.

[37] For over 100 incidents representing 1/3 of reported physical attacks, the impacts were listed as unknown. This analysis presumes that there were no impacts from these incidents. For many other incidents, it was reported that there was no load shedding or loss of power to customers, so these are presumed to have had little-to-no effect.

[38] [Baker 2014]

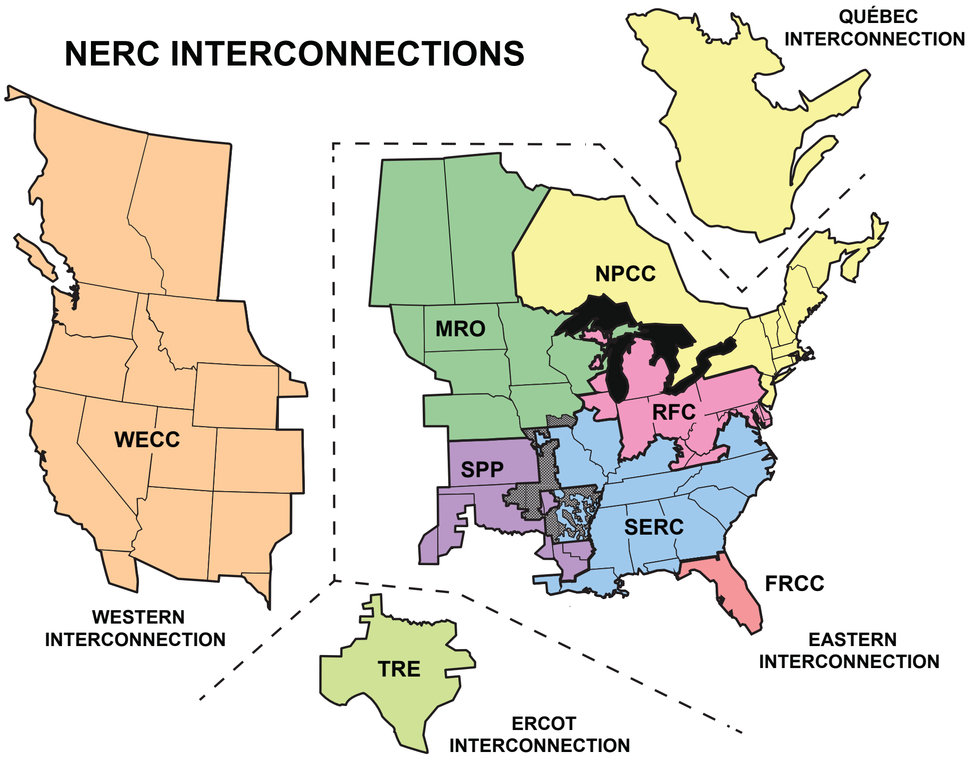

Figure 10: Interconnections and Reliability Regions[39]

To date, "no major power outage in the Western world has originated from an antagonistic attack, [and]… there are few publicly reported sabotage attempts (near-misses)."[40] However, two recent accidental causes of domestic power outages are worth noting, as they serve as examples of what malicious attacks could feasibly achieve:

- In February 2008, a small, isolated fire in a substation on the outskirts of Miami "caused a cascading regional grid collapse — including the Turkey Point nuclear power plant south of Miami — as electricity demand suddenly outstripped what was being produced. Some three million people from South Beach to Tampa to Daytona Beach lost power"[41] for a few hours.
- In 2011, a human error at an Arizona substation tripped a 500 kilovolt (kV) transmission line and cut power to 1.6 million customers in Arizona and southern California. The majority of customers were located in the San Diego Gas & Electric service territory, and about 4 million customers were without power. Most customers were without power for just a few hours;

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[39] North American Electric Reliability Corporation (NERC) (2012, July 25). NERC Interconnections. At http://www.nerc.com/AboutNERC/keyplayers/Documents/NERC_Interconnections_Color_072512.jpg (retrieved 16 April 2015).

[40] [Holmgren 2007]

[41] [Padgett 2008]

however, about 1.4 million of those affected were without power for anywhere from 11[42] to 13[43] hours.

Overall, a significant limitation to estimating risk from this threat is a lack of publicly available information on the electric grid and its resiliency. "Detailed analyses of these grids are, naturally, conducted by the network operators, but are seldom published for business and operational security reasons."[44] Generally speaking, anyone could learn about "transformer vulnerabilities from engineers and operators experienced with this technology, either domestically or abroad, since the same technology is used in power grids throughout the world."[45] Furthermore, knowledge of transformer locations themselves is also relatively easy to gain, such as by viewing images on mapping websites or following the path of high-transmission power lines back to their source.

For the purposes of this assessment, the 2003 Northeast Blackout could be used as a starting point to estimate potential impacts, but it would be difficult to estimate[46] how long a blackout caused by this type of an event would last. Rather than a nationwide or near-nationwide outage, this analysis assumes the outage will affect a metropolitan area. For any blackout, the amount of time[47] it lasted would dictate the severity of the impacts. If a large blackout were to happen because of an adversarial attack, there is one variable that makes it difficult to know how long it would last: the unproven domestic manufacturing capacity to rapidly replace damaged transformers.[48] "Today, there is limited manufacturing capacity in the United States for [high-voltage] transformers. Five U.S. facilities[49] state that they can manufacture transformers rated 345 kV or above, although it is not clear how many units in this range they have actually produced. Canada and Mexico have five additional [high-voltage transformer] manufacturing plants."[50] The estimated capacity of the five U.S. plants is about a typical year's imports, which in 2013[51] was almost 500 transformers of various types. However, it is still unclear how rapidly these facilities could build and transport the high-voltage transformers necessary to rapidly fix a critical substation. It will be important to monitor demonstrated domestic manufacturing capacity, as measured by domestic plants successfully manufacturing high-voltage transformers for domestic utilization.

At the most extreme, there a nationwide failure across multiple interconnections of the U.S. power grid because of an adversarial attack could lead to a catastrophic outage across the country. One scenario could result from attackers causing the loss of power for one of the three grids through a coordinated attack on the critical substations for a specific grid: "four in the East, three in the West and two in Texas."[52] However, there is a high degree of uncertainty around

[42] [Los Angeles Times]
[43] [Los Angeles Times, 9 Sept 2011]
[44] [Holmgren 2006]
[45] [Parfomak 2014]
[46] This scenario is implied by the nationwide option, but it is not clear if a similar 18-month window would apply.
[47] The large-scale loss of electricity for a few days, or if localized a few weeks at most, is a common enough occurrence that American society is relatively resilient to it: people cope, or (as power is restored in localized areas) go to friends, family, or temporary shelters with power, heat or air conditioning, and water.
[48] Large or high-voltage transformers must be custom designed and built [U.S. DOE 2014]
[49] These plants are located in Alabama, Georgia, Missouri, Tennessee and Wisconsin [U.S. DOE 2014 and Thornton 2015]
[50] [Parfomak 2014]
[51] [Thornton 2015]
[52] [Smith March 2014]

whether it would even be possible to simultaneously sabotage critical substations across the interconnections and how many substations would need to be sabotaged in order to cripple the grids, so it is only mentioned here as an area of further study.

Some scholars have created electric grid models to project and estimate potential effects, and they found that consequences were more likely to come[53] from attacks executed by organized groups as opposed to opportunistic individuals. However, "trying to quantitatively evaluate the probability of such low-probability–high-consequence potential terrorist attacks is very challenging, resource-demanding, and subject to inaccuracies."[54] Ultimately, because of this type of uncertainty, this analysis does not make a determination as to the feasibility or probability of a successful attack causing a nationwide or near-nationwide blackout. To more clearly establish the potential risk of attacks, more complete data is needed from owners and operators regarding the impacts of incidents, identification and prioritization of critical assets, models of scenarios and outcomes, and tests of the grid's resiliency. Without additional information, "the true vulnerability of the grid to a[n]…attack remains an open question."[55] However, there is data to conclude that physical attacks on the electric grid are a documented, reoccurring risk, and they will likely continue to happen. Additionally, based on the historical evidence on accidental incidents causing outages, it remains possible for well-planned adversarial actors to cause a blackout.

Assumptions

There are two types of motivations that frame how an adversarial actor could approach an attack: causing as much damage as possible to the grid itself or causing a blackout to a large area. Attacks to the grid that cause medium-term load shedding require significant resources and "will lead to a longer-lasting system 'pain,' and the element replacement/repair costs might be higher."[56] However, these impacts are largely not visible to the public. On the other hand, causing short-term cascading outages requires fewer resources and causes less damage[57] to the grid itself; however, because of automated self-protection measures built into the system itself, these types of events are more likely to cause blackouts. Because so much economic and societal activity is dependent on electricity, blackouts have the ability to cause wider damages beyond the grid itself. Plus, "the U.S. electric power grid has historically operated with such high reliability that any major disruption, either caused by weather, operational errors, or sabotage, makes news headlines."[58]

Therefore, while it is "difficult to accurately understand the objective of the terrorists"[59] or others with malicious intent, it is assumed that the intent of an adversarial attack would be to cause a blackout rather than maximize damage to the grid itself. There is also evidence of this method being a preferred approach of adversarial actors. For example, one white supremacist group posted the following in a manual on sabotage:

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[53] [Holmgren 2006]
[54] [Wang and Baldick 2014]
[55] [Parfomak 2014]
[56] [Wang and Baldick 2014]
[57] Sequential system protection actions are triggered and do not directly damage the facilities.
[58] [Parfomak 2014]
[59] [Wang and Baldick 2014]

> The power generation and distribution systems of most major Western cities are surprisingly vulnerable.... Attacking during peak consumption times (Winter in cold climates and Summer in hot climates) will make power diversion impossible.... Arson, explosives or long-range rifle fire can be used to disable substations, transformers and suspension pylons. A simultaneous attack against a number of these targets can shut down power ... with the advantage that service cannot be quickly restored by diverting power from another source. Each broken link in the power grid must be repaired in order to fully restore service. An individual, equipped with a silenced rifle or pistol, could easily destroy dozens of power transformers in a very short period of time.[60]

The magnitude (the size of the outage) and duration (length of disruption), of an outage affect the impacts of an event.[61] For the purposes of this assessment, the low, best, and high estimates, we have made the following assumptions.

- For the low estimate magnitude, the assumption is that there is a successful attack on the grid infrastructure that causes damage but that the grid is able to offload power and prevent a power outage or disruption. In the low scenario, assumptions about timing and duration are insignificant.
- However, for the high estimate scenario, this assessment assumes that the attack is successful and causes a power outage, the outage affects a metropolitan area in the continental U.S., and the outage lasts for one day, which is consistent with the outage across the Northeast in August 2003.[62]
- The best estimate scenario assumes the attack is successful and causes a power outage, the outage affects a metropolitan area in the continental U.S., and the outage lasts for three hours. The best estimate duration is based on the lengths of the accidental outages discussed in the event background section. In order to estimate the impacts of an outage for the best estimate scenario, this assessment assumes the size of the population affected is 2,138,460. This population size represents the median population size for the 50 largest metropolitan urban areas as captured in the 2010 census.[63]

In order to inform the impact estimates, this summary sheet assesses the risk from a national perspective, average and general data is used in the economic impacts section. This allows for a general calculation to be made; however, if this risk were to be assessed for a specific locality or metropolitan area, specific factors would need to be considered:

- Industries that make up the local economy—especially those in manufacturing or information technology that can be significantly affected by even momentary lapses in power
- Mitigation measures for blackouts that have been taken by companies with significant local economic output

[60] [Parfomak 2014]

[61] Although timing is important in determining the impacts, this assessment did not make assumptions about the time of year or time of day.

[62] While there is research to suggest catastrophic disruption to the grid that could leave a portion of the country without power for an extended period of time, there was not sufficient evidence at the time of this research to estimate the impacts of a catastrophic disruption and further research is warranted.

[63] [Census 2010] The estimate is derived from taking the mean of the top 50 metropolitan areas according to the 2010 population in the Large Metropolitan Statistical Areas—Population data set.

- Seasonal changes in weather patterns (i.e., very hot or very cold temperatures) and their potential stress on the electric grid
- Resiliency of the electric grid in that particular community

Health & Safety Impacts

Based on the assumptions made in this assessment about the magnitude and duration of a potential outage for the low and best estimate scenario, any health and safety impacts would most likely be limited to a few individuals and would likely be within a community's existing public health capacity to address. At the low end, the power being out for a few minutes or even a few hours, it is unlikely to cause any noticeable impact. Instead, the most pronounced impacts are likely to be caused by any power disruptions themselves.

However, there is historical evidence to suggest that health and safety impacts for a multi-day outage, as assumed in the high estimate, would be significant. The August 2003 blackout's impact in New York City (not the entire region) presents a potential scenario. In this case, "respiratory device failure (mechanical ventilators, positive pressure breathing assist devices, nebulizers, and oxygen compressors) was responsible for the greatest burden"[64] on the city's EMS system. These issues were primarily caused by heat, poor air quality and exertion from disabled mass transit systems, but they may also have been "aggravated by a fourth factor: the psychological stress of not knowing what had happened, not knowing what else might happen, not knowing how to get home, and worrying about loved ones."[65] Subsequent studies identified approximately 90 excess fatalities and 400 excess illnesses attributable to the blackout in New York City.[66, 67]

As noted above, the low and best estimates of fatalities and injuries/illnesses were zero by assumption. The best estimates were scaled to the high estimate, in proportion to the total population without power and outage duration. As noted above, of the physical parameters defining the best estimate across impact categories total population affected numbered totaled 2,138,460 and duration 1/8 of a day (3/24 hours). Scaled in proportion to the 90 fatalities and 400 illnesses from the high estimate event with 50,000,000 people out of power for one day (see below), this scenario results in 0.48 fatalities and 2.13 illnesses. Because the best estimate physical model is derived from a median and because of the uncertainties involved, these were rounded to the nearest integer for best estimates of 0 fatalities and 2 illnesses rather than kept as fractional numbers in the manner of other SNRA best estimates representing averages of a distribution or set.

Economic Impacts

There are several types of economic impacts that the nation could face from an adversarial attack on one or more continental U.S. interconnections. There is the cost to the utility owners to repair

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[64] [Prezant 2005]

[65] [Lin 2011]

[66] [Anderson 2012], [Lin 2011]. Excess respiratory illnesses: other illness causes, including diarrheal illness from spoiled food, did not result in detectable excess illnesses [Marx 2006]. Each of these studies used epidemiological methods similar to those used for counting excess fatalities due to influenza and influenza-related illnesses.

[67] Because of New York City's large population size, this figure is higher than what would intuitively be expected in smaller localities. To cite [Anderson 2012], "among US cities, New York, NY, may be particularly vulnerable [to fatalities from power outages] because of its many high-rise buildings and substantial dependence on public transportation."

damage to their electrical infrastructure (e.g. transmission lines, transformers, and substations). These costs can be significant, particularly since transformers are difficult to build and are typically customized to their exact location, which makes stockpiling supplies difficult. This assessment relies on the 2013 Metcalf incident to form the low economic damage value. In the case of the Metcalf attack, estimates of $15 million[68] in damages were widely reported for transformers that were damaged but not in need of replacement. Had all of the 17 transformers suffered damage and needed to be replaced, it could have cost as much as $102 million, based on an approximate cost of $6 million[69] per transformer. In the case of the Metcalf substation disruption, there were no outages, so for the purpose of this assessment $15.11[70] million in direct economic costs forms the low estimate for economic impacts.

In addition to the physical damage to infrastructure, a successful outage (as is assumed in the best and high estimate scenarios) would cause additional direct economic loss. For the best estimate, which assumes that a U.S. metropolitan city of 2,138,460 experiences a three hour outage, this assessment uses the benefit-cost analysis methodology developed by FEMA in 2011. According to the BCA methodology, electricity disruption[71] on economic activity would cost $114.39 per capita per day in direct economic costs.[72] Since the analysis assumes the outage is three hours, the economic cost per three hours in 2015 terms is $14.30 per capita. By multiplying it across the population, the best estimate for direct economic impact is $30.58 million for the cost of the outage itself, or $46 million for total direct economic impact including the $15.11 million cost of damaged infrastructure.

For the high estimate, this assessment again uses the benefit-cost analysis (BCA) guidance from FEMA. Based on historical evidence from the Northeast Blackout, the high estimate assumes there will be 50 million people affected for one day and using the direct impact on the economy of $114.39 per capita per day (in 2015 terms) from FEMA's BCA, the outage would cost $5.72 billion in direct economic loss.[73]

Due to the limitations of available research, there are other variables that would affect economic impacts that were not included in the scenario development – namely the fragility of businesses, mitigation steps that has already been taken, and the timing of the event. These variables warrant further discussion and study, but it is worth noting that some businesses are more fragile than others with regards to a power outage. Some sectors[74] are particularly vulnerable to even momentary lapses in power. One researcher notes "even a one-second outage can damage

[68] [Baker 2014]

[69] According to [U.S. DOE 2014], a large power transformer is estimated to cost $2 to $7.5 million plus expenses for transportation and installation, which can cost 25 to 30 percent more. A simplified figure of $6 million per transformer is used based on the midpoint of the range of cost plus an additional midpoint percentage increase to reflect transportation and installation expenses.

[70] This figure is adjusted for inflation in 2015 terms.

[71] [FEMA 2011] FEMA's BCA methodology is as follows: 1. Estimate the physical damages to the electric power system in dollars, 2. Estimate the functional downtime (system days of lost service), 3. Obtain the number of people served by the electric power utility, and 4. Calculate the economic impacts of lost electric power service, using the per capita economic impacts and the affected population.

[72] [FEMA 2011] Using 2010 numbers, FEMA found that the direct economic cost of an electricity disruption is $106.27 per capita per day. $114.39 reflects this value adjusted for inflation in 2015 terms.

[73] It is worth noting that by using the FEMA BCA methodology on the Northeast Blackout, the direct economic costs in 2003 would equate to $4.48 billion. However, other methodologies can be used to determine the economic cost, but these figures take into account some indirect as well as direct costs. Using a proportional relationship between electricity consumption and national Gross Domestic Product (GDP), one calculation of the impacts of the 2003 blackout showed that "50 million people were without electric power for a day, and so it estimated to have cost $5.6 billion[73], which is within the range of [other, more complex] estimates that have been published."

[74] Continuous manufacturers and digital/IT companies would be examples.

equipment and disrupt highly sensitive operations to the point where labor becomes idled as systems are reset and brought back online."[75] Nationally, these types of highly electricity-dependent companies "account for approximately 40 percent[76] of U.S. gross domestic product (GDP)"[77] even though they represent less than 20 percent of all U.S. business establishments. In order to evaluate the vulnerability of businesses to a blackout, it is important to understand how companies have mitigated their vulnerability to blackouts. Some companies have installed backup generators to prevent lapses in power, while other businesses and economic activities are naturally more resilient[78] to lapses in power. For example, an analysis[79] based on self-reported estimates from businesses estimated that three-quarters of companies would experience no costs from a one-second outage, half of all businesses would not suffer measurable costs from a three-minute outage, and a quarter would not experience real costs from a one-hour outage. Additional research would need to be done to determine how widespread these mitigation actions may be on a national level and how instantaneously they can provide replacement electricity.

The direct costs associated with a loss of power are also impacted by the time of year when the blackout happens. For example, some costs, such as food spoilage and transportation, are dependent on season/weather and time of day. Residential costs—such as the purchase of wood for home heating, alternative light sources, food spoilage, or damage to electrical equipment—are "a fraction of those incurred by end-users in the other sectors"[80] and largely dependent on the timing[81] of a blackout.

Although rigorous study on the indirect costs of an outage was not fully analyzed within this assessment, research has been done to look at the indirect costs of an outage. Researchers noted "there are several types of indirect costs (e.g., accidental injuries, looting, vandalism, legal costs, loss of water supply, insurance rate increases) with monetary impacts that, in some cases, may exceed direct costs. In fact, an analysis of the interruption costs incurred as a result of the 1977 New York City blackout estimated that the indirect costs of the blackout exceeded direct costs by a margin of 5 to 1."[82] While this has the potential to significantly increase the economic impacts

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[75] [Lineweber 2001]

[76] The specific industries and their Standard Industry Classification (SIC) codes came from [Lineweber 2001] and are as follows: Apparel and other Finished Products Made from Fabrics and Similar Materials - 23; Biological Research - 873101; Chemical & Allied Products - 28 (Does not include 2836); Chemical Manufacturing - Biological products, except Diagnostic - 2836; Communications - 48; Computer And Office Equipment - 357; Custom Computer Programming Services - 7371; Data Processing and Preparation - 7374; Depository Institutions - 60; Electronic And Other Electrical Equipment And Components, Except Computer Equipment - 36; Fabricated Metal Products, Except Machinery and Transportation - 34; Food and Kindred Products - 20; Furniture and Fixtures - 25; Gas and Sanitary Services - 49 (does not include 4911 or 4931); Holding And Other Investments Offices - 67; Hospitals - 806; Industrial and Commercial Machinery and Computer Equipment - 35 (Does not include 357); Information Retrieval Services - 7375; Insurance Agents, Brokers, and Service - 64; Insurance Carriers - 63; Leather and Leather Products - 31; Local and Suburban Transit And Interurban Highway Passenger Transportation - 41; Lumber and Wood Products, Except Furniture ; Measuring, Analyzing, And Controlling Instruments; Photographic, Medical And Optical Goods; Watches And Clocks - 38; Miscellaneous Manufacturing Industries - 39; Noncommercial Biological Research - 873301; Non-Depository Credit Institutions - 61; Nursing And Personal Care Facilities - 805; Paper & Allied Products - 26; Petroleum & Coal Products - 29; Pipelines, Except Natural Gas - 46; Primary Metals Industries - 33; Printing, Publishing, and Allied Industries - 27; Railroad Transportation - 40; Real Estate - 65; Rubber & Misc. Plastics Products - 30; Security And Commodity Brokers, Dealers, Exchanges, and Services - 62; Stone, Clay & Glass Products - 32; Systems Integration Services - 7373; Textile Mill Products - 22; Tobacco Products - 21; Transportation By Air - 45; Transportation Equipment - 37; United States Postal Service - 43; Water Transportation - 44.

[77] [Lineweber 2001]

[78] For example, workers who use laptops with built-in batteries.

[79] [Lineweber 2001]

[80] [Balducci 2003]

[81] To think if it in practical terms, losing power for a few hours in the middle of the night could easily be unnoticed by those who are asleep at the time.

[82] [Balducci 2003]

of an intentional disruption to the electrical grid, additional research is required to determine the impacts of indirect costs.

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

Unlike the Space Weather event, the physical scenarios used as the basis of the impact estimates for the Physical Attack on the Power Grid event included only comparatively short-term outages. Additionally, the SNRA project team was not able to find records of people who were displaced from their homes from two or more days due to the 2003 East Coast Blackout, the historical event used to model the high impact estimates.[83] For these reasons, the SNRA project team made the assumption that the number of persons displaced from their homes would be zero for all three of the low, best, and high estimates.

Psychological Impacts

The SNRA metric of psychological distress includes a scaling factor for each event, which was elicited from subject matter experts in 2011 for the first iteration of the SNRA. Although these factors have a strong regularity across the accidental and natural hazards which enabled the provisional determination of factors for many of the new hazard events in the 2015 SNRA, this is not true of the adversarial events. For this reason, the 2015 SNRA does not report psychological distress estimates for the Physical Attack on the Power Grid event.

Environmental Impacts

The environmental impact estimate, which was assessed for the 23 original national-level events of the 2011 Strategic National Risk Assessment (SNRA) by subject matter experts (SMEs) from the U.S. Environmental Protection Agency (EPA), could not be assessed for the Physical Attack on the Power Grid threat event which was added to the SNRA in calendar year 2015.

To support the comparative analysis of the SNRA, the SNRA 2015 project team made a provisional assignment of environmental impact on the same scale as the 2011 events based upon the closely analogous Cyber Attack against Physical Infrastructure national-level event, which was assessed by the EPA SMEs in 2011.

- For a power outage caused by a malevolent actor attacking the grid (with cyber as opposed to physical means), the 2011 SMEs identified the best estimate of environmental impact as *De Minimus* or none.
- Experts indicated, however, that this depends on the duration of the event. If the impacts of a power outage event occur for longer than a few days, then backup systems for sewage plants, chemical facilities, and other infrastructure could fail and result in more severe environmental impacts. The experts provided a Second Best estimate of Low for the environmental impacts of such a longer duration scenario.

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[83] Hospitalizations are not included in the social displacement metric of the SNRA, as this would result in double counting with the Injuries/Illnesses metric.

- The SNRA project team assigned a *provisional* Best estimate of *De Minimus* and a provisional Second Best estimate of Low for the environmental impacts of the Physical Attack on the Power Grid threat event. It must be stressed that this assignment has not been reviewed by the 2011 subject matter experts or by the EPA.

A future iteration of the SNRA will assess the environmental impacts of this event directly.

Potential Mitigating Factors

In March 2014, the Federal Energy Regulatory Commission (FERC)[84] determined that physical attacks "could adversely impact the reliable operation of the Bulk-Power System,[85] resulting in instability, uncontrolled separation, or cascading failures."[86] FERC's intent is to require owners and operators of the Bulk-Power System to improve their resiliency from physical attacks by doing the following:

- Identify which of their facilities are the most critical to the bulk-power system.
- Assess those facilities' risk to physical attacks
- Have those assessments be verified by an appropriate third-party
- Develop and implement a security plan based on those risks

The existence of reliability standards themselves may not be enough to mitigate risk if they are not properly followed and enforced.

At this time, the rule-making process has not yet been completed, and it will still take additional time to be fully implemented. In the meantime, another key form of mitigation is already taken place: voluntary actions by the industry. For example, California-based PG&E announced plans to spend $100 million[87] to improve the security of its critical facilities, and a subsequent robbery[88] at the Metcalf substation in the months following the attack further reinforced the need for these improvements. In the short-term, voluntary risk reduction methods will be a key mitigation strategy.

In addition, government-led research and development holds potential for mid-term mitigation strategies. For example, in partnership with the utility industry and the DHS Office of Infrastructure Protection, the DHS Science and Technology Directorate (S&T) developed a prototype extra high-voltage transformer. Called the Recovery Transformer (RecX) project,[89] this prototype drastically reduced the amount of time needed to repair an extra high voltage transformer in an emergency—from several months to less than one week. Working with its industry partners, S&T successfully demonstrated the RecX prototype for one year, and the pilot ended in March 2013. A final report is currently in development.

[84] FERC is an independent agency within the U.S. Department of Energy, and it regulates the interstate transmission of electricity, natural gas and oil. Its responsibilities including protecting the reliability of the high voltage interstate transmission system through mandatory reliability standards and enforcing its requirements through imposition of civil penalties and other means.

[85] The Bulk-power system and electric grid are synonyms for practical purposes.

[86] FERC Docket No. RM14-15-000; Order No. 802.

[87] [Baker 2014]

[88] [Smith August 2014]

[89] [DHS-ST 2014]

To specifically mitigate health and safety impacts, local communities could identify their most critical systems and vulnerable populations, and steps could then be taken to ensure adequate measures are in place in the event of a power outage. For example, backup power systems could be "mandated, not only for acute care facilities, but also for community-based patients dependent on electrically powered lifesaving devices."[90] This would greatly minimize the impact of shorter-term power outages on public health capacity during emergencies.

[90] [Prezant 2005]

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Space Weather[xix]

The Sun emits bursts of electromagnetic radiation and energetic particles causing utility outages and damage to infrastructure in the United States, resulting in direct economic losses greater than $1 billion.

Data Summary

Category	Description	Metric	Low	Best[xx]	High
Health and Safety	Fatalities	Number of Fatalities	90[xxi]	N/A[xx]	2,000[xxii]
	Injuries and Illnesses	Number of Injuries or Illnesses	400[xxiii]	N/A[xx]	10,000[xxiv]
Economic	Direct Economic Loss	U.S. Dollars	$5.7 Billion[xxv]	N/A[xx]	$2 Trillion[xxvi]
Social	Social Displacement	People Displaced from Homes ≥ 2 Days	0	N/A[xx]	40 million[xxvii]
Psychological	Psychological Distress	Qualitative Bins	See Discussion		
Environmental	Environmental Impact	Qualitative Bins[xxviii]	*De minimus* (Best); Moderate (Second Best)[xxix]		

Likelihood[xxx]	Metric	Low	Best	High
Frequency of Events	Number per Year[xxxi]	1/600 years	1/150 years	1/70 years

[xix] The term "space weather" describes phenomena taking place in the near-Earth environment, primarily due to influences of the solar magnetic field. The largest space weather events are geomagnetic "storms" that are caused by huge magnetic eruptions from the Sun called "coronal mass ejections" or CMEs. Such eruptions are usually accompanied by bursts of X-ray photons ("solar flares") and energetic particles that can have prompt effects on the Earth's atmosphere.

[xx] Best estimates for fatalities, injuries and illnesses, direct economic loss, and social displacement were not calculated for this event.

[xxi] The low estimate for fatalities is informed by the excess fatalities in New York City attributed to the loss of electric power in the 2003 Northeast Blackout (Anderson et al (2012)) and not directly caused by the space weather itself. This event is used as a proxy for the low economic consequence scenario because it is cited by the electric industry (NERC (2012)) as a model for a scenario of electric grid collapse caused by a solar storm not resulting in permanent transformer damage (i.e. the grid shuts down and is able to be restarted within days). The scope of the study was limited to the 8 million residents of New York City out of the 50 million who lost power nationwide.

[xxii] SNRA project team assumption based upon extrapolation of the 2003 East Coast Blackout (50 million people assumed out of power for average of 1 day) to the Lloyd's high estimate scenario of 40 million people out of power from 16 days to up to two years (Lloyd's (2013)). Because of the multiple uncertainties involved, the SNRA project team made the assumption of one month average outage having disruptive effects (i.e. the 16 days plus two weeks in addition) for a scaling estimate of 1.2 billion person-days, or 24 times that of the East Coast Blackout. This factor was applied to the 90 fatalities of the low estimate, for a lower-bound estimation of a true high estimate of 2,000 fatalities (rounded to one significant figure). Although the initial health impacts of a large-scale, sudden blackout may subside in initial days as affected populations adapt to life without power, the exhaustion of fuel and lifeline resources and impacted supply chains for critical goods may result in significantly compounded total population health impacts days or weeks into the blackout. The SNRA high estimate thus almost certainly represents a substantial under-representation of the true numbers of fatalities which may be expected from a catastrophic, multi-state extended power outage disaster. However, the SNRA project team judged that it would be more misleading and unrepresentative of the uncertainties in potential impacts of a space weather event to report no high estimate at all, rather than reporting a high estimate that itself is deeply uncertain.

[xxiii] The low estimate for injuries and illnesses is informed by the excess hospitalizations for complications of respiratory illnesses in New York City for August 14-15 attributed to the loss of electric power in the 2003 Northeast Blackout (Lin et al (2011)) minus the three fatalities due to respiratory illness of Anderson et al (2012), on the assumption that these deaths were most likely pronounced in hospital. This epidemiological study examined hospitalizations for respiratory, cardiovascular, and renal diseases: only respiratory diseases showed statistically significant

hospitalizations over prior year averages (from a subset with comparable temperature ranges) of the same days in August. Other studies have examined excess hospitalizations for severe diarrheal illnesses caused by eating spoiled meat products due to loss of refrigeration [Marx et al (2006)] and other measures of increased burdens on emergency responders and the hospital system in New York City due to the blackout [Prezant et al (2005)] but did not provide quantitative estimates which could be extracted for this summary sheet. The 2003 Blackout is used as a proxy for the low economic consequence scenario because it is cited by the electric industry (NERC (2012)) as a model for a scenario of electric grid collapse caused by a solar storm not resulting in permanent transformer damage (i.e. the grid shuts down and is able to be restarted within days). The scope of the study was limited to the 8 million residents of New York City out of the 50 million who lost power nationwide.

[xxiv] Scaled in a similar fashion to the high estimate of fatalities: see note to fatality high estimate above.

[xxv] The low estimate of $5.7 billion represents the low end of the economic impact estimate and is based on the inflation-adjusted estimate of the 2003 Northeast Blackout using FEMA's Benefit-Cost Analysis guidance on the economic impact of electricity outages [FEMA 2011], using an assumption of 50 million persons without power for an average of one day. The 2003 blackout has been previously cited by the electric industry (NERC (2012)) as a model for a scenario of electric grid collapse caused by a solar storm not resulting in permanent transformer damage (i.e. the grid shuts down and is able to be restarted within days), and is the lowest estimate of solar storm consequences located in the literature.

[xxvi] Lloyd's (2013) pg. 6. The inflation-adjusted value of $2.51 trillion (2011 USD) is rounded down to $2 trillion to represent uncertainty in the range of potential true impacts (rounding to one significant figure) and to represent the losses accumulated in the first year (rounding down) of the Lloyd's high end scenario of 40 million people out of power from 16 days to 2 years (i.e. 2 years to restore power to the last person). Power restoration curves following a disaster are typically sinusoidal or logarithmic (Executive Office of the President (2013) p 21): restoration is faster nearer the beginning, and longer for the remaining tail at the end. However, even a linear restoration function (constant restoration rate) results in 75% of the total person-days out of power accumulating in the first year, resulting in a low bounding estimate of $1.88 trillion of the total $2.51 trillion estimated costs (the Lloyd's model proportions costs to total person-days without power, Lloyd's (2013) p. 17) accumulating in year 1.

[xxvii] Based upon the high end of Lloyd's (2013) scenario of 20 to 40 million people without power for 16 days to 1-2 years. It is possible for many or nearly all of 40 million people without power under circumstances where essential societal lifelines are functioning to stay in their homes for an outage of up to two weeks, even in temperate conditions. However, this may not hold true for a long-term, very extensive power outage affecting total regions and survival lifelines: the high estimate of displacement reflects this possibility.

[xxviii] In 2011, the United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental impacts for this event in the 2011 SNRA. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories. Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'Best' estimate.

[xxix] Experts identified the best estimate for environmental consequences as "de minimus" or none. Experts indicated environmental/ecological effects would likely depend on duration of outages. For one day to a few days, the damage would be relatively minimal/de minimus (this is in the scope of typical power outages due to snowstorms, rain, and other natural disasters). If the outage persisted for weeks, then there is the potential for backup systems to fail. If backup systems (such as diesel fuel delivery) failed, then the lack of power to treatment plants and chemical plants could have a massive impact. A space weather event would most likely affect a large geographic area in addition to having the potential for a longer duration.

[xxx] Note that low and high likelihoods do NOT correspond to low and high impacts. Low, best, and high likelihoods represent the low, best, and high estimates for the likelihood of occurrence of the set of scenarios or incidents captured within the scope (as defined by the event thresholds and other elements of the event description) of the SNRA hazard event as a whole. Low and high estimates of impact (fatalities, direct economic loss, and so on) are provided to represent a range of impacts that could result, given the occurrence of an incident within the scope of the event. When considered as variables defined by these reported and depicted ranges, likelihood and each impact represent independent variables within the SNRA methodology.

[xxxi] Low, best, and high one year frequency estimates come are those of Love (2012), cited by NERC (2014) (p. 9) as the probability model for a Carrington-level storm. The best estimate of frequency corresponds to a return period of 153 years, rounded to 150 years in the data table. The low and high estimates of 1/600 years and 1/70 years represent the 1 standard deviation (68.3%) confidence interval as cited by NERC. The Lloyd's study uses the same probability model.

Event Description

The Sun emits bursts of electromagnetic radiation and energetic particles at an intensity that saturates the G-5 level on NOAA's Geomagnetic Storm Space Weather Scale.[91] The storm is greater than solar storms observed in North America in the past three decades, reaching to the northern tier of the United States (approximately 50° geomagnetic latitude). Such a storm is potentially strong enough to cause widespread and prolonged electric utility outages, and it may be strong enough to cause significant damage to communications and navigation satellite infrastructure. Although the likelihood of such an event may be difficult to study because of its rarity and limited historical data, strong space weather events have happened in the past—most recently with a near-miss in July 2012[92]—and could theoretically cause widespread, lasting damage to our electric power supply system.

Event Background

"Space weather" refers to variations in the space environment between the sun and Earth. In more common contexts, space weather refers to the phenomenon where emissions from the sun—such as solar flares[93] and coronal mass ejections (CME)[94]—affect the Earth and its surrounding space with geomagnetic storms. There have been several key events that are widely discussed in the space weather literature. Two of them in particular are referenced throughout this assessment:

- Carrington Event:

  The Carrington Event is frequently referenced in space weather literature. From August 28 to September 2, 1859 the U.S. experienced the "most extreme space weather events in recorded history. Looking at four key measures of geomagnetic storm strength (sudden ionospheric disturbance, solar wind, geomagnetic storm and aurora), it is the only event that appears within the top five events in each category."[95] The probability model cited by the North American Electric Reliability Corporation (NERC) estimates a return period of approximately 150 years for Carrington-level storms, but with a wide range of uncertainty (range 1/70 – 1/600 years).[96] Because of the existence in the literature of recent peer-reviewed U.S. impact models for this return period and storm magnitude,[97] the SNRA space weather scenario focuses on a Carrington-level storm.

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[91] Geomagnetic storms, solar flares, and solar energetic particles are classified by NOAA's Space Weather Prediction Center on scales ranging from 1 to 5, in analogy to the hurricane and tornado magnitude scales.

[92] Phillips (2014). A powerful CME—potentially as strong as, if not stronger than, the Carrington event—passed through the earth's orbit on July 23, 2012. The earth was not there when it happened, so there were no impacts. NASA had a record of it because the storm cloud hit the STEREO-A spacecraft.

[93] A solar flare is an intense burst of radiation from the sun. It comes from the release of magnetic energy and is associated with sunspots.

[94] The corona is the outer solar atmosphere and is structured by strong magnetic fields. Where these fields are closed, often above sunspot groups, the confined solar atmosphere can suddenly and violently release bubbles of gas and magnetic fields, and these are called coronal mass ejections.

[95] Lloyd's (2013) 6.

[96] NERC (2014) 9, Love (2012).

[97] Lloyd's (2013), Wei et al (2013). An input-output analysis (Schulte in den Bäumen (2014)) estimates U.S. costs of $2.65 billion from a Quebec-level storm (and $1.2 trillion for a Carrington event assuming recovery within five months), but the correspondence of this cost to direct economic impacts as considered in the SNRA are unclear. A 1990 Oak Ridge National Laboratory calculation (Barnes et al (1990)) estimates a range of $3.042 - $6.100 billion ($5.2 - $10.5 billion in 2011 USD) direct economic losses to the U.S. for a Quebec-level storm occurring at peak power which damages four transformers and blacks out the northeastern U.S. for 16-48 hours. However, this study is not as recent as Lloyd's (2013). Swiss Re reports estimates of $200-500 million of economic loss to Europe for a Quebec-level storm affecting that continent (and $129 - $164 billion in impacts to the U.S. and Canada for a Carrington level event resulting in a 3 week blackout) from a transparent economic model reported in sufficient detail to replicate (Swiss Re (2012), Swiss Re (2014)). However, the Swiss Re figures were not used for primary estimates

- Quebec Storm:

  The March 13-14 1989 geomagnetic storm is one of the most well-known storms because of its impact on the electricity grid. It collapsed the Hydro-Quebec power grid and resulted in the loss of power for more than six million people for nine hours. It also tripped equipment and nearly collapsed other parts of the Eastern interconnection of the U.S. electric grid.[98] The sources used for the primary estimates in the SNRA estimate an approximately 1/50 year frequency (range 1/30 – 1/100 years) for a Quebec-level storm.[99]

Space weather events have occurred throughout human history, but they were not recorded until human technology advanced to the point of developing systems that could be affected by geomagnetic and electrical disturbances. The Carrington Event in 1859 resulted in an observable solar flare that disrupted telegraph communications. Research has been done to study how geomagnetic-induced currents affect electric power disturbances. Based on statistical analysis, researchers concluded that roughly four percent of all insurance claims related to electric power disturbances in North America could be attributed directly to space weather, equating to 500 insurance claims per year.[100]

While research has suggested that space weather affects the electric grid, there is still a great deal of debate and uncertainty across the scientific, regulatory, policy, and infrastructure operator communities regarding the likelihood that a solar storm could cause significant damage to critical infrastructure, and the extent and duration of that impact. There are two schools of thought on the potential impacts of space weather events:

- One perspective forecasts a cataclysmic scenario of half the Nation's electric grid out of commission for up to a decade.[101] This is because geomagnetic storms can induce currents in the electric power grid that can last for hours, exciting voltages in an electric power transformer core and magnetically saturating the device. The electromagnetic charge overwhelms the transformer core, melting the copper windings, leading to failure. The transformers cannot be repaired, but rather would need to be replaced, which could take several months to years. The impacts to the national and global economies would be as severe as any economic challenge faced by the U.S. in the past, or greater.[102]

- The other approach asserts that a true reasonable worst-case scenario could look more like the large-scale but temporary August 2003 blackout in the Eastern U.S. and Canada[103] (which was caused by a computer error, not a solar storm). Such a blackout impacting a large portion of the United States would be a genuine disaster, but manageable in a way that the high end

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in the SNRA because they could be found only in presentations (slide decks) and conditional probabilities for the different scenarios among them were unclear.

[98] Lloyd's (2013) 7.

[99] Lloyd's (2013) 4, NERC (2014), Love (2012).

[100] Schrijver et al (2014). For this statistical analysis, the researchers studied 11,242 insurance claims from 2000 through 2010 for equipment losses and related business interruptions in North-American commercial organizations that are associated with damage to, or malfunction of, electrical and electronic equipment.

[101] Note, although this assessment uses the 1/150 year return period, there are other experts who suggest the return period may be even more frequent. For additional information, see National Academies (2008) pp 77-79 (John Kappenman's presentation); Metatech (2010) pp 3-22 – 3-29.

[102] Moran (2014).

[103] NERC (2012) pp 16-24, 46, 69, 85; Pulkkinen (2012).

scenario would not be.[104] One reason for this is that coronal mass ejections (CME) are not no-notice events, and this allows operators time to adapt and mitigate the potential effects. Even during the Carrington event in 1859, which is the basis for much of the concern, scientists noticed the solar flare associated with the CME about 18 hours prior to its arrival. Generally, the CMEs leave the sun at varying speeds and interact with the constant electrically-charged solar wind that travels to the Earth at about 250 meters per second. The estimated time from when a CME-event occurs and its arrival at Earth ranges from about 15 hours to several days.[105]

For the purposes of this assessment, each methodological perspective is taken as one of the endpoints to represent the full span of uncertainty around likelihood between them.

Direct environmental and health effects from space weather are minimal, as damage occurs mainly through the medium of disruption of technology. However, our society's dependence on technology, in particular refrigeration[106] and electric-powered medical devices,[107] mean that there could be significant impacts on health (fatalities, injuries, and illnesses) depending on the severity of a solar storm and its impact on power generation and communications.

Technologies that can be directly affected by extreme space weather include the electric power, spacecraft, aviation, and GPS-based positioning industries. Within the last 30 years, space weather events (of magnitudes below the threshold of the National-Level Event as defined here) have disrupted all of these technologies. Severe storms could result in additional consequences for numerous systems that rely on the electrical grid.

Another factor to consider is the possibility that a localized impact to transformers in one region could also result in a national event if their failure were to disrupt one of the major U.S. grid interconnections. In this situation, "the total number of damaged transformers is less relevant for prolonged power outage than their concentration. The failure of a small number of transformers serving a highly populated area is enough to create a situation of prolonged outage."[108] Considering the impacts on society and population, the Lloyd's study concluded that the highest risk of solar storm induced power outages was the Washington D.C. – New York City corridor, on the Eastern Seaboard. Additional highly vulnerable areas included the Midwest (due to latitude) and along the Gulf Coast (due to ground conductivity and coast effects).[109]

The potential for loss of life *directly* attributed to a solar storm event is believed to be low compared to some other hazard events. Any deaths occurring in large numbers would be caused by the loss of electricity and the resulting cascading effects on other critical infrastructures. Examples include the following:

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[104] Mark Lauby, North American Electric Reliability Corporation (NERC), written submission in Attachment A, FERC (2012). NERC notes that its 2012 conclusion that the most likely outcome of a severe space weather disaster would be a reactive voltage collapse is based on its genuine belief rather than an attempt to dismiss the issue: NERC and the industry regard the possibility of a reactive voltage collapse as unacceptable and are taking action to prevent and mitigate such an event (same reference).

[105] NERC (2011) 4.

[106] Marx (2006).

[107] Anderson et al (2012), Lin (2011), Prezant (2005).

[108] Lloyd's (2013) pg. 13.

[109] Lloyd's (2013) pp 10-11.

- The loss of electricity could cause mass transit and passenger rail control systems to fail, potentially causing accidents with fatalities.
- Water shortages may be caused by the failure of electrical pumps to convey water. Power loss at purification plants could lead to acute exposure to toxicants or disease. By extension, firefighters would not have access to water to put out fires, and hospitals would not have access to water to take care of at-risk patients.
- Even in the low-end scenario, the number of fatalities, injuries and illnesses may be expected to reach the dozens or hundreds due to power losses causing the failure of important systems: home medical devices, refrigeration units, and (in a hot summer or cold winter) air conditioning and electric heating systems.

The injury and fatality estimates of this event come from epidemiological studies of excess fatalities and hospitalizations in New York City during the 2003 East Coast blackout.[110] Although the 8 million population of New York City represent a sixth of the 50 million people affected in the U.S. and Canada, many of these hospitalizations and fatalities were attributed to sociological aspects (higher proportion of home medical devices, failure of water pressure and difficulty of response to high-rise buildings without power) that are particular to densely populated urban areas: thus although these numbers understate the true totals, they are likely closer to them than a straight proportion would suggest (and in any case, are likely to be at least within an order of magnitude). In short, injury, illness or death in mass numbers would likely only be caused by the resulting impact on lifeline functions by a geomagnetic event on critical infrastructure—not directly by the space weather event itself.[111]

Assumptions

Like other natural hazards, changes in the occurrence or severity of solar storms are magnified by the way our society's vulnerability to them has changed in recent decades. Due to an increasing critical dependency on the satellite, navigation, and extra-high-voltage (EHV) electric transmission systems, the impact of a Carrington sized event today would not simply be a display of nature, but could represent a catastrophe. Although there is some uncertainty in the frequency of occurrence of severe space weather, the dominant uncertainties lie in the potential impacts. These knowledge gaps come from 1) the fact that these critical systems have not yet been tested by a real event, 2) the destructive testing necessary to narrow the uncertainties around their true vulnerability has been too costly to undertake, and 3) the speed with which the national economy – possibly handicapped by the loss of critical electric and communications infrastructure – would be able to restore substantial losses to them is unknown.

The SNRA project team used the following assumptions to estimate economic impacts resulting from a space weather event across the following types of infrastructure:

Effects on GPS services:

Direct estimates of the potential cost of a loss or degradation of GPS services from a severe space weather event were not found. However, the total economic benefit of GPS services to

110 Anderson et al (2012), Lin (2011).

111 OECD (2011) p.25.

users (i.e., not counting sales of GPS devices) has been estimated at $28-51 billion per year.[112] Space weather can create microwave emissions that can act as “natural jamming”[113] of GPS singles for about an hour. During the length of a geomagnetic storm, GPS may be unavailable because of interference in the L band. Organizations that rely on GPS for location and timing signals may experience significant disruption.[114]

Effects on Aviation:

A severe event might force the rerouting of hundreds of flights not just over the pole but also across Canada and the northern U.S.[115] These adverse conditions could last for a week.[116] A National Weather Service (NWS) study estimated the cost of such diversions as approximately $100,000 per flight.[117] In addition, GPS-based air navigation could be disrupted. The Federal Aviation Administration’s GPS-based Wide Area Augmentation System (WAAS) was disabled for 30 hours during the severe space weather events of October-November 2003.

Effect on Cellular Communications:

Loss of GPS timing signals of greater than two hours may negatively impact cellular and public safety radio base stations’ ability to work together. For example, “these base stations would be unable to hand off calls to another base station for mobile users moving between coverage areas, and users near the edge of coverage areas may experience interference from adjacent base stations or loss of service.”[118]

Effects on Satellites:

Exposure of spacecraft to energetic particles during solar energetic particle events and radiation belt enhancements can cause temporary operational anomalies, damage critical electronics, degrade solar arrays, and blind optical systems such as imagers and star trackers.[119] In addition to direct effects of radiation, the expansion of the Earth’s atmosphere from a superstorm will cause atmospheric drag on low Earth orbit satellites.[120] In January 1994, Telesat’s Anik E1 and E2 telecommunications satellites were affected by a space weather event; E2 required 6 months to repair at a cost of $50-70 million. The U.S. Department of Defense has estimated that solar disruptions to government satellites currently cost about $100 million per year.[121] A study by Odenwald and Green[122] estimated total costs due to satellite damage and loss of satellite services at $20-70 billion for a severe event.

[112] Pham (2011).
[113] Cerruti et al (2008).
[114] MacAlester et al (2014).
[115] National Academies (2008) pp 50-52.
[116] Odenwald et al (2008).
[117] NOAA (2004) 17.
[118] MacAlester et al (2014).
[119] National Academies (2008) p. 1.
[120] Royal Academy (2013) 35.
[121] *Supra* note 119.
[122] *Supra* note 119.

Effects on Public Safety Telecommunications:

The vast majority of public safety radio communications, including line-of-sight VHF air-to-ground communications used for search and rescue and HF groundwave transmissions out to 10–60 miles, should not be affected.[123] It is possible, however, that cellular base stations—including public safety radio base station antennas—that face the sun could experience increased noise from solar radio bursts at dawn and dusk.[124]

Effect on Electricity Supply:

The effects on the electricity sector could be the most severe from an extreme space weather event, with estimates ranging from billions to trillions of dollars. However, since there is an order of magnitude of difference between the low and high estimate, it is important to be aware that there is significant uncertainty about how much damage an extreme space weather event would do to the physical grid infrastructure, which would determine the duration of an outage. Experts are conflicted on what the impacts of space weather may be.

A low impact scenario which caused a large-scale power collapse of large portions of the national grid but little to no permanent destruction of electric transformers could look like mass blackouts of past experience, such as the August 2003 North East Blackout. However, destruction of key transformers or large numbers of transformers could have significantly more complicated impacts. If there was a prolonged outage for months or even years, this could significantly impact the national economy. The electrical grid is essential to supporting the national economy and our way of life, and unlike the other critical infrastructure sectors and subsectors which could be (and routinely are[125]) impacted in some way by solar storms, the uncertain risk to the electric grid has been a recurrent focus of discussions about solar storm risk.

One core reason is that the grid it is the only subsector that needs to already be substantially functional in order for any permanent damage to be repaired. If there is a collapse of the grid due to widespread damage to electric transformers, it could severely compromise the Nation's ability to manufacture the replacement transformers needed to get the grid back online. This chicken-and-egg dependence not only exponentially increases the time needed to replace physically damaged core equipment, but it can also leave the grid in a crippled state that is out of proportion to the actual extent of the damage. Furthermore, knock-on or cascading effects of the electrical outage on other sectors of the economy would also then continue for the same, disproportionally extended period of time.

Although not analyzed within this assessment, in the event of a widespread persistent loss of power supply, there could be significant psychological impacts through job loss and displacement from uninhabitable areas, and the businesses (such as gas stations and grocery stores) that are able to function may not be able to accept any form of payment other than cash.

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[123] MacAlester et al (2014).

[124] Royal Academy (2013).

[125] Odenwald et al (2008) communicate estimates that, as normal background noise, sub-catastrophic solar storms cost the Nation about $450-500 million per year through disruptions to the electric grid's normal operation (a proportion of the $500 million cited for the 19 month period from June 1 2000 to December 31 2001) and damage to USG owned satellites ($100 million per year, Defense Department estimate).

Frequency

Low, best, and high one year frequency estimates are those of Love (2012), cited by NERC as the probability model for a Carrington-level storm. The best estimate of frequency corresponds to a return period of 153 years, rounded to 150 years in the data table. The low and high estimates of 1/600 years and 1/70 years represent the 1 standard deviation (68.3%) confidence interval as cited by NERC. The Lloyd's study uses the same probability model.[126]

Health & Safety Impacts

The low estimates for fatalities and illnesses come from epidemiological studies of excess fatalities and hospitalizations in New York City during the August 2003 Northeast Blackout. The fatalities are on the order of 100, much larger than the eleven directly attributed to the blackout in its immediate aftermath.[127] Since the approximately 8 million residents of New York City represent a fraction of the 50 million US customers who actually lost power, they represent a lower bound to the true total; however, since the fatalities and illnesses in NYC had much to do with local factors such as high-rise buildings (failure of water pressure, EMT difficulty reaching people on high stories) and being an urban center (older people dependent on home respirators living near a high concentration of world-class hospitals), the true national totals are probably less than seven times the NYC figures, which a proportional scale-up by population would suggest. However, the August 2003 blackout lasted two days, so the potential for fatalities could also increase exponentially in areas with far longer outages. No data could be found to fully calculate these particular impacts of long-term, prolonged blackouts.

The high estimates represent an extrapolation of these known effects to longer blackouts, which required a scaling assumption by the SNRA 2015 project team. The health impacts of the low scenario were scaled up in proportion to the total person-days without power of the 2003 Northeast Blackout (50 million people assumed out of power for average of 1 day), to the Lloyd's high estimate scenario of 40 million people out of power from 16 days to up to two years. Because of the multiple uncertainties involved, the SNRA 2015 project team made the assumption of one month average outage having disruptive effects (i.e. the 16 days plus two weeks in addition) for a scaling estimate of 1.2 billion person-days, or 24 times that of the East Coast Blackout. This factor was applied to the 90 fatalities of the low estimate, for a lower-bound estimation of a true high estimate of 2,000 fatalities (rounded to one significant figure).

Although the initial health impacts of a large-scale, sudden blackout may subside in initial days as affected populations adapt to life without power, the exhaustion of fuel and lifeline resources and impacted supply chains for critical goods may result in significantly compounded total population health impacts days or weeks into the blackout. The SNRA 2015 high estimate thus almost certainly represents a substantial under-representation of the true numbers of fatalities which may be expected from a catastrophic, multi-state extended power outage disaster. However, the SNRA 2015 project team judged that it would be substantially more misleading

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[126] Most SNRA events having a defined frequency distribution cite the 5th and 95th percentiles as the low and high estimates (Appendices B and I, SNRA 2011 Unclassified Documentation of Findings), following customary practice in probabilistic risk assessment (PRA). (For the Love model, the 5th and 95th annual frequencies are 1/3,000 years and 1/51 years respectively.) For the space weather event, the SNRA project team judged that maintaining consistency with the electric power industry source was a higher priority for risk communication purposes.

[127] Minkel (2008).

and unrepresentative of the uncertainties in potential impacts of a space weather event to report no high estimate at all, rather than reporting a high estimate that itself is deeply uncertain.

One health consequence not projected is the impact of increased radiation on the health and safety of airline pilots, crew members and passengers due to a major space weather event. Most flights in the U.S. to expose crew members and passengers to cosmic radiation well above what is experienced on the surface. Dose rates can increase by 10 times or more: exposures depend upon the altitude and latitude of the flight path (polar routes are irradiated most), as well as solar activity. A particularly strong solar storm can boost radiation levels 100 times.[128] However, prior warning of solar storms allow polar flights to be rerouted – the Federal Aviation Administration can issue solar radiation alerts so that pilots know to fly at lower elevations or avoid Polar Regions – and so this particular societal risk is primarily factored in as the increased economic costs from rerouting flights rather than the health impacts to passengers that are averted by this mitigation measure. While a risk, the marginal impacts of increased solar radiation are difficult to quantify—especially when they are in the context of long-term, regular exposure that the aforementioned groups already regularly experience. Therefore, no health consequences can be directly attributed to impacts from space weather in this iteration of the SNRA.

Economic Impacts

The economic impacts to the nation are dominated by the estimates of possible damage to the electric sector. Although existing estimates of the range of possible damage to the transportation, communications, and government facilities sectors are described below and could be quite substantial, their contribution does not register within the single order of magnitude of the total economic damage estimates.

Transportation Sector: Aviation

Aviation	Low	Best	High
Direct Economic Loss	$500,000	$1.3 Million	$3.5 Million

The NRC conference report notes that thirteen air carriers flew a total of 7,300 flights over polar regions in 2007, of which United Airlines alone flew 1,800.[129] Although the NOAA report on the solar storms of October-November 2003[130] notes that two U.S. carriers fly polar routes,[131] the other carrier and its total number of flights is not given, so with the understanding that the true figure will be underestimated, the 2007 United Airlines total is used as a proxy for the annual total of all U.S.-flagged air traffic over the poles, giving a daily average of 4.9 (rounded to 5.0) U.S.-flagged polar flights. The NRC report also notes that a severe solar storm can cause hazardous conditions requiring rerouting of polar flights for several days,[132] and Odenwald et al

[128] Phillips (2013).

[129] National Academies (2008) pp 50-51 [panel].

[130] 2003 saw a significant number of solar storms which did not cause widespread electric outages, in addition to the August 2003 electric outage cited as a model for a solar-storm caused outage but which was not itself caused by a solar storm: it is easy to get these mixed up.

[131] NOAA (2004) p 18.

[132] National Academies (2008) pp 50-51.

note that these disruptions may last for up to a week.[133] For a broad range, the SNRA project team selected 1 day as the minimum polar air disruption time and one week as the maximum. The estimates in the above table were found by using the average cost of $100,000 for the rerouting of a polar flight given by the NOAA study:[134] these estimates are factored in as direct economic loss.

Communications and Government Facilities Sectors: Satellites and GPS

Satellites	Low	Best	High
Direct Economic Loss	$50 Million		$68 Billion

The low end estimate of $50 million damage (repair costs) to the Telsat Anik E2 satellite damaged by the 1994 solar storm cited by the NRC report[135] is taken as the Low Estimate for direct economic loss. Odenwald et al (2005)'s estimates of $24 billion in direct property damage (replacement costs) and $44 billion in business interruption costs (lost transponder revenue) for a solar storm three times that of the 1859 Carrington event in magnitude were summed for the high estimate of direct economic loss.

Indirect economic loss consequent to this direct damage was not estimated. Direct and indirect losses due to physical damage to or service interruption of the GPS satellite system in particular are excluded from the above:[136] no estimates for these are included here.

Energy Sector[137]

Electric Grid	Low	Best	High
Direct Economic Loss	$5.7 Billion		$2 Trillion

The potential impacts on the grid and the economic impacts of an outage are heavily debated in the space weather community. One of the main uncertainties is whether there will be disruptions to the transformers. The *Solar Storm Risk to the North American Electrical Grid* report published by Lloyd's in 2013 noted that "large amounts of geomagnetically induced currents (GIC) flowing through the power grid can damage power transformers and/or lead to voltage collapse, resulting in widespread power outages."[138] Indeed, Lloyd's further concluded that even if a few transformers were damaged (10-20) it could cause significant regional power disruptions.[139]

For the low estimate in this assessment, the G-5 storm disrupts the electric grid and overloads the system, causing widespread outages across the Eastern and Pacific Northwest interconnections

133 Odenwald et al (2008).

134 NOAA (2004) p 17.

135 National Academies (2008) p 25.

136 Odenwald et al (2005) pp 15-16.

137 A note on the methodologies – in order to inform this assessment, this analysis is based on two separate benefit-cost analysis models. The low estimate is informed by the FEMA BCA guidance released in 2011 and the high estimate is informed by the BCA used within the Lloyd's report. This decision was made because of the understanding that there are different BCA considerations for short term (day) electricity outages than there would be for long term (year) outages. For additional information on the methodologies, see FEMA (2011) and Lloyd's (2013).

138 Lloyd's (2013) pg. 6 (see also Molinski et al (2000)).

139 Lloyd's (2013) pg. 6.

and leaving 50 million people without power for a day. Therefore, the low estimate is informed by the Northeast Blackout in 2003, previously cited by the electric power industry[140] as a model for the reasonable-worst-case scenario of an electric grid collapse caused by a 1/100 year solar storm: it is the lowest estimate of solar storm impacts located in the literature. The low estimate of $5.7 billion represents the low end of the economic impact estimate and is based on the inflation-adjusted estimate[141] of the 2003 Northeast Blackout using FEMA's Benefit-Cost Analysis guidance on the economic impact of electricity disruption from outages.[142,143]

The high estimate for economic impact[144] is the high end of the estimate provided by Lloyd's in their 2013 report. Using a benefit cost analysis approach that evaluates the residential, commercial, and industrial costs from an electrical service disruption,[145] Lloyd's estimated that 20-40 million people could be affected for anywhere from 16 days to 1-2 years, and it concludes the economic costs could range from $0.6 – $2.6 trillion.[146] While there is considerable debate within the space weather community about the feasibility of such an event, if one considers the catastrophic scenario[147] described in the Lloyd's report and by experts like John Kappenman in which tens of millions of people do not have power for months or even years, economic losses in the trillions of dollars for such an event[148] are reasonable and possibly understated.[149]

Psychological Distress

Psychological consequences for the SNRA focus on significant distress and prolonged distress, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event.[150] The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary

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[140] NERC (2012).

[141] FEMA (2011). According to FEMA's Benefit-Cost Analysis (BCA) methodology, the impacts of electricity disruption on economic activity are estimated to cost $114.39 per capita per day in direct economic costs (adjusted for inflation in 2015 terms). (This reflects the component for Impact on Economic Activity, $106.27 in 2010 USD; the Impact on Residential Consumers component of $24.58 is not included.)

[142] See also the SNRA 2015 Risk Summary Sheet on Physical Attack on the Power Grid.

[143] It is worth noting that after the Northeast Blackout, the Department of Energy released an after action report that cites the Electricity Consumers Resource Council (ECRC) estimate of $4-$10 billion of total economic loss from the blackout of the 2003 Northeast Blackout. In addition, other methodologies can be used to determine the economic cost, but these figures take into account some indirect as well as direct costs. Using a proportional relationship between electricity consumption and national Gross Domestic Product (GDP), one calculation of the impacts of the 2003 blackout showed that "50 million people were without electric power for a day, and so it [is] estimated to have cost $5.6 billion, which is within the range of [other, more complex] estimates that have been published." Zimmerman (2005) 17-18.

[144] Due to a widespread and long-term electric outage because of the long replacement-time of critical equipment (up to 365 critical Extra-High Voltage [EHV] electric transformers).

[145] Lloyd's (2013) pg. 17. The research assumes a linear relationship with time and electric power consumption: $2.00/kWh, $19.38/kWh, and $8.40/kWh for residential, commercial, and industrial customers, respectively. A factor of 1.31 accounts for inflation from 2001 to 2013.

[146] Lloyd's (2013) pg. 6.

[147] 130 million people without power in a way similar to the 2003 blackout, but widespread destruction of transformers and the long replacement times (the 18 months under ordinary circumstances is lengthened by a crippled national industrial base as a result of the extensive damage to the grid) prolongs the outage from three days to several years.

[148] Extrapolating the cost estimate (approximately $5.7 billion) of the 2003 East Coast Blackout which affected approximately 50 million people for an average of 1 day to 365 days results in $2.1 trillion. The high estimate from Lloyd's assumes more rapid power restoration, but higher economic impacts per unit of power lost.

[149] Continued loss of nearly all the infrastructure dependent upon electric power would most likely have a negative impact on normal consumer spending, and there are other factors such as food spoilage, and regional economic collapse from business closures. All of this would likely represent a substantial fraction of the Nation's annual gross domestic product.

[150] See Appendix G of the SNRA draft Unclassified Documentation of Findings for references and additional discussion of the SNRA Psychological Distress metric.

inputs. A multiplicative factor elicited[151] from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.

- The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + ½\ D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement).
- In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement.
- The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long-term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: Space Weather was given a C_{EF} of 1.0.
- Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.[152]

Environmental Impacts

In 2011, the United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental impacts for this event in the 2011 SNRA. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental impact category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agents, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental impact as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental impacts as “de minimus” or none. Experts indicated environmental/ecological effects would likely depend on duration of outages. For one day to a few days, the damage would be relatively minimal/de minimus (this is in the scope of typical power outages due to snowstorms, rain, and other natural

[151] The elicitations were performed in 2011 for the first iteration of the SNRA, which included space weather as a National-level Event. These elicitations were not repeated in 2015.

[152] Please reference the 2015 detailed findings for Psychological Distress in this document.

disasters). If the outage persisted for weeks, then there is the potential for backup systems to fail. If backup systems (such as diesel fuel delivery) failed, then the lack of power to treatment plants and chemical plants could have a massive impact. A space weather event would most likely affect a large geographic area in addition to having the potential for a longer duration.

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Armed Assault

A hostile, non-state actor(s) uses assault tactics to conduct strikes on vulnerable target(s) within the U.S., resulting in at least one fatality or injury.

Data Summary

Category	Description	Metric	Low	Best	High
Health and Safety	Fatalities	Number of Fatalities	0	2[153]	334
	Injuries and Illnesses	Number of Injuries or Illnesses	0	6	810
Economic	Direct Economic Loss	U.S. Dollars	$61,000	$510,000	$78 million
Social	Social Displacement	People Displaced from Home ≥ 2 Days	0	0	0
Psychological	Psychological Distress	Qualitative Bins	See text		
Environmental	Environmental Impact[154]	Qualitative Bins	De minimus[155]		
LIKELIHOOD	Frequency of Events[156]	Number of Events per Year	0.11	0.48	3

Overview

Frequency, fatality, and injury estimates for the 2015 Strategic National Risk Assessment (SNRA) Armed Assault event were derived from unclassified statistical and historical data published by the Federal Bureau of Investigation (FBI).[157] These primary FBI sources were supplemented with data and research from multiple secondary public sources, in particular the START Global Terrorism Database (GTD)[158] (the primary source for consequence data for the 2011 SNRA event), peer-reviewed literature, and U.S. and foreign press sources.

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[153] Best estimate fatalities, 1.94 (weighted average fatalities given attack).

[154] In 2011, the United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event in the 2011 SNRA. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.

[155] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'Best' estimate.

[156] Low estimate, inverse of maximum inter-arrival time between U.S. historical incidents, Table 4 (9 years, 1985 to 1994); best estimate, average frequency 1980–2012, Table 4; high estimate, most incidents in one year (3 in 2009), Table 4.

[157] FBI (1982), FBI (1983), FBI (1984), FBI (1986), FBI (2000), FBI (2006), FBI (2011); additional FBI sources as cited.

[158] The Global Terrorism Database (GTD) is an open-source database including information on terrorism events around the world (including domestic, transnational, and international incidents) from 1970 to 2010. For each GTD incident, information is available on the date and location of the incident, the weapons used and nature of the target, the number of casualties, and—when identifiable—the group or individual responsible.

START, the National Consortium for the Study of Terrorism and Responses to Terrorism, is a DHS Center of Excellence and network of scholars coordinated from the University of Maryland. Since 2011 when the first SNRA was executed the START GTD has become the most commonly cited source for global terrorism statistical data, and is now used as the primary data source (with similar parameters as the 2011

Assumptions

Historical incident statistics published by the FBI were used as the primary data source for this event. These were supplemented with additional data from the START Global Terrorism Database,[159] scholarly reviews, and press sources as needed.

Historical incidents of indiscriminate violence resulting in one or more fatality or injury other than the attacker(s), identified as acts of terrorism by U.S. Government sources, occurring in the U.S. homeland between 1980 and 2012 were included (Table 4). All of the following criteria were required to be met:

- U.S. Government (FBI) characterization of the incident as a terrorist attack;
- Occurring within the U.S. homeland;[160]
- Resulting in at least one fatality or injury, other than the attacker(s);
- Indiscriminate (assassinations are excluded from scope); and
- Meeting the definition of the Armed Assault event given above.

Targeted attacks where the victim was known and selected by the attacker were considered assassinations, as opposed to armed assault/active shooter incidents (regardless of whether they met other criteria for terrorism). However, attacks targeting particular people that resulted in harm to others were included in the scope of this event.

The beginning observation period date of 1/1/1980 was determined by the primary FBI source data set which included U.S. incidents from 1980 to 2005.[161] The end observation date of 12/31/2012 was selected, because in many cases a definite determination by the U.S. Government that an act is terrorist in nature requires some degree of distance.[162]

- In an absence of a single authoritative FBI list of designated terrorist incidents post-2005, meeting this requirement necessitated searching through public statements and speeches by political leadership, review articles, newspaper interviews, Federal indictments, and other sources to effect a positive determination for each incident that the U.S. Government (in all cases, the FBI) considered a terrorist assault as opposed to a hate crime, active shooter, or some other violent act.

This determination is not often clear or fixed in the immediate aftermath of an attack. For example, the March 2013 Boston Marathon bombing was deliberately not classified as a terrorist attack by the U.S. Treasury for insurance purposes.[163] The U.S. Government designation as terrorist or non-terrorist of the November 2013 assault on a Transportation Safety Administration checkpoint which killed one of the Department's own also remains ambiguous at the time of writing.[164]

SNRA) for the U.S. Government's annual Statistical Annex on Terrorism published for the U.S. State Department's Country Reports on Terrorism. START GTD (2013).

[159] START GTD (2013).

[160] Including territories and possessions identified in the Stafford Act and the Homeland Security Act of 2002, as amended.

[161] FBI (2006).

[162] FBI (2006) 32 (2002 LAX shooter discussion).

[163] Insurance Journal (2014, September 19), (2013, November 27).

[164] February 2015.

Frequency

Incidents between 1980–2005 causing fatalities or injuries were those identified by the last FBI statistical review of terrorism in the United States.[165] Incidents occurring from 2006–2012 were those specifically identified as terrorist acts in subsequent FBI reviews and official statements.

Incidents that targeted and resulted in harm to specific individuals were classified as assassinations outside the scope of the other events.[166] Literature sources, in particular but not limited to the other FBI statistical annual reports[167] (1981–2005) and the START Global Terrorism Database,[168] were consulted to determine the discriminate or indiscriminate nature of the attack. Incidents involving the use of explosives as the primary instrument of violence,[169] aircraft as a weapon, or unconventional (chemical, biological, radiological, nuclear (CBRN)) materials were excluded from the scope of the Armed Assault event. One incident involved an attack with a vehicle, driven into a crowd as opposed to a vehicle bomb;[170] the remainder involved firearms.

To identify the national risk baseline for this kind of attack, the resulting list of 16 incidents were analyzed as a recurring historical event similar to the SNRA's analysis of natural and technological hazards.

- In part, this reflects agnosticism in the absence of other public information of predictive value. Terrorism is driven by multiple deterministic drivers, as well as stochastic (chance) factors. However, without knowledge of those factors that would both remain valid and have predictive value for each successful attack in the United States for the next 3–5 years (the time frame of the 2015 SNRA), representation as a random event without additional qualifications accurately represents our actual state of knowledge.[171]
- Additionally, given current disagreements about the nature and future path of terrorism, this choice is also motivated by the utility of a description of the historical baseline which can be objectively agreed upon, by decision makers with differing beliefs about the future threat environment, as a common point of departure.
- However, it is also chosen for consistence with the findings of past U.S. Government reviews that periods of political violence of even greater intensity—and public awareness of that intensity—than that of today are in fact the historical norm for our country, rather than the exception.[172]

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[165] FBI (2006).

[166] Assassinations are not currently considered in the SNRA, but are part of one of the Department's highest profile missions (protection of dignitaries).

[167] FBI (1992), FBI (1993), FBI (1994), FBI (1995), FBI (1996), FBI (1997), FBI (1998), FBI (1999), FBI (2000), FBI (2001), FBI (2006).

[168] START GTD (2013).

[169] This division is intended to clarify the scope of the SNRA 2015 explosives and armed assault events. Although SNRA 2011 national-level events were intended to be mutually exclusive in scope, the focus of the Armed Assault attack on coordinated team attacks using hand carried explosives resulted in a substantial overlap of the historical data sets used for the primary consequence estimates of each event. While this is not a methodological issue when the data are intentionally used as proxy estimates for future attacks in the U.S. as they were in the 2011 SNRA (both events used world-wide 1970–2010 incident data from the START GTD), it becomes a prohibitive issue when the same historical data are used as the basis for each event's frequency estimates, as they are in SNRA 2015.

[170] The 3/3/2006 Chapel Hill assault (Table 4).

[171] Mohtadi et al (2005, 2009a).

[172] Staff and Commission reports and data set produced for/by the 1968–69 National Commission on the Causes and Prevention of Violence (Graham et al (1969), Kirkham et al (1969), Levy (1969a, b, c), National Commission on the Causes and Prevention of Violence (1969)). See also [non-USG] Gage (2004), Gage (2011), START GTD (2013), Turchin et al (2014).

The average frequency of attacks in the 33-year observation period was used as the basis of the best estimate. Similar to natural hazards, the low estimate of frequency is the inverse of the longest time gap between events (the longest inter-arrival time), and the high estimate the largest number of events in one year.

Health and Safety

Perpetrator fatalities and injuries were not counted. For events occurring 1980–2005, the numbers given by the FBI were used. For events occurring 2006–2012, the numbers given by the primary FBI sources were supplemented with data from the GTD and other sources. The average number of fatalities and injuries were taken as the best estimates.

- The low estimate for both fatalities and injuries is zero, since events with one fatality and zero injuries (and the converse) define the lower threshold of the set.
- Rather than the highest of this set, the high estimates for fatalities and injuries are taken from the September 2004 school siege and massacre in the Russian town of Beslan to represent the range of catastrophic human consequences evidenced by history to be possible outcomes of terrorist armed assault attacks.[173]

Direct Economic Loss

The SNRA direct economic metric includes

- **Decontamination, Disposal, and Physical Destruction (DDP):** The value or replacement cost of physical buildings, infrastructure, building contents, vehicles, and other physical property directly destroyed by the attack. This includes decontamination, if any, and debris removal costs.
- **Business Interruption:** Business interruption costs caused directly by the incident or the immediate investigation, as opposed to shock, substitution, or second-order effects on the economy.
- **Medical Costs:** Cost of medical care to injured, including those who become fatalities.
- **Lost Demand from Fatalities:** No economic value was assigned to a human life (or injury) in itself as a Value of Statistical Life, because this is a value judgment which differs from person to person, and because it would represent double counting with these impacts counted separately. The lost contribution to the national economy as spending was captured, but capped at one year for consistency with benchmark risk assessments. This value was taken at $42,500, the midpoint of the median $35,000-$50,000 household earning value used as the average one year spending per person by past assessments.

Direct economic costs were calculated by the SNRA project team using the following assumptions:

- **DDP Costs:** The SNRA project team made the assumption that the property damage costs were dominated by the other costs counted under the direct economic damage metric, and

[173] Official figures, Russian Government. 334 fatalities and 810 non-fatal injuries include victims and response personnel (civil and military), but does not include the hostage-takers. RT (2014).

could be neglected in comparison for the order of magnitude precision of the SNRA.[174] Except for the most complex armed assault events such as Beslan or the 2008 Mumbai attacks—conducted by coordinated assault teams using hand-carried explosives or incendiaries in addition to guns—the direct property damages of active-shooter attacks (terrorist or otherwise) are much smaller than for explosives or other terrorist attack types.

- **Business Interruption:** Business interruption costs were estimated from the $10 million lost business costs to the approximately 500 businesses in the 12-block immediate impact area of the 2013 Boston Marathon bombing that was restricted for approximately one week of investigation.[175]
  - The size and duration of the restricted immediate impact area was considered to be a reasonable estimate for the post-attack investigation of any terrorist attack of comparable magnitude in this country.
  - For the purposes of estimating business interruption costs for armed assault attacks, the resulting proportional multiplier of $37,000 per casualty (fatality + injury) of the Boston bombings was used to estimate business interruption costs for the historical armed assault attacks in this data set.[176]
- **Medical Costs:** An average medical cost of $5,200 per fatality and $24,000 per non-lethal injury[177] was applied. These estimates, based upon the average medical costs for gunshot injuries due to deliberate assault or homicide in the U.S., were judged to be most representative of injuries due to other extreme violence and were used for each of the conventional terrorism events of the 2015 SNRA.
- **Lost Demand from Fatalities:** To estimate the costs of lost demand from deaths, the SNRA project team multiplied the number of deaths listed in Table 4 by $42,500, the same figure used across the SNRA 2011 events.[178,179]

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[174] The scope of the Armed Assault event contains spectacular exceptions, some of which—such as the 2008 coordinated team attacks in Mumbai, India—comprise the original exemplar of the Armed Assault event in the 2011 SNRA. However, the SNRA 2011 data which define the scope of the event in fact are dominated by small-scale shooting incidents which would be categorized as active shooter or spree killer incidents were they not politically motivated.

[175] Exclusion zone 12 blocks, with 500 businesses, Luna (2013); cost to businesses in exclusion zone for one week restrictions $10 million, Dedman et al (2013). Costs of the citywide lockdown and law enforcement deployment were excluded from the estimate here, because they are not characteristic of the aftermath of most terrorist attacks in this country. Direct property damage costs were also excluded, since these were specific to the bomb attack. Note that estimates of $250-$300 million often reported (Green et al (2013), Dedman et al (2013), Luna (2013)) in the media refer to costs of the lockdown. They are a reasonable estimate of this (being calculated as a 1/2-1/3 of one day's economic activity of Boston), but such broad lockdowns accompany few, if any, of the other bombing and shooting attacks included here. Most conventional-weapon terrorist attacks (bombs, flame, guns) are very localized in their direct effects to property and business interruption.

[176] This counts interruptions to public sector activity, such as the Fort Hood or Little Rock shootings at U.S. Government facilities, on the same basis as private sector economic activity. This equivalence is applied only in this estimator (e.g., lost taxes or parking fines and public sector response costs not counted in the medical costs are not included in the total direct economic loss estimates).

[177] Medical cost per fatal and non-fatal injury for gunshot injuries in the United States from Corso et al (2007), adjusted from 2000 to 2011 dollars using the general CPI-U inflator (1.306). Estimated costs from lost labor productivity are not included.

[178] This number originates from the 2008 Bioterrorism Risk Assessment (BTRA 2008) (the BTRA as a whole is classified Secret, but its economic methodology appendix is U//FOUO), and represents the midpoint (the expected value of a linear uniform distribution over the interval) of the $35,000-$50,000 median household income band in 2011. DHS (2008) pp. E2.7-34. (Appendix reference is UNCLASSIFIED//FOR OFFICIAL USE ONLY; Extracted information is UNCLASSIFIED.)

[179] Some calculations in prior estimates subtract, from the base $42,500 per fatality, $6,000 for increased economic activity from funerary expenses. As this difference was inconsistently applied in the 2011 SNRA and was considered insignificant within the targeted order of magnitude precision of the SNRA, this adjustment was discontinued for new estimates generated for the 2015 revision.

As with the fatality and injury numbers, the lowest and average estimates of the historical data set were used as the low and best estimates of direct economic loss. The high estimate is that of the representative worst case scenario based on the Beslan attack, with the same multipliers applied to fatalities and injuries to estimate the direct economic costs of a similar scale scenario in this country.

Indirect, induced, or total economic loss estimates were not calculated for the 2015 revision of the SNRA.

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

Since attacks targeted at specific persons were excluded from the scope of the armed assault event, all attacks in this set occurred in public places rather than private homes or residential neighborhoods. For this reason, the project team assumed that the number of persons displaced from their homes would be zero for all three of the low, best, and high estimates.

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event.[180] The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs. A multiplicative factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.

- The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + ½\ D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement).
- In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement.
- The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: Armed Assault was given a C_{EF} of 1.1.

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[180] See Appendix G of the SNRA draft Unclassified Documentation of Findings for references and additional discussion of the SNRA Psychological Distress metric.

- Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

In 2011, the United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event in the 2011 SNRA. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- The environmental assessment included effects resulting from terrorism threats, but did not include human health effects or effects in urban areas because these effects are already reflected in other consequence measures.
- Experts identified the best estimate for environmental consequences as "*de minimus*." Environmental impacts would be minimal.

Trend Adjustment (Optional)

Although it is not applied in this summary sheet, an alternative analysis could incorporate trend information from allied nations with similar security conditions (Western Europe and Canada) by multiplying the best and high estimate frequencies by a factor proportional to the frequency of current attacks relative to 4–5 years ago. This adjustment should be considered only if the trend is unambiguous.

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Additional Relevant Information

Table 4: U.S. Historical Incidents 1980–2012

Date	City	State	Fatal	Injured	Displaced[181]	DE (2011)[182,183]	Perpetrator	Target	Source[184]
4/19/80	Chattanooga	TN	0	4	0*	$240,000	Ku Klux Klan	Crowd	FBI[185]
11/27/81	Fort Buchanan	PR	0	1	0*	$61,000	PR nationalists	Military base	FBI[186]
5/16/82	San Juan	PR	1	3	0*	$270,000	PR nationalists	U.S. Navy sailors	FBI[187]
5/19/82	Villa Sin Miedo	PR	1	12	0*	$820,000	PR nationalists	Police	FBI[188]
2/13/83	Medina	ND	2	4	0*	$410,000	Sheriff's Pos. Comitatus	Police, U.S. Marshals	FBI[189]
11/06/85	Bayamon	PR	0	1	0*	$61,000	PR nationalists	U.S. Army soldier	FBI[190]
3/1/94	New York	NY	1	3	0*	$270,000	Individual	Jewish students in van	GTD, FBI[191]
7/02-04/99	Multiple[192]	IL, IN	2	8	0*	$660,000	Individual	Multiple minorities	GTD, FBI[193]
8/10/99	Granada Hills	CA	1	5	0*	$390,000	Individual	Jews, Asians	FBI[194]
7/4/02	Los Angeles	CA	2	4	0*	$410,000	Individual	El Al terminal LAX	GTD, FBI[195]
3/3/06	Chapel Hill	NC	0	9[196]	0*	$550,000	Individual	Car driven into crowd	GTD, FBI[197]
6/1/09	Little Rock	AR	1	1	0*	$150,000	Individual	Recruiting center	GTD, FBI[198]
6/10/09	Washington	DC	1	0	0*	$85,000	Individual	U.S. Holocaust Museum	FBI, P[199]
11/5/09	Fort Hood	TX	13	32	0*	$3,000,000	Individual	Fellow soldiers	GTD, FBI, P[200]
8/05/12	Oak Creek	WI	6	4	0*	$750,000	Individual	Sikh worshippers	GTD, FBI, P[201]
8/15/12	Washington	DC	0	1	0*	$61,000	Individual	Family Research Council	GTD, FBI[202]

[181] Persons displaced from home for 2 or more days assumed to be zero for all events except where indicated otherwise by the source(s). Assumed zeroes are marked with an asterix; other zeroes from sources.

[182] DE = Direct economic loss, 2011 dollars. All numbers are estimates based upon extrapolations from a subset of incidents. For the definition of direct economic loss used in the SNRA see the text of this risk summary sheet above.

[183] For the armed assault events, decontamination/disposal/physical destruction (DDP) was assumed to be zero (insignificant in proportion to other components); business interruption, $37,000 per fatality and injury as multiplier based upon the $10 million direct lost income (Dedman et al (2013)) of the 500 businesses in the 12-block restriction zone during the one week of investigation following the 2013 Boston Marathon bombing, Luna (2013); medical costs, $5,200 per fatality and $24,000 per non-fatal injury, average medical costs for gunshot injuries in the U.S. from Corso et al (2007) excluding costs from lost labor productivity; and $42,500 one year lost spending per fatality. All costs adjusted to 2011 dollars.

[184] Where FBI and other sources differ on details (date, location, fatalities, injuries), the FBI figures are given.

[185] FBI (2006).

[186] FBI (1982, 2006).

[187] FBI (1983, 2006).

[188] FBI (1983, 2006).

[189] FBI (1984, 2006).

[190] FBI (1986, 2006).

[191] GTD 199403010007, FBI (2006).

[192] Chicago, Skokie, and Northbrook IL, and Bloomington IN.

[193] FBI (2000) pp 4-5 and FBI (2006), list. GTD 199907020004, 199907020005, 199907020006, 199907030007, 199907030008, 199907040005, but coded as doubtful for terrorism (doubtterr=1).

[194] FBI (2000) p 5 and FBI (2006), list. Also GTD 199908100001, but coded as doubtful for terrorism (doubtterr=1).

[195] GTD 200202040010, FBI (2006).

[196] While all injuries were comparatively minor, they included several broken bones; six people assaulted were taken to hospital, treated, and released. Braun et al (2014).

[197] GTD 200603030013, FBI (2011).

[198] FBI (2011). GTD event 200906010028, but not coded as meeting terrorism criterion 3. For detail see Coleman et al (2011).

[199] FBI (2011), Obama (2013). Also GTD 200906100003, but not coded as meeting terrorism criterion 2.

[200] GTD 200911060002, FBI (2011), Obama (2013). GTD lists date as 11/06/2009 and 31 injuries; FBI lists 32 injuries. NCTC 2014 Counterterrorism Calendar (not cited) lists 29 wounded.

[201] GTD 201208050006, FBI (2011), Obama (2013).

[202] GTD 201208150059. FBI: FBI statement in U.S. Attorney DC (2013, September 19); also confession and conviction to terrorism charge (District of Columbia Code).

Explosives Terrorism Attack

An act of terrorism using one or more explosive or incendiary devices against people or property in the United States.

Data Summary

Category	Description	Metric	Low	Best	High
Health and Safety	Fatalities	Number of Fatalities	0[203]	1[204]	3,650[205]
	Injuries and Illnesses	Number of Injuries or Illnesses	0[206]	11[207]	4,500[208]
Economic	Direct Economic Loss	U.S. Dollars	$42,000[209]	$3.4 million[210]	$20 billion[211]
Social	Social Displacement	People Displaced from Home ≥ 2 Days	0[212]	5[213]	400[214]
Psychological	Psychological Distress	Qualitative Bins	See text		
Environmental	Environmental Impact	Qualitative Bins	Low[215]		
LIKELIHOOD	Frequency of Events	Number of Events per Year	0.72[216]	7.0[217]	25[218]

203 Minimum from Table 11.

204 Average (1.00) number of fatalities from Table 11.

205 Extrapolated by OBP and from Lundberg (2013), based on successful 1993 WTC bombing, successful 2005 Bojinka plot, and successful 2006 trans-Atlantic aviation plot. See Health and Safety discussion for details.

206 Minimum from Table 11.

207 Average (10.8) number of injuries from Table 11.

208 Number of injuries, 1998 bombing of the U.S. Embassy in Nairobi, Kenya: SNRA project team assumption using this historical event as proxy. See Health and Safety discussion.

209 Total 2011-dollar adjusted property damages ($1.061 billion) 1988-1988 divided by total number of bombing incidents (25,065), including actual, attempted, and [1998 reporting only] accidental explosive and incendiary U.S. incidents.

210 Estimate based upon per-casualty average property damage of all U.S. bombings 1988-1998, FBI (1999b), for decontamination, disposal, and physical destruction (DDP); per-casualty proportion of $10 million direct business interruption costs to the businesses in the 12 block exclusion zone following the 2013 Boston Marathon bombing, Luna (2013), Dedman et al (2013); medical costs, medical costs for gunshot injuries per fatality and per non-fatal injury, Corso et al (2007); one year lost spending to the national economy per fatality, $42,500, SNRA 2015 standard (this does not represent a value of statistical life (VSL)). See Direct Economic Loss section for details. All estimates converted to 2011 U.S. dollars.

211 Mean of four property loss estimates from a 20,000 lb. VBIED in major US cities in Kunreuther et al (2014), adjusted to 2011 dollars.

212 Minimum from Table 11 (SNRA project team assumption of 0 for all 1980-2005 incidents excepting Oklahoma City bombing).

213 Average from Table 11.

214 Maximum from Table 11(400 persons displaced from home, 1998 Oklahoma City bombing, DOJ (2000)).

215 Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as to reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the ‘Best’ estimate.

216 Inverse of maximum inter-arrival time, 508 days expressed in years, between incidents in Table 11 (11/27/1993 Chicago firebombings and 4/19/1995 Oklahoma City bombing).

217 Average number per year of explosive/incendiary incidents 1980-2005 as reported by FBI (2006), 181 incidents in 26 years (Table 11).

218 Maximum number of explosive/incendiary incidents 1980-2005 occurring in any one year (each of 1981 and 1982) in Table 11.

Event Background

Frequency, fatality, and injury estimates for the 2015 Strategic National Risk Assessment (SNRA) Explosives Terrorism Attack event were derived from unclassified statistical and historical data published by the Federal Bureau of Investigation (FBI).[219] These results were compared with and supplemented by data and research from additional primary and secondary public sources, peer-reviewed literature, and U.S. and foreign press sources.

Weapon Characteristics and Tactics[220]

An Explosives Terrorism Attack is an act of terrorism using one or more "explosive devices" against people or property in the U.S., including vessels or aircraft en route to or from U.S. territory, intended to destroy, incapacitate, harass, or distract. Terms such as bomb, homemade bomb, incendiary device, firebomb, and more recently improvised explosive device (IED) are also used to describe the type of weapons involved.[221] The term IED will be used to generically refer to constructed devices with explosive and incendiary effects in the following discussion.

IEDs consist of a variety of components including an initiation system, a main explosive charge, and a container to house and sometimes conceal the components. Because they are improvised, IEDs can come in many forms, ranging from a small pipe bomb to a sophisticated device capable of causing massive damage and loss of life. IEDs are often surrounded by or packed with additional materials or "enhancements" such as nails, glass, or metal fragments designed to increase the amount of shrapnel propelled by the explosion. Enhancements may also include other elements such as hazardous materials.

Many commonly available materials, such as fertilizer, gunpowder, and hydrogen peroxide, can be used as the main charge explosive materials in IEDs (see Table 5). Explosives must contain a fuel and an oxidizer, which provides the oxygen needed to sustain the reaction. A common example is ANFO, a mixture of ammonium nitrate, which acts as the oxidizer, and fuel oil (the fuel source). Concern about the use of explosives created from liquid components transported in a stable form and mixed at the site of attack is the reason that in 2006 the U.S. Department of Homeland Security restricted the amount of liquids passengers may carry on commercial aircraft. Explosives are sensitive to heat, shock, and friction, which are used to initiate them. Initiation systems may rely on a variety of methods depending on the intended use, such as a burning fuse, electric charge, chemical reaction, physical force, or some combination. In practice, those methods may employ simple mechanisms like a pressure plate, digital timer, mechanical clock, or other means to being the initiation process. Initiated systems are triggered by the bomber or by the victim, depending on intended use.

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[219] FBI (1963, 1981, 1982, 1983, 1986, 1987, 1999b, 2000, 2006, 2007b, 2008a, 2010, 2011), FBI (2009, April 21); additional FBI sources as cited.

[220] Substantial portions of this section are adapted from National Academies and U.S. Department of Homeland Security (2004), IED attack: improvised explosive devices (NAS/DHS (2004)).

[221] Explosive devices are sometimes considered weapons of mass destruction (WMDs). See relevant definitions for terrorism, destructive devices, and WMDs in 18 U.S.C. §921, §1864, §2331, and §2332, and 26 U.S.C. §5845. For the purposes of the SNRA, this threat event includes explosive attacks (including rocket attacks) and incendiary attacks.

Table 5: Examples of Explosive Materials[222]

	Common Uses	Common Form	Known IED Use
High explosives (HE)			
Ammonium nitrate and fuel oil (ANFO)	Fertilizer, engine fuel, mining and blasting (in mixed form)	Solid	Oklahoma City bombing
Triacetone Triperoixide (TATP)	No common uses; mixed from common household items	Crystalline solid	2005 bombings in London
Semtex, C-4	Primarily military explosives	Plastic solid	Irish Republican Army bombings
Ethylene glycol dinitrate (EGDN)	Component of low-freezing dynamite	Liquid	Millennium Bomber, intended for Los Angeles airport, 1999
Urea nitrate	Fertilizer	Crystalline solid	World Trade Center 1993
Low explosive			
Smokeless powder	Ammunition	Solid	Olympic Park bombings

In addition to the initiation systems, IEDs tactics include how they are placed at the target. They can be carried, placed, or delivered by person or vehicle; thrown by a person; delivered in a package; or concealed at the target location in advance, such as along a roadside. Bombs can also be surreptitiously carried by an unknowing individual on their person or in their bags or vehicle. This tactic is sometimes used to avoid security measures and reduce the likelihood of attribution to the actual bomber. Another common tactic is to target multiple locations simultaneously or in near succession. Security and rescue efforts can be hampered by the need to respond to more than one site. Suicide tactics are also associated with bombings. Suicide tactics allow the perpetrators to get close to their target and time the attack precisely for maximum success. Another tactic, known as a secondary attack, uses a distraction, such as a phoned bomb threat, 911 call, fire alarm, gunfire, small initial bombing, or other surprises, to drive or attract people to a location and then detonate the device at the gathering point. Evacuees, first responders, and bystanders are usually the targets of secondary attacks.

Effects

An explosion in or near a building or public transportation venue may blow out windows, destroy walls, and shut down building systems such as power, ventilation, fire suppression, water/sewage, and others. Exit routes may be disrupted or destroyed, and smoke and dust may travel through stairways and elevator shafts, making navigation difficult. Building failure may result in the release of hazardous materials used within a building, such as radioactive material from medical devices, or incorporated within the structure of a building, such as asbestos

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[222] NAS/DHS (2004), *op. cit*.

insulation. An IED attack may cause disruptions in municipal services such as electricity, water, communications, and transportation, which may continue for days to weeks after the attack.

The explosion of a bomb can cause secondary explosions if gasoline, natural gas, or other flammable material is ignited. Secondary hazards that result can include fire with possibly toxic smoke, disruption of electric power, ruptured natural gas lines and water mains, and debris. There can be a loss of traffic control in the area of the blast with possible traffic accidents involving fleeing people.

The extent of damage caused by an IED depends on the quantity and type of its explosive content, construction, and placement relative to its target. Table 6 predicts the damage radius based on the volume or weight of explosive (TNT equivalent) and the type of bomb. Vehicle bombs, also known as vehicle-borne IEDs (VBIEDs), can carry significantly more explosive material, and therefore, do more damage.

Table 6: Recommended Evacuation Distance based on Potential Effects of Explosive Weights[223]

Device Type	Explosive Capacity (High Explosives Only)	Building Evacuation Distance	Outdoor Evacuation Distance
Pipe Bomb	5 lb	70 ft	1,200 ft
Suicide Bomber	20 lb	110 ft	1,700 ft
Briefcase/Suitcase	50 lb	150 ft	1,850 ft
Car	500 lb	320 ft	1,900 ft
SUV/Van	1,000 lb	400 ft	2,400 ft
Small Moving Van/ Delivery Truck	4,000 lb	640 ft	3,800 ft
Moving Van/Water Truck	10,000 lb	860 ft	5,100 ft
Semi-Trailer	60,000 lb	1,570 ft	9,300 ft

The type of injuries and the number of people hurt will vary depending on the physical environment and the size of the blast; the amount of shielding between victims and the blast; fires, or structural damage that result from the explosion; and whether the explosion occurs in a closed space or an open area. There are several known injuries common to explosions:

- Overpressure damage to the lungs, ears, abdomen, and other pressure-sensitive organs—blast lung injury, a condition caused by the extreme pressure of a HE explosion, is the leading cause of illness and death for initial survivors of an explosions;
- Fragmentation injuries caused by projectiles thrown by blast—material from the bomb, shrapnel, or flying debris that penetrates the body and causes damage;
- Impact injuries caused when the blast throws a victim into another object, e.g., fractures, amputation, and trauma to the head and neck;

[223] NAS/DHS (2004), *op. cit.*

- Thermal injuries caused by burns to the skin, mouth, sinus, and lungs;
- Other injuries including exposure to toxic substances, crush injuries, and aggravation of pre-existing conditions (asthma, congestive heart failure, etc.).

Some health effects caused by IEDs, including eye injuries, abdominal injuries, and traumatic brain injuries may not be apparent initially, but can cause symptoms and even fatalities hours to months after the event. Psychological effects in attack survivors, first responders, and others are not unusual in the aftermath of a high-casualty event. While most symptoms diminish with time, in some cases assistance and guidance from mental health professionals may be required.

Usage History in the United States

Terrorists and criminals with diverse motives have used explosive devices in the United States. Thousands of terrorist and criminal incidents involving bombings, attempted bombings, incendiary bombings, stolen explosives, and related offenses occur each year. Most are minor criminal and mischief-related events. Table 7 shows statistics for explosive-related incidents in the United States from 1973 through 1999,[224] while Table 8 shows selected incidents, including 44 high-casualty incidents (i.e., more than four casualties), since the late 19th Century. In the past 127 years, periods of both intense explosive device use and relative infrequency have occurred. Flashpoints of activity often coincide with periods of social or economic unrest, such as labor and anarchist movement violence in the late 19th and early 20th century, Jim Crow and Civil Rights eras, and during anti-war and anti-government violence in the 1960s through 1980s. In several cases, individual or small groups of serial bombers have conducted terror campaigns with extreme frequency for a short period or infrequently over extended periods of time. Examples include more than 44 bombings and attempted bombings from April to June 1919 by Galleanist anarchists;[225] the New York City bomber George Metesky in the 1940s and 1950s;[226] the Weather Underground during the 1960s and 1970s;[227] Ted Kaczynski during the late 1970s through 1990s;[228] Eric Rudolph during the 1990s;[229] and al Qaeda and affiliated groups since the 1990s.[230]

The recognized likelihood and risk of explosive attacks to the Nation remains an enduring policy and security concern for the U.S. Government today.[231]

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[224] The last year FBI published national statistics.

[225] FBI At: http://www.fbi.gov/philadelphia/about-us/history/famous-cases/famous-cases-1919-bombings

[226] FBI At: http://vault.fbi.gov/Criminal%20Profiling/Criminal%20Profiling%20Part%201%20of%207

[227] FBI At: http://www.fbi.gov/news/stories/2004/january/weather_012904

[228] FBI At: http://www.fbi.gov/news/stories/2008/april/unabomber_042408

[229] FBI At: http://www.fbi.gov/news/stories/2005/may/swecker_051605

[230] FBI At: http://www.fbi.gov/news/testimony/al-qaeda-international

[231] Chertoff, Michael (2007), testimony: http://www.gpo.gov/fdsys/pkg/CHRG-110shrg38842/html/CHRG-110shrg38842.htm; DNI (2008), Annual Threat Assessment; Obama, Barack (2012, February): http://www.whitehouse.gov/sites/default/files/docs/cied_1.pdf; DoD/JIEDDO (2012, June), https://www.jieddo.mil/content/docs/20120712_Barbero_testimony.pdf; DNI (2013, March), Annual Threat Assessment, http://www.intelligence.senate.gov/130312/clapper.pdf; Mueller, Robert (2013, August), Reflections: http://www.npr.org/2013/08/23/214549458/outgoing-fbi-boss-on-his-legacy-and-what-kept-him-up-at-night.

Table 7: Bombing and Arson-related Incidents in the United States 1973–1999[232]

Year	Incidents	Actual Explosions	Injuries	Fatalities
1999	1,797	1,193	114	9
1998	2,300	1,432	160	16
1997	2,217	1,590	204	18
1996	2,573	1,884	336	23
1995	2,577	1,968	744	193
1994	3,163	2,461	308	31
1993	2,980	2,418	1,323	49
1992	2,989	2,493	349	26
1991	2,499	1,974	230	29
1990	1,582	1,198	222	27
1989	1,208	844	202	11
1988	977	749	145	20
1987	848	704	107	21
1986	858	709	185	14
1985	847	677	144	28
1984	803	645	112	6
1983	687	569	100	12
1982	795	679	99	16
1981	1,142	952	133	30
1980	1,249	1,078	160	34
1979	1,220	1,033	173	22
1978	1,301	1,117	135	18
1977	1,318	1,115	162	22
1976	1,570	1,257	212	50
1975	2,074	1,701	326	69
1974	2,044	1,651	207	24
1973	1,955	1,529	187	22
Total	45,573	35,620	6,779	840
Per Year	**1,688**	**1,319**	**251**	**31**
Per Explosion			**0.19**	**0.024**

232 Reconstructed from data, Bureau of Alcohol, Tobacco, and Firearms (ATF) (2004-2013) and Bureau of Justice Statistics (FBI data) (1973–1999).

Table 8: Selected U.S. Terrorist Bombings 1886–2013 (Not SNRA Data Set)[xxxii]

Date	City	State	Fatal	Injured	Displaced	Perpetrator	Target	Source
05/04/1886	Chicago	IL	11	100	0*	Labor/Anarchists	Crowd (Haymarket Square)	AP[xxxiii]
6/6/1904	Cripple Creek	CO	14	7		Labor/Anarchists	Independence Depot railway station	Press[xxxiv]
10/01/1910	Los Angeles	CA	20	100	0*	Labor/Anarchists	LA Times building	Press[xxxv]
7/4/1914	New York City	NY	0	19	140	Labor/Anarchists	Apartment in New York City	Press[xxxvi]
07/22/1916	San Francisco	CA	10	40	0*	Labor/Anarchists	Crowd (Preparedness Day Parade)	Press[xxxvii]
11/24/1917	Milwaukee	WI	11	2	0*	Unknown	Church; exploded in police station	Press[xxxviii]
09/04/1918	Chicago	IL	4	75	0*	Labor/Anarchists	Federal Building	Press[xxxix]
09/16/1920	New York City	NY	40	300	0*	Unknown	Wall Street	FBI, Press[xl]
5/18/1927	Bath	WI	45	58	0*	Individual	Bath School House	NCTC, FBI[xli]
10/10/1933	Chesterton	IN	7	0	0*	Individual	United Airlines	AP[xlii]
11/16/1940	New York	NY	0	10	0*	Individual	ConEd Power Plant	Press[xliii]
11/1/1955	Longmont	CO	44	0	0*	Individual	United Airlines Flight 629	FBI[xliv]
12/2/1956	New York	NY	0	6	0*	Individual	Brooklyn Paramount Theater	Press[xlv]
11/16/1959	Gulf of Mexico		42	0	0*	Individual	National Airlines Flight 967	Press
1/6/1960	Bolivia	NC	34	0	0*	Individual	National Airlines Flight 2511	Press
10/13/1960	New York	NY	0	33	0*	Individual	Time Square Subway Station	Press
11/7/1960	New York	NY	1	18	0*	Individual	125th Street Subway Station	Press
5/22/1962	Unionville	MO	45	0	0*	Individual	Continental Airlines Flight 11	Press
09/16/1963	Birmingham	AL	4	16	0*	Ku Klux Klan	Church	AP, FBI[xlvi]
8/7/1969	New York	NY	0	20	0*	Weather Underground	Marine Midland Building	Press[xlvii]
3/6/1970	New York	NY	3	2		Weather Underground	Greenwich Village townhouse	Press
3/8/1971	St. Louis	MO	0	10	0*	Unknown	Military	GTD[xlviii]
1/26/1972	New York	NY	1	13	0*	Jewish Defense League	Business	GTD[xlix]
8/6/1974	Los Angeles	CA	3	26	0*	Individual	Airport/Aircraft	GTD[l]
01/24/1975	New York City	NY	4	53	0*	PR nationalists	Fraunces Tavern	AP, FBI[li]
7/15/1975	Los Angeles	CA	0	4	0*	Cuban Action	Diplomatic	GTD[lii]
12/29/1975	New York City	NY	11	75	0*	Croatian nationalists	TWA terminal, LaGuardia (locker)	AP[liii]

Date	City	State	Fatal	Injured	Displaced	Perpetrator	Target	Source
4/22/1976	Boston	MA	0	22	0*	United Freedom Front	Government	GTD[liv]
8/3/1977	New York City	NY	1	7	0*	FALN[lv]	Business	GTD[lvi]
12/11/1979	New York City	NY	0	8	0*	Omega-7	Diplomatic	GTD[lvii]
01/13/1980	New York City	NY	0	4	0*	Cuban exiles	Aeroflot	GTD, FBI[lviii]
03/17/1980	New York City	NY	0	3	0*	Croatian nationalists	Yugobank office	GTD, FBI[lix]
08/20/1980	Berkeley	CA	0	2	0*	Iranian exiles	High school student meeting	GTD, FBI[lx]
10/12/1980	New York City	NY[lxi]	0	5	0*	Armenian nationalists	Turkish mission (UN), travel agency	GTD, FBI[lxii]
5/16-18/1981	New York City	NY	1	0	0*	PR nationalists	Pan Am terminal JFK	GTD, FBI[lxiii]
6/27/81	College Park	MD	1	4		Unknown	Educational Institution	GTD[lxiv]
04/05/1982	New York City	NY	1	7	0*	Jewish Defense League	Restaurant (arson)	GTD, FBI[lxv]
8/11/1982	Honolulu	HI	1	15	0*	May 15 Organization[lxvi]	Airport/Aircraft	GTD[lxvii]
12/31/1982	New York City	NY	0	3	0*	PR nationalists	Federal buildings	GTD, FBI[lxviii]
08/15/1985	Paterson	NJ	1	1	0*	Jewish Defense League	Alleged war criminal	GTD, FBI[lxix]
09/06/1985	Brentwood	NY	0	1	0*	Jewish Defense League	Alleged war criminal	GTD, FBI[lxx]
10/11/1985	Santa Ana	CA	1	7	0*	Jewish Defense League	Arab-American activist	GTD, FBI[lxxi]
10/28/1986	Multiple[lxxii]	PR	0	1	0*	PR nationalists	Multiple bombings	GTD, FBI[lxxiii]
8/21/89	Atlanta	GA	0	8	0*	ACFJS[lxxiv]	NGO	GTD[lxxv]
10/21/1989	Lockerbie	UK	270			Libyan Government	Pam Am Flight 103	FBI[lxxvi]
02/26/1993	New York City	NY	6	1,042	0*	al Qaeda	World Trade Center	GTD, FBI[lxxvii]
04/19/1995	Oklahoma City	OK	168	754	400[lxxviii]	Individual	Federal Building	GTD, FBI[lxxix]
07/27/1996	Atlanta	GA	1	110	0*	Individual	Olympic Games	GTD, FBI[lxxx]
01/16/1997	Atlanta	GA	0	6	0*	Individual	Abortion clinic	GTD, FBI[lxxxi]
02/21/1997	Atlanta	GA	0	4	0*	Individual	Nightclub	GTD, FBI[lxxxii]
01/29/1998	Birmingham	AL	1	1	0*	Individual	Abortion clinic	GTD, FBI[lxxxiii]
06/24/1998	Santa Isabel	PR	0	1	0*	PR nationalists	Bank offices	GTD, FBI[lxxxiv]
08/02/2008	Santa Cruz	CA	0	1	4	Animal Liberation Front	Researcher's home	GTD, FBI[lxxxv]
4/15/2013	Boston	MA	3	264		Individual	Boston Marathon finish line	FBI[lxxxvi]

[xxxii] This data set is intended for developing distributions for extended visualizations and stakeholder engagement in follow-on work to the 2015 SNRA, and is still under development and documentation.
[xxxiii] AP (2013); characterization of anarchist movement bombings as terrorist, FBI (2008a).
[xxxiv] http://law2.umkc.edu/faculty/projects/ftrials/haywood/HAY_N66.HTM
[xxxv] AP (2013), King (1960), Harrison (2011); characterization of anarchist movement bombings as terrorist, FBI (2008a).
[xxxvi] All four persons killed were the bomb plotters. Seven seriously injured, 'about a dozen' less seriously injured. 140 displaced: 150 building tenants, minus seven injured and four plotters killed (who were building residents), rounded to two significant figures [NYT (1914) has contradictory reports of building damage, but describes substantial damage to apartments in the majority of floors]. NYT (1914, 1915), AP (1914).
[xxxvii] AP (1961), ATF (1970), Gage (2004) 4; characterization of anarchist movement bombings as terrorist, FBI (2008a).
[xxxviii] AP (1917), NYT (1917), LA Times (1917), Tanzilo (1992), Gurda (2001); USG characterization as terrorist act, Hutchinson (2001).
[xxxix] AP (1918a, 1918b), Morning Oregonian (1918), NYT (1918a, 1918b); characterization of anarchist movement bombings as terrorist, FBI (2008a).
[xl] AP (2013); Gage (2004) pp 142, 143; FBI (2007b).
[xli] NCTC (2007) https://www.fbiic.gov/public/2008/sept/NCTC%20Did%20you%20know%20the%20first%20suicide%20car%20bombing%20took%20place%20in%20Bath,%20Michigan%20in%201927.pdf
[xlii] AP "Suspects Bomb Wrecked Plane." Prescott Evening Courier. 10/12/1933. Page 3. At http://news.google.com/newspapers?id=D_EKAAAAIBAJ&sjid=0E8DAAAAIBAJ&pg=5344%2C6739444
[xliii] Forbes at www.forbes.com/sites/williampentland/2014/03/16/meet-americas-first-electric-grid-saboteur
[xliv] http://www.fbi.gov/about-us/history/famous-cases/jack-gilbert-graham
[xlv] New York Times at: http://query.nytimes.com/gst/fullpage.html?res=9C05E4DF1530F933A2575AC0A9629C8B63
[xlvi] AP (2013), FBI (1963) part 1, page 50.
[xlvii] New York Times at: http://cityroom.blogs.nytimes.com/2009/08/27/1969-a-year-of-bombings/
[xlviii] GTD
[xlix] GTD 197201260003
[l] GTD 197408060004
[li] AP (2013), FBI (1999a) 16.
[lii] GTD 197507150001
[liii] AP (2013).
[liv] GTD 197604220004
[lv] Fuerzas Armadas de Liberacion Nacional.
[lvi] GTD 197708030006
[lvii] GTD 197912110003
[lviii] GTD 198001130006, FBI (2006).
[lix] GTD 198003170025, FBI (2006).
[lx] GTD 198008200004, FBI (1982) 48, FBI (2006).
[lxi] Includes the bombing of the Turkish Mission to the UN with four injuries, and a second bombing the same day of a travel agency in Hollywood, CA causing one injury.
[lxii] GTD 198010120008, 198010120009, FBI (2006).
[lxiii] GTD 198105160004, FBI (1982, 2006).
[lxiv] GTD 198106270006
[lxv] GTD 198204050005, FBI (1983, 2006).
[lxvi] May 15 Organization for the Liberation of Palestine
[lxvii] GTD 198208110007
[lxviii] GTD 198212310009, 198212310010, 198212310011, 198212310012, FBI (1983, 2006).
[lxix] GTD 198508150001, FBI (1986, 2006).
[lxx] GTD 198509060007, FBI (1986, 2006).
[lxxi] GTD 198510110002, FBI (1986, 2006).
[lxxii] Fajardo, Fort Buchanan, Santurce, Aguadilla, Mayaguez, Bayamon (FBI (1987)).
[lxxiii] GTD 198610280017, 198610280018, 198610280019, 198610280020, 198610280021, 198610280022, 198610280023, FBI (1987, 2006).
[lxxiv] Americans for a Competent Federal Judicial System.
[lxxv] GTD 198908210014
[lxxvi] FBI At: http://www.fbi.gov/news/stories/2003/december/panam121903
[lxxvii] GTD 199302260001, FBI (1999b, 2006).
[lxxviii] U.S. Department of Justice (2000), p. 1.
[lxxix] GTD 199504190004, FBI (2006).
[lxxx] GTD 199607270003, FBI (2006).
[lxxxi] GTD 199701160006, FBI (2006).
[lxxxii] GTD 199702210003, FBI (2006).
[lxxxiii] GTD 199801290002, FBI (2006).
[lxxxiv] GTD 199806240003, FBI (2006).
[lxxxv] GTD 200808020023; FBI (2009, April 21). Press release regarding a man suspected of different crimes, but describing the 2008 Santa Cruz firebombing as a terrorist act. For additional detail see McCord (2008), Knoll et al (2008), Buchanan et al (2008), FBI (2010).
[lxxxvi] FBI At: http://www.fbi.gov/boston/press-releases/2013/federal-grand-jury-returns-30-count-indictment-related-to-boston-marathon-explosions-and-murder-of-mit-police-officer-sean-collier

Assumptions

Frequency

To identify the national risk baseline for this kind of attack, explosives terrorist attacks were analyzed as a recurring historical event similar to the SNRA's analysis of natural and technological hazards. In part, this analytic treatment reflects agnosticism in the absence of other public information of predictive value. Terrorism is driven by multiple deterministic drivers, as well as stochastic (chance) factors. However, without absolute knowledge of those factors that would both remain valid and have predictive value for each successful attack in the United States for the next three to five years (the time frame of the 2015 SNRA), representation as a random event without additional qualifications is the most accurate representation of our actual state of knowledge.[233] This treatment was also chosen for consistency with the findings of past U.S. Government reviews that periods of political violence of even greater intensity—and public awareness of that intensity—than that of today are, in fact, the historical norm for our country, rather than the exception.[234]

Historical incident data can be derived from several publically available government and academic sources. Because publically available Department of Justice (DOJ) data is limited to after 1973 and include criminal and terrorism intent, other sources are needed to help build a dataset of terrorism-related bombings. The RAND Database of Worldwide Terrorism Incidents (RDWTI) and University of Maryland START Global Terrorism Database (GTD)[235] are valuable sources for bombing incident data already filtered for terrorist intent; however, they do not contain data from incidents prior to 1970.

The DOJ has formally maintained bombing incident statistics since the early 1970s through the FBI Bomb Data Center (to 1999) and the U.S. Bomb Data Center (USBDC) of the Bureau of Alcohol, Tobacco, and Firearms (ATF).[236] Data were released publically through annual reports until the early 2000s and are now made available via summary publications. DOJ data include all types of incidents related to bombings—threats, failed attempts, and successful bombings, as well as arson/incendiary incidents. An advantage of the DOJ data is that it best demonstrates the frequency of explosive threats, overall, regardless of terrorism intent or outcome. Table 7 shows that a very high frequency of successful bombing and incendiary attacks of all kinds have occurred in the 26 years for which data is publically available—close to 1,400 events per year.

A longer time period provides additional information useful for the estimation of the likelihood of rare, high-impact explosive attacks (Table 8). As part of SNRA 2015 project work, analysts from multiple DHS components[237] developed new data sets and methods for estimating the absolute and conditional probabilities of such events.

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[233] Mohtadi et al (2005, 2009a).

[234] Staff and Commission reports and data set produced for/by the 1968-69 National Commission on the Causes and Prevention of Violence (Graham et al (1969), Kirkham et al (1969), Levy (1969a, b, c), National Commission on the Causes and Prevention of Violence (1969)). See also [non-USG] Gage (2004), Gage (2011), START GTD (2013), Turchin et al (2014). The labor and anarchist related disturbances of the 1880s through the early 1920s saw dozens of bombings every year, which reached national attention (FBI Philadelphia Division (unknown date: retrieved February 2015), 1919 Bombings: http://www.fbi.gov/philadelphia/about-us/history/famous-cases/famous-cases-1919-bombings.) However, bombings that reach national attention historically have represented the tip of a very large iceberg of bombings that do not. For example, by the close of the 1960s, total bombings were estimated to number in the thousands per year (4,330 in the sixteen months from January 1969 to April 1970: Allyn, Bobby (2009, August 27), 1969, a year of bombings. Note, *New York Times*: at http://cityroom.blogs.nytimes.com/2009/08/27/1969-a-year-of-bombings/).

[235] START, the National Consortium for the Study of Terrorism and Responses to Terrorism, is a DHS Center of Excellence and network of scholars coordinated from the University of Maryland. Since 2011, when the first SNRA was executed, the START GTD has become the most commonly cited source for global terrorism statistical data, and is now used as the primary data source (with similar parameters as the 2011 SNRA) for the U.S. Government's annual Statistical Annex on Terrorism published for the U.S. State Department's Country Reports on Terrorism. START GTD (2013). The Global Terrorism Database (GTD) is an open-source database with information on terrorism events around the world (including domestic, transnational, and international incidents) from 1970 to 2010. For each GTD incident, information is available on the date and location of the incident, the weapons used and nature of the target, the number of casualties, and—when identifiable—the group or individual responsible.

[236] DOJ At: http://www.justice.gov/oig/reports/ATF/a0501/final.pdf

[237] National Protection and Programs Directorate (NPPD), DHS Office of Policy, and FEMA. The following discussion represents work still in progress, and does not represent the opinion of any one contributing Component or analytic team. The intended end state of this project is the

- For purposes of illustration, Table 8 includes data that can be used to estimate the likelihood of an explosive attack resulting in four or more casualties—what could be considered a "mass casualty incident." Forty-four such incidents within the 127-year historical dataset in Table 8 represent a mean likelihood of 0.3 incidents per year.
- Low, mean, and high likelihood estimates of a mass casualty bombing in the next five years can be developed by reviewing the data in Table 8 and identifying the number of qualifying incidents per five-year historical period. Forty-four events within 25 five-year periods represent a mean of 1.76 incidents per period, with a low of 0 (multiple periods) and high of six (1975–1980).

Using mass casualty incidents as the basis for overall frequency analysis may be more reliable under the assumption that those incidents were more reliably reported and recorded than the vastly larger number of incidents in which there were no casualties. Such incidents are also more likely to be considered events of national significance. However, the disadvantage of that approach is that the chance factors associated with bombing consequences mean that the risk posed by bombings that did not result in casualties may be overlooked. It is for this reason that the 2015 SNRA examines bombing attacks with a lower threshold,[238] in order to capture this broader picture of risk to the Nation.

Low, best, and high frequency estimates of Explosives Terrorism Attacks are based upon 1980-2005 data reported by the FBI. This data set was chosen because of its high quality, prior vetting, and internal consistency. It was also chosen to avoid the inherent value judgments and interpretation of what to include in the data set designated as 'terrorist', which are properly questions for stakeholders rather than the analyst. The prior designation by a single U.S. Government entity responsible for counterterrorism of a set of historical incidents spanning three decades made this data set ideal for the purposes of the SNRA. The best estimate of frequency represents the average number of occurrences per year of this set; the low estimate of frequency represents the inverse of the longest inter-arrival time (the longest gap between incidents); and the high estimate of frequency represents the largest number of incidents occurring in any one year.

Health and Safety

Estimating consequences from explosive attacks is also difficult due to the multiple factors involved in the outcome of an explosion, such as explosive quantity, proximity to target, blast mitigation, and chance (i.e., intended targets are not present). However, historical incident data and predictive modeling based on potential impacts from past events and adversary capability can assist in health and safety consequence estimation.

The low and best estimates of fatalities and injuries are the minimum (0 for both) and average numbers of fatalities and injuries per incident in Table 11. Perpetrator fatalities and injuries are not included in the data tables and were not included in the quantitative calculations for this event.

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representation of the Explosives Terrorism Attack event, along with the other threats and hazards in the 2015 SNRA, in full distributional form. Its purpose is to put the threshold decisions (terrorist attacks only? minimum fatalities or casualties? hoaxes causing economic impacts?) that are presently made by DHS analysts by necessity into the hands of stakeholders where they belong. This work is still in progress.

[238] Comparable to those of the CBRN terrorist attacks in the 2011 SNRA.

For the high estimate, the SNRA project team judged that this historical data set was not adequately representative of the potential for larger mass-casualty events than have been observed to date in the United States, and would not be suitable as the basis for a high estimate for the risk communication purposes of the SNRA. High estimates for the SNRA impacts were adapted from historical events overseas and plausible alternative outcomes to 'near-miss' explosives attacks targeting the U.S. population or U.S. interests.

For injuries, the 1998 bombing of the U.S. Embassy in Nairobi Kenya is one of the most significant in the historical record, with more than 4,500 reported.[239] This is likely a conservative high estimate because a similar sized VBIED in a major urban core in the U.S. would be expected to affect a higher population density; however, in the absence of other defensible estimates located in the literature, it was taken as a reasonable high estimate.

For fatalities, three previous incidents in the historical record were identified as suitable for alternative outcome analysis: (1) the failed 2006 plot to simultaneously target seven transatlantic aircraft;[240] (2) the failed 1995 plot simultaneously targeting 11 transpacific aircraft, known as the "Bojinka plot";[241] and (3) the successful 1993 bombing of the World Trade Center.[242] Had either of the aviation plots succeeded, fatality estimates can be made based on aircraft capacity and the assumption of total loss of airframe. Further, assuming full aircraft in the Boeing 747[243] or 777[244] class, fatality estimates would range from approximately 2,840 to 4,460 overall, for an average of 3,650. According to the U.S. Government, transnational terror groups remain interested in targeting aviation,[245] and more recent attempts made in 2009[246] and 2010[247] support the reasonability of these scenarios as the basis for the fatality high estimate.

Estimates of alternative outcomes during the World Trade Center Bombing have also been conducted that assume the same loss as a single tower during the 9/11 attacks—approximately 2,000 fatalities.[248] However, during 9/11, the majority of the potential victims were able to evacuate prior to the towers' collapse. A VBIED detonating without warning, like in 1993, capable of collapsing the building would not afford victims the opportunity to evacuate. Theoretically, most or all of those in the building itself would be killed as well as many in the path of the collapsing building. Twenty-five thousand people were estimated to work in each of the World Trade Center towers.

Direct Economic Loss

The SNRA direct economic metric includes

[239] FBI at http://www.fbi.gov/about-us/history/famous-cases/east-african-embassy-bombings-1998

[240] FBI at http://leb.fbi.gov/2011/september/the-evolution-of-terrorism-since-9-11

[241] New York Times at http://www.nytimes.com/1996/09/09/nyregion/bomb-trial-jurors-say-panel-had-no-doubts.html

[242] FBI at http://www.fbi.gov/news/stories/2008/february/tradebom_022608

[243] Boeing technical data. 747 class averages 467 passengers per aircraft. At http://www.boeing.com/boeing/commercial/747family/index.page?

[244] Boeing technical data. 777 class averages 344 passengers per aircraft. At http://www.boeing.com/boeing/commercial/777family/background.page?

[245] FBI (2011) 4.

[246] DOJ at http://www.justice.gov/opa/pr/umar-farouk-abdulmutallab-sentenced-life-prison-attempted-bombing-flight-253-christmas-day

[247] FBI (2011) 8.

[248] Lundberg (2013) 204.

- Decontamination, Disposal, and Physical Destruction (DDP): The value or replacement cost of physical buildings, infrastructure, building contents, vehicles, and other physical property directly destroyed by the attack. This includes the cost of decontamination, if any, and debris removal costs.
- Business Interruption: Business interruption costs caused directly by the incident or the immediate investigation, as opposed to shock, substitution, or second-order effects on the economy.
- Medical Costs: Cost of medical care to injured, including those who become fatalities.
- Lost Demand from Fatalities: No economic value was assigned to a human life (or injury) in itself as a Value of Statistical Life, because this is a value judgment that differs from person to person, and because it would represent double counting with these impacts counted separately. The lost contribution to the national economy as spending was captured, but capped at one year for consistency with benchmark risk assessments. This value was taken at $42,500, the midpoint of the median $35,000–$50,000 household earning value used as the average one year spending per person by past assessments.

Direct economic costs for the low and best estimates were calculated separately from the high estimate. The low and best estimates were calculated by the SNRA project team using the following assumptions:

Low and Best Estimates

DDP Costs

A per-casualty multiplier (factor approach) was constructed as the average property damage per casualty for all U.S. bombings between 1988 and 1998. Property damage figures were converted to 2011 dollar values prior to calculation. Because these figures include many thousands of bombings of much lower destructive power than those of the SNRA data set (Table 11), the average property damage of $227,000 per casualty, as opposed to average property damage per incident (which was used as the low estimate, see below) was used to construct this multiplier for the best estimate (Table 9).

Table 9: Direct Economic Loss Estimates for Historical Incidents of Table 11[249]

Inputs per	Fatality	Injury
DDP	$227,000	$227,000
BI	$37,000	$37,000
Medical	$5,200	$24,000
Lost spending	$42,000	$0

	Fatalities	Injuries	
Number	1	10.8	**Total**
DDP	$227,000	$2,451,600	$2,678,600
BI	$37,000	$399,600	$436,600
Medical	$5,200	$259,200	$264,400
Lost spending	$42,000	$0	$42,000
			$3,421,600

Because this approach would have resulted in zero dollar loss (as the other components of the SNRA direct economic loss metric are also tied to the fatality and injury estimates) for the low

[249] Kunreuther et al (2014).

estimate, which was judged unrealistic for the comparatively small set of incidents called out by the FBI source as terrorist incidents, the average property damage per incident of the 1988-1998 set was used as a reasonable low estimate of direct economic loss. Total 2011-dollar adjusted property damages ($1.061 billion) from 1988 to 1988 were divided by the total number of bombing incidents (25,065), including actual, attempted, and [1998 reporting only] accidental explosive and incendiary U.S. incidents, to generate a low estimate of $42,000.

Business Interruption

Business interruption costs were also estimated by a proxy multiplier applied to the total number of fatalities and injuries. The only definite estimate of business interruption that could be obtained for any of the historic events was zero.[250] Since this was due to unusual circumstances particular to the event, a per-casualty multiplier was obtained from the 2013 Boston bombing in the same manner as for the armed assault event.[251]

Business interruption costs were estimated from the $10 million lost business costs to the approximately 500 businesses in the 12-block immediate impact area of the 2013 Boston Marathon bombing, restricted for approximately one week of investigation.[252] The size and duration of the restricted immediate impact area was considered to be a reasonable estimate for the post-attack investigation of any explosives terrorist attack of comparable magnitude in this country. This per-casualty (fatality + injury) cost of $37,000 of the Boston bombings was applied to the remaining incidents.[253,254]

Medical Costs

To these costs, an average medical cost of $5,200 per fatality and $24,000 per non-lethal injury were applied.[255] These numbers are the same as used for armed assault.

- These numbers differed substantially from medical costs due to burns, blunt-force, and other trauma injuries from violent causes in the United States, which averaged in the low- to mid-

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[250] This was the 1920 Wall Street bombing (Gage (2004)). Business and political leaders perceived this attack to be an attack upon the capitalist system and rapidly restored normal commercial operations as an act of defiance and to maintain investor confidence. The bomb site was cleaned up the same day; normal business operations with replacement staff resumed the following day; and public communications by political, business, and press leaders designed to boost investor confidence resulted in stock and bond values rising above their pre-attack averages within days. The prioritization of restoring normal operations and public confidence over preserving evidence at the bomb site for investigation resulted in minimal interruption of business compared with other historic U.S. terrorist attacks. However, this prioritization came at the cost of justice: the perpetrator or group was never determined.

[251] Because the SNRA project team could not be confident in the assessment of zero business interruption cost for the 1920 attack based upon inference from the literature, this multiplier was also applied to obtain proxy business interruption estimates for this attack rather than using the apparent historical value of zero.

[252] Exclusion zone 12 blocks, with 500 businesses, Luna (2013); cost to businesses in exclusion zone for one week restrictions $10 million, Dedman et al (2013). Costs of the citywide lockdown and law enforcement deployment were excluded from the estimate here, because they are not characteristic of the aftermath of most terrorist attacks in this country. Direct property damage costs were also excluded, since these were specific to the bomb attack. Note that estimates of $250-$300 million often reported (Green et al (2013), Dedman et al (2013), Luna (2013)) in the media refer to costs of the lockdown. They are a reasonable estimate of this (being calculated as a 1/2-1/3 of one day's economic activity of Boston), but such broad lockdowns accompany few, if any, of the other bombing and shooting attacks included here. Most conventional-weapon terrorist attacks (bombs, flame, guns) are very localized in their direct effects to property and business interruption.

[253] This counts interruptions to public sector activity, such as the Fort Hood or Little Rock shootings at U.S. Government facilities, on the same basis as private sector economic activity. This equivalence is applied only in this estimator (e.g., lost taxes or parking fines and public sector response costs not counted in the medical costs are not included in the total direct economic loss estimates).

[254] As the Boston bombing itself occurred in 2013 after the timeframe of the main data sources used for this event, it was not included directly but only as a source of proxy estimates to fill in data gaps for other incidents.

[255] Medical cost per fatal and non-fatal injury for gunshot injuries in the United States from Corso et al (2007), adjusted from 2000 to 2011 dollars using the general CPI-U inflator (1.31). Estimated costs from lost labor productivity are not included.

single thousands. However, gunshot injuries were judged to be a closer analog to injuries from terrorist explosive devices due to their exceptionally violent and targeted nature.

- This assumption was supported by a parallel analysis of the 1995 Oklahoma City bombing,[256] which resulted in an average per-injury cost of $23,000 (2011 dollars).[257]

Lost Demand from Fatalities

To estimate the costs of lost demand from deaths, the SNRA project team multiplied the number of deaths listed in Table 9 by $42,500, the same figure used across the SNRA 2011 events.[258]

High Estimate

Like health and safety consequences, direct economic losses caused by IEDs can have vast disparity. Loss will range from minimal in most cases to billions of dollars for the most large-scale attacks in densely built urban environments.

As with health and safety analysis, a high estimate ($350 million) generated by this method using the high fatalities (168) and injuries (1,042) from the data set in Table 11 appeared overly conservative given knowledge of historical incidents. This estimate has been exceeded routinely, including an estimated $4.3 billion in property losses attributed to the 1992 IRA bombing of the London Financial District.[259] Instead, the SNRA project team constructed the high estimate from an analysis of property losses expected following a 20,000-lb. VBIED in Los Angeles, New York City, Chicago, or Houston.[260] The results are shown in Table 10. The average property loss of $20 billion is significant, but not unreasonable when compared to historical incidents such as the 1995 Oklahoma City bombing or 1993 World Trade Center bombings, both of which caused nearly $1 billion in property loss, but also contained damage to a more isolated area than would be expected in the center of an urban core.

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[256] Shariat et al (1998).

[257] Costs: Hospital acute care costs, excluding emergency transport, physician, surgeon, and rehabilitation charges, $2.5 million [$3.7 million in 2011 dollars]. Mean charges: treated and released from ER, [over] $350 [$520], hospitalized, $28,000 [$41,000]. Long term medical costs (follow-up 1996) for 494 persons interviewed of 914 persons affected by the bombing: $5.7 million [$8.2 million] total, average $16,000 [$23,000] per person. 84 incurred no medical expenses, so 410 persons did; 410 x $16,000 = $6.56 million; it is unclear how to account for the discrepancy. 92 percent of the 494 interviewed (454) had been injured in the bombing. The project team used $5.7 million total /454 injured = $13,000 per injury long-term cost, $5.7 million x 754/454 = $9.5 million [$13.6 million 2011 dollars]. Total medical costs in 2011 dollars is $17.3 million, or $23,000/injury.

[258] This number originates from the 2008 Bioterrorism Risk Assessment (BTRA 2008) (the BTRA as a whole is classified Secret, but its economic methodology appendix is U//FOUO), and represents the midpoint (the expected value of a linear uniform distribution over the interval) of the $35,000-$50,000 median household income band in 2011. DHS (2008) pp. E2.7-34. (Appendix reference is UNCLASSIFIED//FOR OFFICIAL USE ONLY; Extracted information is UNCLASSIFIED.)

[259] GTD 199204100007 (2011 USD).

[260] Kunreuther et al (2014). Converted to 2011 dollars using 2014 to 2011 CPI of 0.950. The property damage metric in the RMS insurance model used for this study corresponds to the SNRA DDP (structure and contents) and business interruption cost estimates: published scenarios such as these also calculate all losses, not only insured losses, so these numbers are directly comparable without additional adjustment. Workers' compensation costs, typically on the same order of magnitude as property damage losses in RMS scenarios, are not counted in the SNRA direct economic loss metric.

Table 10: Massive VBIED Property Loss Model[261]

City	Property Loss ($2011 billion) (DDP + BI)
Chicago	$25.1
Houston	$18.1
Los Angeles	$18.9
New York	$18.4

This scenario does not report fatalities or injuries. However, estimation of medical costs and lost spending due to fatalities using the 3,650 fatalities and 4,500 injuries of the SNRA high estimate and the inputs of Table 9 summed to $280 million. As the correlation between the high estimates of fatalities and injuries and direct economic loss would have required additional analyst assumptions and this addition would not have had an effect on the total within the order of magnitude precision of the SNRA, the reported high direct economic estimate includes only the $20.1 billion average of the DDP + business interruption estimates above.

Indirect, induced, or total economic loss estimates were not calculated for the 2015 revision of the SNRA.

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured. As noted, incidents of bomb threats or hoaxes frequently displace people for shorter periods of time but still cause disruption and economic impact.

- A few of the attacks in the historic data set that were directed at specific persons, such as the 1985 and the 2008 bombings by the Jewish Defense League (JDL) and the Animal Liberation Front (ALF) respectively, occurred in residential neighborhoods. Like most terrorist attacks, bombings tend to occur in urban centers where concentrations of people can be found rather than residential neighborhoods.
- In the majority of cases, however, the number of displaced from these historical attacks could not be determined from primary sources available to the SNRA project team. The one exception in the SNRA primary data set was the 1995 Oklahoma City bombing that left approximately 400 people homeless (Table 11).
- Although not included in the SNRA primary data set, two other incidents are included in Table 8—the 2008 ALF firebombing attack, which displaced a family of four, and a 1914 accident where a group of bomb-makers working in their apartment blew themselves up but also caused substantial injury and damage to the other apartments and residents of their building (estimated 140 displaced).

[261] Kunreuther et al (2014).

The SNRA project team was unable to identify other instances of terrorist explosives attacks in the event data set resulting in displacement. For this reason, the 2015 SNRA project team made the assumption that the remaining events most likely resulted in zero persons displaced from their homes.

Low, best, and high estimates reflect the minimum (0), average (2.2, reported as 2), and maximum (400) numbers of persons displaced from the set of incidents in Table 11.

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event.[262] The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs. A multiplicative factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.

- The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + ½\ D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement).
- In words, this formula suggests that there are five significantly distressed persons for each life lost; one for each person injured; and one for each two people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement.
- The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long-term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: Explosives Terrorist Attack was given a CEF of 1.2.
- Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

In 2011, the United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event in the 2011 SNRA. Estimates are based on the following assumptions:

[262] See Appendix G of the SNRA draft Unclassified Documentation of Findings for references and additional discussion of the SNRA Psychological Distress metric.

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity,—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- The environmental assessment included effects resulting from terrorism threats, but did not include human health effects or effects in urban areas, because these effects are already reflected in other consequence measures.
- Experts identified the best estimate for environmental consequences as "Low" explaining that the overall environmental consequences are low, but that they could become more severe if a water treatment plant or chemical plant were targeted.

Additional Relevant Information

Adjustment for population density

Fatality, injury, and direct economic loss incident information for older historical attacks in urban areas (the majority of attacks) could be multiplied in proportion to the greater population density or greater density of modern very high-occupancy business district buildings over the past, using historical relative urban population density data.[263] However, the effects of adjusting the threshold for the higher-casualty observation class (the threshold will differ from four casualties and will be different for different time periods) would need to be accounted for in some way.

Scope

Risks posed by IEDs occur regardless of the actor's intent (e.g., terrorism vs. criminal): therefore a more thorough analysis of historical incidents would ideally include criminal incidents.

Moreover, IED incidents are unusual in that threats or hoaxes can easily present significant economic consequences (and occasional injuries/fatalities due to panic). Therefore, effective risk communication would also ideally include consideration for these types of incidents. For example, economic impacts from business interruption and response costs are not insignificant. A series of Twitter-based bomb threats to planes necessitated response from military aircraft estimated to cost $22,500 per hour.[264] Closing Denver International Airport at noon for two hours to evaluate a threat or security breach was estimated to cost $2.5 million in flight cancellations directly related to the airport and affect an additional 800 flights nationwide.[265]

[263] Such as those presented in figures 2.1, 2.2, pp. 4–5 RMS (2004).
[264] See http://www.economist.com/blogs/gulliver/2015/01/hoax-bomb-threats
[265] See Forrest et al (2012)

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Table 11: SNRA 2015 Data Set
U.S. Historical Explosives and Incendiary Terrorist Attacks 1980-2005[266]

Date	Location	Incident type	Perpetrator	Killed	Injured	Dis-placed
1/7/1980	San Juan, PR	Pipe Bombing	Anti-Communist Alliance	0	0	0*[267]
1/13/1980	New York, NY	Bombing	Omega 7	0	4	0*
1/13/1980	Miami, FL	Bombing	Omega 7	0	0	0*
1/19/1980	San Juan, PR	Bombing	Omega 7	0	0	0*
3/17/1980	New York, NY	Bombing	Croatian Freedom Fighters	0	3	0*
3/25/1980	New York, NY	Attempted Bombing	Omega 7	0	0	0*
6/3/1980	Washington, DC	Bombing	Croatian Freedom Fighters	0	0	0*
6/3/1980	New York, NY	Bombing	Croatian Freedom Fighters	0	0	0*
7/14/1980	Dorato, PR; San Juan, PR	Multiple Bombings (2)	[268]	0	0	0*
7/14/1980	Ponce, PR; Mayaguez, PR	Multiple Arsons (2)	[269]	0	0	0*
7/22/1980	Puerto Rico (multiple)[270]	Multiple Bombings (4)	[271]	0	0	0*
8/20/1980	Berkeley, CA	Pipe Bombing	Iranian Free Army	0	2	0*
10/7/1980	New York, NY	Attempted Bombing	[272]	0	0	0*
10/12/1980	New York, NY	Bombing	[273]	0	4	0*
10/12/1980	Hollywood, CA	Bombing	[274]	0	1	0*
12/21/1980	New York, NY	Pipe Bombing	[275]	0	0	0*
12/30/1980	Hialeah, FL	Attempted Bombing	Omega 7	0	0	0*
1/8/1981	Puerto Rico (multiple)[276]	Multiple Incendiary Bombings (3)	[277]	0	0	0*
1/12/1981	San Juan, PR	Bombing	[278]	0	0	0*
1/23/1981	New York City, NY	Bombing	Croatian Freedom Fighters	0	0	0*
1/26/1981	San Francisco, CA	Bombing	[279]	0	0	0*
2/2/1981	Los Angeles, CA	Attempted Bombing	October 3	0	0	0*
2/22/1981	Hollywood, CA	Bombing	[280]	0	0	0*
3/15/1981	San Juan, PR	Attempted Bombing	[281]	0	0	0*
4/27/1981	Washington, DC	Incendiary Bombing	Iranian Patriotic Army	0	0	0*
5/16-18/81	New York City, NY	Multiple Bombings (5)	P.R. Armed Resistance	1	0	0*
6/25/1981	Torrance, CA	Incendiary Bombing	Jewish Defenders	0	0	0*
6/26/1981	Los Angeles, CA	Bombing	June 9 Organization	0	0	0*

[266] FBI (2006) 57-66. Explosives attacks (including rocket attacks), incendiary attacks, and attempted attacks designated as terrorist in nature in cited source.
[267] * = Assumption, SNRA project team.
[268] Organization of Volunteers for the Puerto Rico Revolution.
[269] Organization of Volunteers for the Puerto Rico Revolution.
[270] Hato Rey, PR; Santurce, PR; Rio Piedras, PR.
[271] Revolutionary Commandos of the People, Ready and at War.
[272] International Committee Against Nazism.
[273] Justice Commandos of the Armenian Genocide.
[274] Justice Commandos of the Armenian Genocide.
[275] Armed Forces of Popular Resistance.
[276] Santurce, PR; Ponce, PR; Rio Piedras, PR.
[277] People's Revolutionary Commandos.
[278] Ejercito Popular Boricua Macheteros.
[279] Jewish Defense League/American Revenge Committee.
[280] Armenian Secret Army for the Liberation of Armenia.
[281] Armed Forces of Popular Resistance.

Date	Location	Incident type	Perpetrator	Killed	Injured	Dis-placed
8/20/1981	Washington, DC	Arson	Black Brigade	0	0	0*
8/20/1981	Los Angeles, CA	Bombing	June 9 Organization	0	0	0*
8/27/1981	Carolina, PR	Bombing	Grupo Estrella	0	0	0*
9/3-4/1981	New York City, NY	Multiple Bombings (2)	Jewish Defense League	0	0	0*
9/11/1981	Miami, FL	Multiple Bombings (2)	Omega 7	0	0	0*
9/12/1981	New York City, NY	Bombing	Omega 7	0	0	0*
9/22/1981	Schenectady, NY	Bombing	Communist Workers Party	0	0	0*
9/24/1981	Miami, FL	Attempted Bombing	Omega 7	0	0	0*
10/1/1981	Hollywood, CA	Bombing	[282]	0	0	0*
10/25/1981	New York City, NY	Incendiary Bombing	Jewish Defense League	0	0	0*
11/11/1981	Santurce, PR	Bombing	[283]	0	0	0*
11/20/1981	Los Angeles, CA	Bombing	[284]	0	0	0*
11/27/1981	Santurce, PR; Condado, PR	Multiple Bombings (2)	[285]	0	0	0*
12/24/1981	New York City, NY	Attempted Pipe Bombing	Jewish Defense League	0	0	0*
2/19/1982	Miami, FL	Multiple Bombings (2)	Omega 7	0	0	0*
2/19/1982	Washington, DC	Bombing	Jewish Defense League	0	0	0*
2/21/1982	Rio Piedras, PR	Pipe Bombing	[286]	0	0	0*
2/28/1982	New York City, NY	Multiple Bombings (4)	[287]	0	0	0*
3/22/1982	Cambridge, MA	Bombing	[288]	0	0	0*
4/5/1982	Brooklyn, NY	Arson	Jewish Defense League	1	7	0*
4/28/1982	New York City, NY	Multiple Bombings (2)	Jewish Defense League	0	0	0*
4/29/1982	San Juan, PR; Bayamon, PR	Multiple Bombings (2)	[289]	0	0	0*
5/17/1982	Union City, NJ	Incendiary Bombing	Omega 7	0	0	0*
5/20/1982	San Juan, PR	Attempted Bombing	[290]	0	0	0*
5/30/1982	Van Nuys, CA	Attempted Bombing	[291]	0	0	0*
6/10/1982	Carolina, PR	Multiple Bombings (3)	[292]	0	0	0*
7/4/1982	New York City, Astoria, NY	Multiple Pipe Bombings (2)	Croatian Freedom Fighters	0	0	0*
7/5/1982	New York City, NY	Multiple Pipe Bombings (2)	Jewish Defense League	0	0	0*
8/20/1982	Old San Juan, PR	Bombing	[293]	0	0	0*
9/1/1982	Naranjito, PR	Attempted Bombing	[294]	0	0	0*
9/2/1982	Miami, FL	Bombing	Omega 7	0	0	0*
9/8/1982	Chicago, IL	Bombing	Omega 7	0	0	0*

[282] Armenian Secret Army for the Liberation of Armenia.
[283] Ejercito Popular Boricua Macheteros.
[284] Justice Commandos of the Armenian Genocide.
[285] Ejercito Popular Boricua Macheteros.
[286] Antonia Martinez Student Commandos.
[287] Armed Forces of National Liberation.
[288] Justice Commandos of the Armenian Genocide.
[289] Provisional Coordinating Committee of the Labor Self-Defense Group.
[290] Ejercito Popular Boricua Macheteros.
[291] Armenian Secret Army for the Liberation of Armenia.
[292] Armed Forces of Popular Resistance.
[293] Armed Forces of National Liberation.
[294] Ejercito Popular Boricua Macheteros.

Date	Location	Incident type	Perpetrator	Killed	Injured	Dis-placed
9/20/1982	New York City, NY	Bombing	[295]	0	0	0*
9/25/1982	Miami, FL	Attempted Bombing	Omega 7	0	0	0*
10/22/1982	Philadelphia, PA	Attempted Bombing	[296]	0	0	0*
12/8/1982	Washington, DC	Attempted Bombing	Individual	0[297]	0	0*
12/16/1982	Elmont, NY	Multiple Bombings (2)	United Freedom Front	0	0	0*
12/21/1982	New York City, NY	Attempted Pipe Bombing	Jewish Defense League	0	0	0*
12/31/1982	New York City, NY	Multiple Bombings (5)	[298]	0	3	0*
1/11-12/83	Miami, FL	Multiple Bombings (3)	Omega 7	0	0	0*
1/28/1983	New York City, NY	Bombing	Revolut'ary Fighting Group	0	0	0*
2/19/1983	Washington, DC	Pipe Bombing	Jewish Defense League	0	0	0*
3/20/1983	San Antonio, TX	Bombing	Republic of Revolutionary	0	0	0*
4/26/1983	Washington, DC	Bombing	Armed Resistance Unit	0	0	0*
4/27/1983	Miami, FL	Attempted Bombings (4)	Haitian Extremists	0	0	0*
5/12/1983	Uniondale, NY	Bombing	United Freedom Front	0	0	0*
5/13/1983	New York City, NY	Bombing	United Freedom Front	0	0	0*
5/27/1983	Miami, FL	Bombing	Omega 7	0	0	0*
8/8/1983	Detroit, MI	Attempted Incendiary Bombing	Fuqra	0	0	0*
8/9/1983	Detroit, MI	Arson	Fuqra	0[299]	0	0*
8/18/1983	Washington, DC	Bombing	Armed Resistance Unit	0	0	0*
8/21/1983	New York City, NY	Bombing	United Freedom Front	0	0	0*
8/27/1983	Washington, DC	Incendiary Bombing	Unknown	0	0	0*
10/12/1983	Miami, FL	Pipe Bombing	Omega 7	0	0	0*
10/30/1983	Hato Rey, PR	Rocket Attack	[300]	0	0	0*
11/7/1983	Washington, DC	Bombing	Armed Resistance Unit	0	0	0*
12/13-14/83	East Meadow, NY	Multiple Bombings (2)	United Freedom Front	0	0	0*
1/29/1984	New York City, NY	Bombing	United Freedom Front	0	0	0*
2/23/1984	New York City, NY	Bombing	Jewish Direct Action	0	0	0*
3/19/1984	Harrison, NY	Bombing	United Freedom Front	0	0	0*
4/5/1984	New York City, NY	Bombing	Red Guerrilla Resistance	0	0	0*
4/20/1984	Washington, DC	Bombing	Red Guerrilla Resistance	0	0	0*
8/22/1984	Melville, NY	Bombing	United Freedom Front	0	0	0*
9/26/1984	New York City, NY	Bombing	Red Guerrilla Resistance	0	0	0*
9/26/1984	Mount Pleasant, NY	Bombing	United Freedom Front	0	0	0*
10/12/1984	Puerto Rico (multiple)[301]	Multiple Bombings (5)	[302]	0	0	0*
1/25/1985	Old San Juan, PR	Rocket Attack	[303]	0	0	0*

[295] Armed Forces of National Liberation.
[296] Justice Commandos of the Armenian Genocide.
[297] The only fatality was the attacker, shot by police (bomb was a hoax). FBI (1983) 116.
[298] Armed Forces of National Liberation.
[299] The only fatalities were the attackers. FBI (1984) 30.
[300] Ejercito Popular Boricua Macheteros.
[301] Levittown, PR; Rio Piedras, PR; Ponce, PR; Mayaguez, PR; Cayey, PR.
[302] Organization of Volunteers for the Puerto Rican Revolution.
[303] Ejercito Popular Boricua Macheteros/ Organization of Volunteers for the Puerto Rican Revolution.

Date	Location	Incident type	Perpetrator	Killed	Injured	Dis-placed
2/23/1985	New York City, NY	Bombing	Red Guerrilla Resistance	0	0	0*
5/15/1985	Northridge, CA	Pipe Bombing	Jewish Defense League	0	0	0*
8/15/1985	Paterson, NJ	Bombing	Jewish Defense League	1	1	0*
9/6/1985	Brentwood, NY	Bombing	Jewish Defense League	0	1	0*
11/10/1985	Santa Ana, CA	Bombing	Jewish Defense League	1	7	0*
1/6/1986	Puerto Rico (multiple)[304]	Multiple Bombings (4)	[305]	0	0	0*
3/17/1986	Ponce, PR	Attempted Bombing	Commando Rojo	0	0	0*
4/14/1986	Rio Piedras, PR	Bombing	[306]	0	0	0*
9/15/1986	Coeur d'Alene, ID	Pipe Bombing	Aryan Nations	0	0	0*
9/29/1986	Coeur d'Alene, ID	Multiple Bombings (4)	Aryan Nations	0	0	0*
10/20/1986	New York City, NY	Incendiary Bombing	Jewish Defense League	0	0	0*
10/28/1986	Puerto Rico (multiple)[307]	Multiple Bombings (7)	[308]	0	1	0*
11/4/1986	Puerta De Tierra, PR	Attempted Bombing	[309]	0	0	0*
12/28/1986	Yauco, PR; Guayama, PR	Multiple Bombings (2)	[310]	0	0	0*
4/16/1987	Davis, CA	Arson	Animal Liberation Front	0	0	0*
5/25/1987	Puerto Rico (multiple)[311]	Multiple Bombings (7)	Guerr. Forces of Liberation	0	0	0*
1/12/1988	Rio Piedras, PR	Multiple Incendiary Bombings (2)	[312]	0	0	0*
5/26/1988	Coral Gables, FL	Bombing	[313]	0	0	0*
7/22/1988	Caguas, PR	Pipe Bombing	[314]	0	0	0*
9/19/1988	Los Angeles, CA	Bombing	Up the IRS, Inc.	0	0	0*
11/1/1988	Rio Piedras, PR	Multiple Bombings (2)	[315]	0	0	0*
4/3/1989	Tucson, AZ	Arson	Animal Liberation Front	0	0	0*
6/19/1989	Bayamon, PR	Multiple Bombings (2)	[316]	0	0	0*
1/12/1990	Santurce, PR; Carolina, PR	Multiple Pipe Bombings (2)	[317]	0	0	0*
2/22/1990	Los Angeles, CA	Bombing	Up the IRS, Inc.	0	0	0*
5/27/1990	Mayaguez, PR	Arson	Unk. Puerto Rican Group	0	0	0*
9/17/1990	Arecibo, PR; Vega Baja, PR	Multiple Bombings (2)	[318]	0	0	0*
2/3/1991	Mayaguez, PR	Arson	Popular Liberation Army	0	0	0*
2/18/1991	Sabana Grande, PR	Arson	Popular Liberation Army	0	0	0*
3/17/1991	Carolina, PR	Arson	Unk. Puerto Rican Group	0	0	0*
4/1/1991	Fresno, CA	Bombing	Popular Liberation Army	0	0	0*
7/6/1991	Punta Borinquen, PR	Bombing	Popular Liberation Army	0	0	0*

[304] Cidra, PR; Toa Baja, PR; Guanica, PR; Santurce, PR.
[305] Ejercito Revolucionario Clandestino/ National Revolutionary Front of Puerto Rico.
[306] Organization of Volunteers for the Puerto Rican Revolution.
[307] Bayamon, PR; Fajardo, PR; Mayaguez, PR; Aguadilla, PR; Santurce, PR; Fort Buchanan, PR.
[308] Ejercito Popular Boricua Macheteros.
[309] Ejercito Popular Boricua Macheteros.
[310] Ejercito Popular Boricua Macheteros.
[311] Caguas, PR; Carolina, PR; Mayaguez, PR; Cidra, PR; Aibonita, PR; Ponce, PR.
[312] Pedro Albizu Campos Revolutionary Forces.
[313] Organization Alliance of Cuban Intransigence.
[314] Ejercito Popular Boricua Macheteros.
[315] Pedro Albizu Campos Revolutionary Forces.
[316] Ejercito Popular Boricua Macheteros.
[317] Eugenio Maria de Hostos International Brigade of the Pedro Albizu Campos Revolutionary Forces.
[318] Pedro Albizu Group Revolutionary Forces.

Date	Location	Incident type	Perpetrator	Killed	Injured	Dis-placed
11/19/1992	Urbana, IL	Attempted Firebombing	[319]	0	0	0*
12/10/1992	Chicago, IL	[320]	Boricua Revolutionary Front	0	0	0*
2/26/1993	New York, NY	Car Bombing	Int'l Islamist Extremists	6	1,042	0*
7/20-22/93	Tacoma, WA	Multiple Bombings (2)	American Front Skinheads	0	0	0*
11/27-28/93	Chicago, IL	Firebombings (9)	Animal Liberation Front	0	0	0*
4/19/1995	Oklahoma City, OK	Truck Bombing	Individual	168	754	400[321]
4/1/1996	Spokane, WA	Pipe Bombing/Bank Robbery	Individual	0	0	0*
7/12/1996	Spokane, WA	Pipe Bombing/Bank Robbery	Individual	0	0	0*
7/27/1996	Atlanta, GA	Pipe Bombing	Individual	2	112	0*
1/2/1997	Wash. DC; Leavenworth, KS	Letter Bbing (count.as 1 incident)	Unknown	0	0	0*
1/16/1997	Atlanta, GA	Bombing of Abortion Clinic	Individual	0	8	0*
2/21/1997	Atlanta, GA	Bombing of Alt. Lifestyle Nightclub	Individual	0	5	0*
1/29/1998	Birmingham, AL	Bombing, Reproductive. Svcs Clinic	Individual	1	1	0*
3/31/1998	Arecibo, PR	[322]	[323]	0	0	0*
6/9/1998	Rio Piedras, PR	Bombing of Bank Branch Office	[324]	0	0	0*
6/25/1998	Santa Isabel, PR	Bombing of Bank Branch Office	[325]	0	1	0*
6/27/1998	Espanola, NM	Arson	Individual	0	0	0*
10/19/1998	Vail, CO	Arson Fire at Ski Resort	Earth Liberation Front	0	0	0*
3/19/1999	Santa Fe, NM	Attempted Bombing	Individual	0	0	0*
3/27/1999	Franklin Township, NJ	Bombing of Circus Vehicles	Animal Liberation Front	0	0	0*
5/9/1999	Eugene, OR	Bombing	Animal Liberation Front	0	0	0*
12/25/1999	Monmouth, OR	Arson	Earth Liberation Front	0	0	0*
12/31/1999	East Lansing, MI	Arson	Earth Liberation Front	0	0	0*
1/3/2000	Petaluma, CA	Incendiary Attack	Animal Liberation Front	0	0	0*
1/15/2000	Petaluma, CA	Incendiary Attack	Animal Liberation Front	0	0	0*
1/22/2000	Bloomington, IN	Arson	Earth Liberation Front	0	0	0*
5/7/2000	Olympia, WA	Arson	Revenge of the Trees	0	0	0*
7/2/2000	North Vernon, IN	Arson	Animal Liberation Front	0	0	0*
12/1/2000	Phoenix, AZ	Multiple Arsons	Individual	0	0	0*
12/9-30/00	Suffolk Ct., Long Island, NY	Multiple Arsons	Earth Liberation Front	0	0	0*
1/2/2001	Glendale, OR	Arson	Earth Liberation Front	0	0	0*
2/20/2001	Visalia, CA	Arson	Earth Liberation Front	0	0	0*
3/30/2001	Eugene, OR	Arson	Earth Liberation Front	0	0	0*
4/15/2001	Portland, OR	Arson	Earth Liberation Front	0	0	0*
5/21/2001	Seattle, WA	Arson	Earth Liberation Front	0	0	0*
5/21/2001	Clatskanie, OR	Arson	Earth Liberation Front	0	0	0*

[319] Mexican Revolutionary Movement.
[320] Car Fire and Attempted Firebombing (2)
[321] DoJ (2000).
[322] Bombing of Superaqueduct Construction Project.
[323] Ejercito Popular Boricua Macheteros.
[324] Ejercito Popular Boricua Macheteros.
[325] Ejercito Popular Boricua Macheteros (suspected).

Date	Location	Incident type	Perpetrator	Killed	Injured	Dis-placed
10/14/2001	Litchfield, CA	Arson	Earth Liberation Front	0	0	0*
3/24/2002	Erie, PA	Arson	Earth Liberation Front	0	0	0*
8/11/2002	Warren, PA	Arson	Earth Liberation Front	0	0	0*
11/26/2002	Harborcreek, PA	Arson	[326]	0	0	0*
1/1/2003	Girard, PA	Arson	Earth Liberation Front	0	0	0*
8-9/2003	San Diego, CA	Arson	Earth Liberation Front	0	0	0*
8/28/2003	Emeryville, CA	Bombing	Individual (suspected)	0	0	0*
9/26/2003	Pleasanton, CA	Bombing	Individual (suspected)	0	0	0*
1/19/2004	Henrico County, VA	Arson	ELF suspected	0	0	0*
4/1/2004	Oklahoma City, OK	Arson	Individual/Aryan Nations	0	0	0*
4/20/2004	Redmond, WA	Vandalism and Arson	Earth Liberation Front	0	0	0*
5-7/2004	Provo, UT	Vandalism and Arson	Animal Liberation Front	0	0	0*
12/27/2004	Lincoln, CA	Attempted Arson	Earth Liberation Front	0	0	0*
1-2/2005	Auburn, Sutter Creek, CA	Attempted Arson and Arson	Earth Liberation Front	0	0	0*
4/13/2005	Sammanish, WA	Arson	Earth Liberation Front	0	0	0*
7/7/2005	Los Angeles, CA	Attempted Arson	[327]	0	0	0*
9/16/2005	Los Angeles, CA	Attempted Arson	Animal Liberation Front	0	0	0*
11/20/2005	Hagerstown, MD	Arson	Earth Liberation Front	0	0	0*

[326] Earth Liberation Front/ Animal Liberation Front.
[327] Animal rights extremists (suspected).

Aircraft as a Weapon

A hostile non-state actor(s) crashes a commercial or general aviation aircraft into a physical target within the U.S. resulting in at least one fatality or injury other than to the attacker(s).

Data Summary

Category	Description	Metric	Low	Best	High
Health and Safety	Fatalities[328]	Number of Fatalities	2	290	2,800
	Injuries and Illnesses[329]	Number of Injuries or Illnesses	3	640	5,100
Economic	Direct Economic Loss[330]	U.S. Dollars	$4.0 million	$2.5 billion	$27 billion
Social	Social Displacement[331]	People Displaced from Home ≥ 2 Days	0	3,000	32,000
Psychological	Psychological Distress	Qualitative Bins	See text		
Environmental	Environmental Impact[332]	Qualitative Bins	Low		
LIKELIHOOD	Frequency of Events[333]	Number of Events per Year	0.036	0.13	0.27

Overview

Frequency estimates for the 2015 Strategic National Risk Assessment (SNRA) Aircraft as a Weapon event were derived from unclassified analysis published by the Federal Bureau of Investigation (FBI).[334] For consequence estimates, these primary FBI sources were supplemented with data and research from multiple secondary public sources including insurance studies and

[328] Low, average (293), and high (2,753) fatalities from the list of historical incidents in Table 12.

[329] Low, average (643), and high (5,124) injuries from the list of historical incidents in Table 12.

[330] Low, average, and high direct economic loss estimates for the list of historical incidents in Table 12. For 9/11 attack, DDP and business interruption costs are taken from Hartwig (2013), other incidents per-fatality multiplier from RMS scenario in Carroll et al (2005); all incidents include medical and fatality lost-spending estimates. See text for details.

[331] Low, average (5,124), and high displacement from historical incidents in Table 12. The SNRA measure of social displacement was defined as the number of people forced to leave home for a period of two days or longer.

[332] In 2011, the United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event for the 2011 SNRA. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories. Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'Best' estimate.

[333] 5th, mean, and 95th percentile of the uncertainty distribution for frequency parameter λ for aircraft as a weapon attacks treated as a Poisson process: gamma(3,23) posterior from gamma(1,0) prior updated with two event counts in 23 years (01/01/1992-12/31/2014). Best estimate reflects mean and range represents central 90% credible interval. See text for discussion.

[334] FBI (2006), FBI (2011).

models, the START Global Terrorism Database (GTD),[335] peer-reviewed literature, and U.S. and foreign press sources.

Event Background

Terrorists have long viewed aviation as a target for attack and exploitation. Successful attacks in the air domain can inflict mass casualties and grave economic damage and attract significant public attention. Historically, large passenger aircraft have been at the greatest risk to terrorism, whether bombings, taking of hostages, traditional hijacking, and attack using human-portable surface-to-air missiles. Aircraft have also been used as weapons against targets on the ground, most notably, but not limited to, the attacks of September 11, 2001.[336]

Use of aircraft as a weapon for suicide attacks goes back to at least the Japanese kamikaze attacks of World War II. Attacks by non-state actors resulting in fatalities or injuries other than the attacker include the 9/11 attacks and the 2010 attack on the Austin, Texas IRS building represented in Table 12. Failed attempts include at least one attack by the Tamil Tigers in Sri Lanka,[337] a 1972 attempt to commandeer a commercial aircraft to crash into the White House,[338] and a 2002 suicide attack on the Bank of America corporate building in Tampa, Florida by a teenager in a light plane.[339] Leaders of the Rajneeshee community considered a suicide airplane attack upon the county courthouse as one of several options for resolving their political dispute with the Oregon county where they had established their commune, before settling on the *Salmonella* contamination plan for which they are better known.[340]

For this incident, the SNRA only considered the risk of aircraft being used as a kinetic mode of attack (e.g., a 9/11 style attack) rather than the risk of an improvised explosive device (IED) being detonated on an aircraft. The latter risk is considered under the explosives incident category in the SNRA.

Assumptions

The 2015 SNRA used the same historical incident data as the 2011 SNRA for fatalities and injuries, with the addition of a 1945 incident where a B-25 bomber crashed into the Empire State Building. Social displacement estimates were also based upon this data set for the 2015 SNRA. Direct economic loss estimates leveraged historical data and published insurance models for property damage and business interruption, and literature sources for medical costs.

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[335] The Global Terrorism Database (GTD) is an open-source database including information on terrorism events around the world (including domestic, transnational, and international incidents) from 1970 to 2010. For each GTD incident, information is available on the date and location of the incident, the weapons used and nature of the target, the number of casualties, and—when identifiable—the group or individual responsible.

START, the National Consortium for the Study of Terrorism and Responses to Terrorism, is a DHS Center of Excellence and network of scholars coordinated from the University of Maryland. Since 2011 when the first SNRA was executed the START GTD has become the most commonly cited source for global terrorism statistical data, and is now used as the primary data source (with similar parameters as the 2011 SNRA) for the U.S. Government's annual Statistical Annex on Terrorism published for the U.S. State Department's Country Reports on Terrorism. START GTD (2013).

[336] DHS (2007).

[337] 20 February 2009: START GTD 200902200005.

[338] 9/11 Commission Report (2004) endnote 21, p. 561; Jenkins (2014).

[339] 5 January 2002: START GTD 200201050007. This did not result in injuries or fatalities other than to the pilot.

[340] Zeitz (2011). See Biological-Chemical Terrorism Attack (small-scale) risk summary sheet.

Frequency estimates were based upon the U.S. subset of these incidents identified as terrorist incidents by the Federal Bureau of Investigation (FBI).[341]

Frequency

Aircraft as a weapon attacks were treated in a fashion similar to other adversarial and non-adversarial events in the 2015 SNRA.[342] Low, best, and high frequency estimates represent the 5th percentile, mean, and 95th percentile of the uncertainty distribution for the annual frequency[343] of aircraft as a weapon attacks.[344] For events with few or no historical observations, representation of the unknown likelihood by a distribution encoding the information from these observations allows the uncertainty in the event's true underlying frequency of occurrence to be strongly bounded within the credible interval of frequencies that is consistent with the observational evidence. Given the choice of observation period, number of incidents meeting the counting threshold, and the desired credible (confidence[345]) range of uncertainty expressed as a percentage, the mean, lower, and upper bounds of this interval are uniquely determined in an objective and repeatable manner.

The SNRA project team selected the 23-year period of 1992–2014 as the observation period for determining the frequency estimates for similar reasons as the SNRA 2015 large-scale chemical, biological, radiological, nuclear (CBRN) attack events.[346] Two historical aircraft-as-a-weapon attacks in this period, the 9/11 attacks[347] and the 2010 suicide attack on the Austin, Texas IRS building,[348] met the threshold criteria of this event and are categorized as terrorist attacks by the FBI. The 9/11 attacks were treated as a single attack for the purposes of the SNRA, following the counting convention of the FBI.

The frequency parameter λ (annual frequency of successful attacks) was parameterized by a gamma(3,23) distribution. This distribution was obtained by updating the gamma(1,0) agnostic prior distribution, with two event counts in the 23 years from 01/01/1992 to 12/31/2014.

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[341] FBI (2006, 2011).

[342] Each SNRA 2015 event is modeled as a Poisson (random and 'memory-less') process. This reflects both 1) agnosticism regarding the relative dominance of factors acting to increase (demonstration of feasibility, copy-cat attacks) and decrease (suppressive actions by USG and law enforcement agencies in reaction) the frequency of subsequent attacks following a first successful attack, and 2) the multiple independent processes driving aircraft-as-a-weapon attack attempts as evidenced by the historical record of repeated attacks by multiple, independent non-state actors with differing ideologies and motives. See Mohtadi et al (2005, 2009a).

[343] The frequency parameter λ of the modeled Poisson process.

[344] In most cases, events in the SNRA having a large data set of historical incidents generally estimate low and high frequencies as the inverses of the longest and shortest inter-arrival times between incidents. For rare events where the number of historical incidents is too small to support a meaningful estimate of inter-arrival time, low and high frequency estimates usually represent the 5th and 95th percentiles of the distribution modeling the uncertainty in the event's underlying frequency of occurrence. See SNRA 2011 draft Unclassified Documentation of Findings appendices B (Frequency) and I (Thresholds).

[345] This interval, corresponding to the confidence interval of frequentist statistics, is referred to as the 'Bayesian confidence interval' or 'credible interval' by different authors. The latter will be used here for clarity. NRC (2003) B-11.

[346] Although successful and unsuccessful suicide attacks using aircraft have a long history as noted above, this choice of observation period was motivated by an analytic assumption that the underlying frequency of this mode of attack is strongly influenced by factors particular to the 'new age of suicide terrorism' following the fall of the Soviet Union and the end of the Cold War at the end of 1991. This differs from the 1980–2012 observation period used for the other conventional terrorism attacks and for small-scale chemical-biological attacks, which have a longer demonstrated history of successful attacks in this country. It is the same observation period used for the large-scale CBRN terrorism events, which share similar assumptions regarding a fundamental difference in the underlying conditions driving frequency of successful attacks before and since 1991.

[347] FBI (2006) 65.

[348] FBI (2011). Also Obama (2013) [description as terrorist], GTD 201002180013 [incident detail].

Health and Safety

The SNRA project team used the following to estimate health and safety consequences resulting from an aircraft-as-a-weapon attack:

- Historical events: the SNRA project team analyzed a set of 11 historical events in which aircraft intentionally or unintentionally crashed into buildings or crowds of people. These include the two aircraft-as-a-weapon terrorist attacks in the historical data set used as the basis of the frequency estimates, as well as additional historical incidents. A detailed listing of these events is found in Table 12 under "Additional Relevant Information."
- This list comprises the same data set used for SNRA 2011, with the addition of the 1945 incident where a B-25 bomber crashed into the Empire State Building (incident 1, Table 12).
- The analysis does not take into account possible higher-consequences events that have not yet occurred, but rather assumes maximum fatalities and injured counts from the 9/11 attacks in New York.

Direct Economic Loss

Direct economic costs in the SNRA include decontamination, disposal, and physical destruction (DDP) costs; business interruption costs; medical costs; and lost demand from fatalities.

The SNRA project team used the following assumptions to estimate the direct economic costs resulting from an aircraft-as-a-weapon attack:

- **Business Interruption and DDP Costs:** For the 9/11 attacks, the historical DDP and business interruption costs were used.[349]
- For the other historical attacks, proxy estimates for property damage including structure, contents, and aircraft hull loss costs and direct business interruption costs were taken from the insurance model in Carroll et al (2007). These were applied as multipliers of $1.20 million DDP and $0.723 million direct business interruption per fatality.[350]
- **Medical Costs:** The numbers of injured were based on the set of events listed above. To account for the distribution of injuries and corresponding medical costs from single events, the SNRA project team multiplied total injuries from the events in the historical data set by $5,200 per fatal injury and $24,000 per non-fatal injury.[351] These estimates, based upon the average medical costs for gunshot injuries due to deliberate assault or homicide in the U.S.,

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[349] In USD$2011 (CPI 2012-2011 0.9797) $12.7 billion DDP including property damage to World Trade Center, aviation hull loss, and other property damage, and $12.7 billion business interruption, from Hartwig (2013).

[350] In $2011 (CPI 1.152 2005-2011): building property damage $1.95 billion, contents property damage $1.12 billion, aircraft hull $144 million, for 2,632 fatalities (model) and 35,524 non-fatal injuries. As Carroll do not report passenger fatalities, 68 fatalities were added to this fatality number representing the average number (59.3) of passenger fatalities per plane in fatal U.S. airline passenger airplane crashes 1982-2009 (NTSB (2013a)) excluding the 9/11 hijackers increased in proportion by 0.16, the ratio of total crew to non-hijacker passenger fatalities on the 9/11 flights, to account for crew fatalities not reported in these statistics. The scenario of Carroll et al represents the 93rd casualty (fatalities + injuries) percentile of the RMS (Risk Management Solutions) aircraft as a weapon scenario space (scenario counts as opposed to probability weighted scenarios). Additional information is given but without breakdown by fatalities and injuries: this scenario was selected as representative because of its use by the authors and citation by other RAND studies (e.g., Morral et al (2012) 51) as representative. DDP/BI values were calculated in proportion to fatalities as opposed to total fatalities plus injuries, because was unclear what subset of the injuries reported in Carroll corresponded to the injuries in the SNRA historical data set.

[351] Medical cost per fatal and non-fatal injury for gunshot injuries in the United States from Corso et al (2007), adjusted from 2000 to 2011 dollars using the general CPI-U inflator (1.306). Estimated costs from lost labor productivity are not included.

were judged to be most representative of injuries due to other extreme violence and were used for each of the conventional terrorism events of the 2015 SNRA.[352]

- **Lost Demand from Fatalities:** To estimate the costs of lost demand from deaths, the SNRA project team multiplied the number of deaths listed in Table 12 by $42,500, the same figure used across the SNRA 2011 events.[353]

All cost estimates were converted to constant 2011 dollars to maintain comparability with SNRA 2011 events.

The 2015 SNRA project did not attempt to calculate indirect, induced, or total economic cost estimates.

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

- Low, best, and high estimates represent the minimum, average, and maximum estimates of persons from the historical incidents in Table 12.
- Several of these incidents resulted in no displacement from homes, confirming the SNRA 2011 low estimate of 0.
- The SNRA 2015 high estimate of 32,000 displaced represents the number of residents of Lower Manhattan who evacuated their homes following the 9/11 attacks who had not returned by September 13.[354]

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event.[355] The equation for

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[352] Medical costs from Explosives/Kinetic/Incendiary (E/K/I) injuries taken as a class are comparatively well studied and were used as a proxy for medical costs in the Aircraft as a Weapon attack SNRA event. SNRA 2011 also used E/K/I medical costs for the AAW event, but these were represented by a uniform distribution over $13,490 to $122,802, the distribution used by the RAPID assessment for medical costs associated with E/K/I injuries, by repeated random sampling from each distribution. This distribution represents the range of average medical costs for fifteen blast related injuries from nonspecific chest pain ($13,490) to spinal cord injury ($122,802) from the 2009 National Inpatient Survey (see AHRQ (2011) for corresponding 2011 estimates). As this distribution averages to $68,150 per injury, the SNRA 2015 medical cost estimates for conventional terrorism events are approximately 2–3 times smaller than those of SNRA 2011.

[353] This number originates from the 2008 Bioterrorism Risk Assessment (BTRA 2008) (the BTRA as a whole is classified Secret, but its economic methodology appendix is U//FOUO), and represents the midpoint (the expected value of a linear uniform distribution over the interval) of the $35,000–$50,000 median household income band in 2011. DHS (2008) pp. E2.7-34. (Appendix reference is UNCLASSIFIED//FOR OFFICIAL USE ONLY; Extracted information is UNCLASSIFIED.)

[354] Extrapolated from data provided by the 25% of Lower Manhattan residents responding to the World Trade Center Health Registry Survey. 61% of respondents evacuated their homes, of whom 91.2% had not returned to their homes by September 13: this proportion was extrapolated to the 57,511 total resident population of Lower Manhattan. Farfel et al (2008). These evacuating residents represented a small fraction of the 1 million people (the SNRA 2011 high estimate) who left Lower Manhattan on September 11, the majority of whom were returning to homes elsewhere. The SNRA 2015 best estimate of 32,000 is on the order of the SNRA 2011 best estimate of 50,000 (SNRA 2011 draft Unclassified Documentation of Findings, Appendix F).

[355] See Appendix G of the SNRA draft Unclassified Documentation of Findings for references and additional discussion of the SNRA Psychological Distress metric.

this index uses the fatalities, injuries, and displacement associated with an event as primary inputs. A multiplicative factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.

- The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + ½\ D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement).
- In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement.
- The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long-term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: Aircraft as a Weapon was given a C_{EF} of 1.2.
- Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

In 2011, the United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event in the 2011 SNRA. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- The environmental assessment included effects resulting from terrorism threats, but did not include human health effects or effects in urban areas, because these effects are already reflected in other consequence measures.
- Experts identified the best estimate for environmental consequences as "Low." Experts indicated that one airplane could cause tens of acres of environmental impact of a limited duration but the identified event would likely occur in an urban environment. Consequences could be elevated to "Medium" depending on the target (e.g., a chemical plant).

Potential Mitigating Factors

The frequency estimates related to this event depend on the ability of potential terrorists to gain access to an airplane through either hostile takeover or other means using illicit documents, or a legal process. The nature of the consequences is related to the size of the airplane and the ability to direct it to a desired target.

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Additional Relevant Information

Table 12: List of Analyzed Events

#	Event	Date	Fatalities	Injuries	Displaced	Direct Economic Loss ($2011)[356]
1	USAAF B-25 Bomber Crashes into Empire State Building (New York, NY, USA)	7/28/1945	14[357]	26[358]	0[359]	$28,063,000
2	Ramstein Air Show Disaster (Ramstein, Germany)	8/28/1988	70[360]	1,500[361]	0[362]	$173,194,000
3	Flight 1862 Crash (Amsterdam, Netherlands)	10/4/1992	47[363]	26[364]	250[365]	$92,740,000
4	Air France Concorde Crash (Paris, France)	7/25/2000	113[366]	6[367]	0[368]	$221,615,000
5	September 11th Attacks (New York, Virginia, Pennsylvania, USA)	9/11/2001	2,753[369]	5,124[370]	32,000[371]	$26,902,541,000
6	Small Plane Hits the Pirelli Tower (Milan, Italy)	4/18/2002	3[372]	30[373]	0[374]	$6,600,000
7	Small Plane Crashes in Park (San Dimas, CA, USA)	7/4/2002	4[375]	9[376]	0[377]	$8,056,000
8	Ukraine Air Show Disaster (Lviv, Ukraine)	7/27/2002	77[378]	241[379]	0[380]	$156,698,000
9	Military Plane Crashes into Building (Tehran, Iran)	12/6/2005	115[381]	90[382]	250[383]	$227,551,000
10	Small Plane Hits Apartment Complex (New York, NY, USA)	10/11/2006	2[384]	3[385]	80[386]	$3,992,000
11	Suicide Attack on IRS Building (Austin, TX, USA)	2/18/2010	2[387]	13[388]	0[389]	$4,232,000

356 See text for description of the method used to calculate representative direct economic loss estimates. Estimates are rounded to nearest thousand to avoid (reduce) communicating false precision.
357 Barron (1995).
358 Washington Post (1998b).
359 Barron (1995), Resner (1945).
360 Bulau (2008).
361 Ibid.
362 Planes crashed into crowd at airshow and forest: Ibid.
363 Netherlands (1994).
364 Ibid.
365 Residents of destroyed apartments initially missing. BBC (1992, October 4), Montgomery (1992).
366 France (2002).
367 Ibid.
368 Aircraft crashed into a hotel, no other property damage. France (2000) 14, 18.
369 AP (2011, June 18).
370 FEMA (2001).
371 SNRA 2015 project team estimate from World Trade Center Health Registry counts: 61% of respondent residents evacuated homes of which 91.2% did not return within two days, times 57,511 total residents of lower Manhattan (12,371 residents of lower Manhattan, 25% of total population, registered with survey: 7,458/12,371 responding residents evacuated). Farfel et al (2008).
372 NTSB (2002).
373 Ibid.
374 Office building: Ibid.
375 NTSB (2004).
376 Ibid.
377 Ibid.
378 Ukraine (2002).
379 BBC (2005, June 24).
380 Aircraft crashed into crowd at airshow: Ibid.
381 USA Today (2011, July 16).
382 Ibid.
383 Reuters (2005, December 6).
384 NTSB (2007)
385 Ibid.
386 SNRA 2015 project team estimate: 100 of 137 apartments affected, many residents in temporary quarters elsewhere for months; approximately ¼ of building floors (38th to 47th floors) most affected by fire and breakage, times 2.3 average residents per apartment = approximately 70–80 residents. Upper end of range taken as estimate for residents forced to leave home for 2 days or more. Barron (2007).
387 Fox (2010, February 19).
388 Ibid.
389 Ibid. (Pilot burned family home prior to attack, but this was not a consequence of the attack itself.)

Human Pandemic Outbreak

A severe outbreak of pandemic influenza with a 25% gross clinical attack rate spreads across the U.S. populace.

Table A. Pandemic: SNRA Data Summary

Category	Description	Metric	Low	Best	High
Health and Safety	Fatalities	Number of Fatalities[a]	77,000	154,000	230,000
	Injuries and Illnesses	Number of Injuries or Illnesses[b]	62 Million	77 Million	110 Million
Economic	Direct Economic Loss	U.S. Dollars (2011)[c]	$71 Billion	$110 Billion	$180 Billion
	Indirect Economic Loss	U.S. Dollars (2011)	N/A		
Social	Social Displacement	People Displaced from Home ≥ 2 Days	0[d]		
Psychological	Psychological Distress	Qualitative Bins	See text		
Environmental	Environmental Impact	Qualitative Bins[e]	Low[f]		
LIKELIHOOD	Frequency of Events	Number per Year	See Table B		

Table B. Conditional and Absolute Likelihood Ranges for Pandemic Relative Severity

				Low	Best	High
Frequency of All Influenza Pandemics Absolute Likelihood (Number Per Year)[g]				0.017	0.033	0.10
Conditional Likelihood of Severity, Given Pandemic Occurrence	Mild	Low	0.10	0.0017	0.0033	0.010
		High	0.30	0.0051	0.0099	0.030
	Middle	Low	0.50	0.0085	0.0165	0.050
		High	0.80	0.0136	0.0264	0.080
	Severe/ Worst Case	Low	0.10	0.0017	0.0033	0.010
		High	0.10	0.0017	0.0033	0.010
				Absolute Likelihood by Relative Severity		

[a] Fatality low, best, and high estimates were calculated using an attack rate of 25%, a U.S. population of 307 million, and a case fatality rate of 0.1%–0.3% (best: 0.2%). Reed et al (2013, January). Novel framework for assessing epidemiologic effects of influenza epidemics and pandemics; and Technical Appendix. *Emerging Infectious Diseases* 19(1) 85–91, at http://wwwnc.cdc.gov/eid/article/19/1/12-0124_article; Technical Appendix at http://wwwnc.cdc.gov/eid/article/19/1/12-0124-techapp1.pdf (retrieved June 2013).

[b] Illness low, best, and high estimates correspond to a U.S. population of 307 million and attack rates of 20%, 25%, and 35% respectively.

[c] Sum of estimated hospitalization costs, business interruption from workdays lost, and one year's lost spending per fatality. See Direct Economic Impact for details.

[d] Social displacement was assumed to be zero for the Human Pandemic Outbreak national-level event.

[e] In 2011, the United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.

[f] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The experts provided a best estimate of 'Moderate' for a pandemic scenario with severe social impacts and a second best estimate of 'Low' for a less severe pandemic scenario (see Environmental Impacts). The SNRA used 'Low' as the best estimate and 'Moderate' as the second best estimate for the Pandemic national-level event, because the final numbers on other consequence scales defined a scenario with social impacts corresponding to the less severe as opposed to the more severe pandemic scenario.

[g] The SNRA data tables are presented differently for Pandemic than for other national-level events to address partner risk communication concerns that are specific for pandemic influenza. The same information is presented as in other data tables, but additional information is also presented.

The frequency estimates (0.017/year, 0.033/year, 0.10/year) in the top row of Table B represent the likelihood of occurrence of the set of influenza pandemic events as a whole, not the conditional or absolute likelihoods of occurrence of the low, best, and high impact estimates in particular. (Low, best, and high impact estimates also do not necessarily correlate with each other across impact metric, e.g. the high estimates of fatalities, illnesses, and direct economic impacts do not necessarily correlate together in a single scenario.) The overall frequency of occurrence of an event and the conditional probabilities of an incident having low, moderate, or high impacts are independent variables. The top row frequency estimates are the low, best, and high frequencies indicated on the SNRA's comparative charts.

The approximate likelihoods of the 'mild' (10-30%), 'middle' (50-80%), and 'severe/worst case' (~10%) scenarios as described under "Additional Relevant Information" given occurrence of an influenza pandemic in the set as a whole, are listed in the first vertical column to the left. Similarly to the frequency of occurrence of pandemics as a whole, these conditional likelihoods have substantial uncertainties associated with them, and so are represented as ranges. Given the occurrence of an influenza pandemic, these represent the probabilities that the pandemic will be 'mild', 'middle', or 'severe/worse case'. Note that the designation 'mild' is strictly relative: the least severe historical instance of a 'mild' pandemic, the 2009 H1N1 influenza, killed more Americans than any other natural or accidental hazard incident or modeled scenario in the SNRA data set. Note also that these three categories do not correspond to the low, best, and high impact estimates of the SNRA Pandemic event as given in Table A: the SNRA low, best, and high impact estimates reflect a broad 1957-like pandemic scenario, and the range of impacts described by the SNRA scenario straddle the boundary of the 'mild' and 'middle' categories described in Table B and "Additional Relevant Information." The range of impacts for the SNRA Pandemic event correspond to a high-'mild' to a 'middle' scenario.

The absolute frequency of each of the 'mild', 'middle', and 'worse case' scenarios described under "Additional Relevant Information" would be the product of the 0.017 – 0.10/year absolute frequency of the Pandemic event as a whole and their approximate conditional likelihoods of 10-30%, 50-80%, and 10% respectively, or 0.002-0.03, 0.008-0.08, and 0.002-0.01/year. These are presented in the body of Table B. Because of the multiple uncertainties involved with pandemic likelihoods, only the ranges (the high and low of each product) are considered to be informationally meaningful: these are colored in violet.

For additional detail, see "Additional Relevant Information" and associated discussion.

Event Background

There have been eight naturally caused influenza pandemics (including pandemics subsequently deduced to have been caused by influenza virus) since 1729.[390] Thus, the historic frequency is once every 10 to 60 years. New influenza viruses that affect humans can emerge and spread rapidly. Influenza pandemics can occur at any time due in part to the following factors: the quality and scope of epidemiological and laboratory resources to identify and diagnose viruses with pandemic potential—both in the United States and globally; the complex reassortment of new influenza viruses between animal and human hosts; potential lack of antibody resistance to new influenza virus strains in the population at large; potential resistance of new influenza virus strains to available antiviral medications; time needed to identify, develop, produce, and distribute an effective pandemic influenza vaccine; and countermeasure resources in the United States and globally to mitigate the transmission of a pandemic virus.

Assumptions

The Strategic National Risk Assessment (SNRA) project team used the following assumptions to estimate health and safety consequences caused by a pandemic event:

- The scenario is based on a U.S. population of approximately 307 million.
- Likelihood, fatality, and illness best estimates and ranges were provided to the SNRA project team by the U.S. Centers for Disease Control and Prevention (CDC).
- These experts stress that it is impossible to predict the timing or severity of the next pandemic.
- All of the estimates are given absent any intervention (i.e., before interventions are applied or attempted).[391]
- The modeled National-level Event is based on assuming a 25% attack rate[392] and death rates associated with a scenario modeled on a 1957-scale pandemic if it were to occur in today's population.[393,394]

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[390] Different authors have different lists of which influenza years they consider to have been pandemics, but most modern writers' lists of likely influenza pandemics in the past three centuries include from about 8 to 12 events in total (when the 2009 H1N1 pandemic is included). Serological studies—blood tests to characterize antigens to surface proteins of influenza viruses a person may have been exposed to in his/her lifetime—have been successfully used to determine the serotypes (combinations of particular H and N surface proteins) of influenza outbreaks back to around 1900. However, making a determination of which historical outbreaks before that point were pandemics by the modern virological definition from past writers' observations indicative of a new influenza serotype (e.g., cross-continent spread, patterns of residual immunity from previous outbreaks) involves a great deal of inference and human judgment. Potter C. W. (2001, October), A history of influenza. *Journal of Applied Microbiology* 91(4) 572-579; Taubenberger et al (2009, April), Pandemic influenza—including a risk assessment of H5N1, *Revue Scientifique et Technique (Rev. Sci. Tech.)* 28(1) 187–202, at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2720801/ (accessed March 2013); Patterson, Karl D. (1986), Pandemic Influenza, 1700-1900: A study in historical epidemiology, Rowan & Littlefield, publishers; Dowdle, W. R. (1999), Influenza A virus recycling revisited. *Bulletin of the World Health Organization* 77(10) 820-828; at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2557748/ (accessed April 2013); Morens et al (2010, November), Historical thoughts on influenza viral ecosystems, or behold a pale horse, dead dogs, failing fowl, and sick swine. *Influenza and Other Respiratory Viruses* 4(6) 327-337, at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3180823/ (accessed May 2013).

[391] See "Potential Mitigating Factors".

[392] The attack rate is the percentage of population that becomes clinically ill due to influenza. Clinical illness is defined as a case of influenza that causes some measurable economic impact, such as one-half day of work lost or a visit to a physician's office.

[393] Reed et al (2013), *op. cit.*

[394] Medical technologies to improve survival probabilities in the elderly and health-compromised populations most at risk of dying from influenza have advanced in past decades. However, the larger fraction of these high-risk subpopulations in today's U.S. population—due in large part to these same advances—means that total fatalities from an influenza pandemic of similar virulence could be much higher today than in 1957.

Frequency

Low (1/60 years), best (1/30 years), and high (1/10 years) frequency estimates reflect the historic frequency of influenza pandemics of natural origin since 1729 of once every 10 to 60 years, averaging 1 in 30 years. These correspond to the absolute likelihood of the set of pandemics as a whole: the conditional likelihood of pandemic scenarios of different severities given occurrence of a pandemic event is discussed under "Additional Relevant Information".

Fatalities and Illnesses

Fatality low, best, and high estimates were calculated using an attack rate of 25%, a U.S. population of 307 million, and a case fatality rate of 0.1%–0.3% (best: 0.2%).[395] Illness low, best, and high estimates correspond to the same U.S. population and attack rates of 20%, 25%, and 35% respectively.[396]

Comparisons to other estimates of health and safety impacts: Large uncertainties dominate any estimate of the human consequences of the next influenza pandemic.

- Severity of virus: Although useful indications of the potential range of impacts may be inferred from records of the historical variability of the influenza virus (Figure 11, Figure 12), patterns deduced from the historical record have been insufficient in themselves for constructing predictive models for the severity of the next pandemics.[397] Many planning scenarios model experts' best judgment of a 'most representative' scenario, such as the 1957-scale pandemic model used for the SNRA and many other planning scenarios in this country; others model a 1918-scale pandemic as a maximal scenario for planning purposes.[398] Current U.S. Government guidance is to plan to both a 'moderate' 1957/1968-style pandemic and a 'severe' 1918-style pandemic to ensure preparedness for a range of impacts.[399]

Melzer et al (1999). The economic impact of pandemic influenza in the United States: priorities for intervention, *Emerging Infectious Diseases* 5(5) 659-671, at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2627723/; with Appendix II, from http://wwwnc.cdc.gov/eid/article/5/5/99-0507-techapp2.pdf (accessed April 2013); Zimmerman et al (2010, September 7), Prevalence of high risk indications for influenza vaccine varies by age, race, and income, *Vaccine* 28(39) 6470–77, at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2939262/ (retrieved 17 June 2013).

The SNRA project team is not aware of any longitudinal study looking at the proportion of high-risk populations defined in comparable terms. However, the scale of this increase is apparent in studies of the U.S. populations covering shorter time periods. One illustration of this is the increase of the overall percentage of the U.S. population at high risk from complications of influenza from 15.5% to 20% in the five year period 1973–1978: Table 12, Office of Technology Assessment, U.S. Congress (1981, December), Cost Effectiveness of Influenza Vaccination. NTIS order #PB82-178492, also at http://ota.fas.org/reports/8112.pdf.

[395] Melzer et al, Standardizing scenarios to assess the need to respond to an influenza pandemic, *Clinical Infectious Diseases* [forthcoming]; Reed et al (2013), *op cit.*

[396] The 15%/25%/35% attack rate range used in CDC community planning tools (e.g., FluWorkLoss) was truncated below at 20% to correspond to the lowest U.S attack rate of the naturally occurring influenza pandemics of the last century (19.9% for the 2009 H1N1 pandemic: Table D.4, technical appendix, Reed et al (2013). Although lower attack rates are reported for other historical pandemics these are reported only as the lower end of a range: the 19.9% attack rate is presented as a single estimate for the 2009 pandemic).

[397] Dowdle, W. R. (1999), Influenza A virus recycling revisited. *Bulletin of the World Health Organization* 77(10) 820–828; at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2557748/ (accessed April 2013).

[398] National Infrastructure Simulation & Analysis Center (NISAC), for the Office of Infrastructure Protection, U.S. Department of Homeland Security (2007, October 10), National Population, Economic, and Infrastructure Impacts of Pandemic Influenza with Strategic Recommendations; also the 'high' scenario of the 2005 HHS Pandemic Influenza Plan (p. 18), and the 'high' and conservative fatalities planning factors of the UK Pandemic Influenza Strategy 2011 (pp. 16–17, 20–25) (overall, the UK strategy stresses a range of scenarios similar to HHS recommendations). Department of Health, United Kingdom (2011, November 10), UK Influenza Pandemic Preparedness Strategy 2011, at https://www.gov.uk/government/publications/responding-to-a-uk-flu-pandemic (accessed June 2013); U.S. Department of Health and Human Services (2005, November), HHS Pandemic Influenza Plan, at http://www.flu.gov/planning-preparedness/federal/hhspandemicinfluenzaplan.pdf (accessed April 2013).

[399] HHS Pandemic Influenza Plan, *op cit*; U.S. Centers for Disease Control and Prevention, CDC Resources for Pandemic Flu [web portal], http://www.cdc.gov/flu/pandemic-resources/ (accessed June 2013).

- Mitigation measures: In addition to the inherent characteristics of the virus, the actual consequences of a future pandemic will also depend upon the availability, speed of deployment, and effectiveness of medical and non-medical measures to mitigate disease spread and lethality. Despite extensive study in the literature,[400] the extent to which the effects of the next pandemic will be mitigated in practice is dominated by open questions (see Potential Mitigating Factors).

Direct Economic Loss

Direct economic impacts as defined in the SNRA include decontamination, disposal, and physical destruction costs including property (structure, contents, physical infrastructure, and other physical property) and crop damage; one year's lost spending due to fatalities; medical costs; and business interruption directly resulting from the impacts of an event. For the 2015 SNRA, direct economic impacts were calculated based upon previous work done for the DHS RAPID model.[401],[402] This method was used, because it aligned better to the harmonized SNRA definition of direct economic impact than that used for the 2011 SNRA; however, given the 2015 SNRA fatality and illness inputs, both methods gave similar results (see below).

The SNRA project team used the following assumptions to estimate economic consequences caused by a pandemic event:

- All of the estimates are given absent any intervention (i.e., before interventions are applied or attempted).
- All estimates were converted to 2011 dollars for comparison with the existing events of the SNRA.
- **Decontamination, Disposal, and Physical Destruction costs** were assumed to be negligible in comparison with the other components of the SNRA direct economic loss measure for the Pandemic event.[403]
- **Medical Costs:** The SNRA project team made the assumption that hospitalizations would dominate the medical costs for the Pandemic event. A fatality/hospitalization ratio of 11%, the midpoint of the middle (Scale 4)-level scenario of CDC's current pandemic classification model[404] was applied to the low, best, and high fatality estimates.[405] The resulting estimates of

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[400] Longini et al (2004, April 1). Containing pandemic influenza with antiviral agents. *American Journal of Epidemiology* 159(7) 623–633; Miller et al (2008, August 1). Prioritization of influenza pandemic vaccination to minimize years of life lost. *Journal of Infectious Diseases* 198(3) 305-311; Perlroth et al (2010, January 15). Health outcomes and costs of community mitigation strategies for an influenza pandemic in the United States. *Emerging Infectious Diseases* 50(2) 165–174; Meltzer et al (1999), *op cit.*; NISAC (2007), *op cit.*; Office of Technology Assessment (1981), *op cit.*; CDC (2011, May 10). Ten Great Public Health Achievements – United States, 2001–2010. *Mortality and Morbidity Weekly Report (MMWR)* 60(19) 619–623; CDC (2011, September 30), Notice to Readers: Revised Estimates of the Public Health Impact of 2009 Pandemic Influenza. *MMWR* 60(38) 1321; Atkins et al (2011, September). Estimating effect of antiviral drug use during pandemic (H1N1) 2009 outbreak, United States. *Emerging Infectious Diseases* 17(9) 1591–1598.

[401] The Risk Assessment Process for Informed Decision Making (RAPID) 2010 (or RAPID II) was a strategic level, DHS-wide process to assess risk and inform strategic planning priorities developed by the DHS Office of Risk Management & Analysis (National Protection & Programs Directorate). The RAPID engine is a suite of computational tools for calculating human and economic measures of risk and the relative effectiveness of different DHS programs in risk reduction. Like the SNRA it is a quantitative tool for calculating and comparing risks in the homeland security mission space with each other, but unlike the SNRA it is designed for additionally calculating the comparative effectiveness of different programs in buying down risk. RAPID is presently maintained by the DHS Office of Policy.

[402] Note that the following is *based* on work done in developing the RAPID model, not the model itself. Common inputs include average hospitalization costs and direct business interruption costs per workday lost.

[403] This assumption may not hold true for an extremely severe pandemic causing social disruption on the scale of the 1918 pandemic: see Environmental Impact section below, discussion of Moderate impact estimate.

[404] Scales as in Reed et al (2013).

numbers hospitalized were multiplied by $21,154, the average cost of influenza-related hospitalizations from the RAPID model adjusted to 2011 dollars, to obtain total estimated hospitalization costs.[406],[407]

- **Business Interruption** costs for the SNRA were estimated based on the workdays lost due to illnesses, including caregiver absences from work due to ill family members. The CDC FluWorkLoss model was used to estimate workdays lost for the SNRA.[408] FluWorkLoss is highly customizable to input assumptions and values.[409] However, for a given set of input assumptions, the output average total workdays lost per illness is a linear function of Case Fatality Rate (CFR) independent of attack rate, total fatalities, or pandemic duration. The relationship[410] corresponding to the FluWorkLoss default assumptions was used to estimate total workdays lost for each of the low/best/high fatality and illness scenarios. These totals, converted to total work-years lost,[411] were multiplied by the U.S. average annual output per worker of $144,654[412] to produce estimates of total business interruption directly caused by a pandemic event.
- **Lost Demand from Fatalities:** To estimate the costs of lost demand from deaths, the SNRA project team multiplied the number of deaths listed in the Data Summary Table by $42,500, the same figure used across the SNRA 2011 events.[413]

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405 A constant ratio was used because the correlation of this measure to other measures across different scale scenarios was unknown: the different severity measures of the Reed model are used as inputs to determine a severity level and do not represent a prediction that these scenarios will be correlated in a real world pandemic event. As a sensitivity analysis, a functional relationship between this ratio and case fatality rates at the boundaries of each scenario (e.g. 0.05% CFR and 6.5% fatality/hospitalized ratio at the scale 2–scale 3 boundary) of (fatality/hospitalized) = 0.0374 ln(CFR) + 0.3516 [$R^2 = 0.9986$] was assumed and applied to the low/best/high fatality-illness scenarios to obtain fatality/hospitalized ratios of 9.3%, 11.9%, and 13.4% respectively. This resulted in total direct economic impacts of $74/$112/$172 billion respectively, compared with $71/$114/$180 billion total direct economic impacts of the final SNRA 2015 estimates.

406 Similarly to the DHS Terrorism Risk Assessments, RAPID estimates of hospitalization costs were derived from the Nationwide Impatient Sample (NIS), Healthcare Cost and Utilization Project (HCUP), Agency for Healthcare Research and Quality and are based on a five day hospitalization ($18,367 in $2005). HCUP Nationwide Impatient Sample (NIS). Healthcare Cost and Utilization Project (HCUP) 2005. Agency for Healthcare Research and Quality, Rockville, MD: http://www.hcup-us.ahrq.gov/nisoverview.jsp.

407 Low/best/high estimates 700,000/1.4 million/2.091 million hospitalizations and $14.8/$29.6/$44.2 billion total medical costs from hospitalization.

408 U.S. Centers for Disease Control and Prevention (2006). FluWorkLoss 1.0 [computer file]. At http://www.cdc.gov/flu/pandemic-resources/tools/fluworkloss.htm (retrieved 5 April 2013).

409 Dhankhar et al (2006, September 29). FluWorkLoss: Software to estimate the impact of an influenza pandemic on work day loss [manual]. U.S. Centers for Disease Control and Prevention. At http://www.cdc.gov/flu/pandemic-resources/tools/downloads/fluworkloss_manual_102306.pdf (retrieved 5 April 2013).

410 Total workdays lost/illness = 250.0×CFR + 1.192.

411 Using relationship of 240 workdays/work-year (RAPID II standard value).

412 Annual output per worker is taken from IMPLAN (2011) values for the average annual output per employee across all economic sectors (RAPID II standard value).

413 The SNRA and RAPID models use this figure to maintain comparability with the economic methodology of the 2008 Bioterrorism Risk Assessment (BTRA 2008) from which they derive. $42,500 represents the midpoint (the expected value of a linear uniform distribution over the interval) of the $35,000–$50,000 median household income band in 2011. U.S. Department of Homeland Security (2008). Bioterrorism Risk Assessment: pp. E2.7–34. (BTRA assessment in its entirety is SECRET; Referenced appendix is UNCLASSIFIED//FOR OFFICIAL USE ONLY; Extracted information is UNCLASSIFIED.)

Table 13: SNRA 2015 Direct Economic Loss Calculations

Parameters	Low	Best	High
Fatalities	77,000	154,000	230,000
Illnesses	61,400,000	76,800,000	107,000,000
Factors	**Low**	**Best**	**High**
Decontamination, disposal, and physical destruction (DDP)	$0	$0	$0
Business interruption: Cost of workdays lost	$53,364,548,000	$78,270,471,000	$125,769,360,000
Medical: Cost of hospitalizations	$14,808,081,000	$29,616,162,000	$44,231,930,000
One year lost spending per fatality	$3,272,500,000	$6,545,000,000	$9,775,000,000
	Low	**Best**	**High**
Total Direct Economic Loss	$71,445,129,000	$114,431,633,000	$179,776,290,000

Comparisons to other estimates of economic impact: The economic loss model used by the 2011 SNRA included medical costs and a partial valuation of lost productivity due to time off work. Additionally, approximately 83% of the economic impacts from the 2011 model were associated with the value of lost productivity due to premature death, a component not included in the SNRA 2015 direct economic loss metric. However, when adjusted for the updated fatality/illness inputs of the 2015 SNRA, the 2011 model has a best estimate of $116 billion, with a range of $53 to $157 billion. Although calculated by different loss estimation methods, these estimates closely coincide with those of the 2015 SNRA ($114 billion, with a range of $71 to $180 billion).

In comparison to the 1957-scale scenario estimates of the 2015 SNRA, a 2006 study of the potential economic impact of an influenza pandemic gave an estimate of impact for a "mild" pandemic of 0.8% of global GDP, equivalent in the U.S. to approximately $117.6 billion.[414] Although calculated with a different methodology, this estimate is also within the range given in the "Data Summary" for the 1957 scenario.

A Congressional Budget Office (CBO)[415] study of a 1918-type outbreak scenario, assuming 2 million deaths, estimated that such a pandemic would cause the U.S. GDP ($14.7 trillion) to decrease by 4.25% - equivalent to $625 billion. This is above the range included in the Table, but it represents a comparatively less likely worst case scenario. The CBO's "mild" pandemic scenario, equivalent to the 1968 and 1957 pandemics, assumed 100,000 might die, and cause an impact of about 1% of GDP ($147 billion). A detailed Canadian study[416] estimated that a 1918-

[414] McKibinnin WJ and Sidorenko AA. Global macroeconomic consequences of pandemic influenza. Lowry Institute Analyses paper. Lowy Institute for International Policy. Feb. 2006.

[415] Congressional Budget Office (2006, July: updated/corrected from December 2005). A potential influenza pandemic: an update on possible macroeconomic effects and policy issues. At http://www.cbo.gov/publication/17785 (accessed April 2013).

[416] James S and Sargent T. The economic impact of an influenza pandemic. Economic Analysis and Forecasting Division, Department of Finance – Canada. (unpublished paper) May 2006.

type pandemic would reduce the Canadian economy by a maximum of 1.1% GDP—equivalent in the U.S. to US $161.7 billion.

Social Displacement

Social displacement was assumed to be zero for the Human Pandemic Outbreak national-level event.[417]

Note that hospitalization is not counted as social displacement for the purposes of the SNRA, since it would result in double counting with illnesses. Social distancing, quarantine, large-scale telework, and children and family staying home or college students returning home as a result of school closures are also not counted as social displacement, because they result in more people staying home rather than leaving home.

Psychological Distress

Psychological consequences for the SNRA focus on significant distress and prolonged distress, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event.[418] The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs. A multiplicative factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.

- The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + \frac{1}{2}\ D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement).
- In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement.
- The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long-term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: Human Pandemic Outbreak was given a C_{EF} of 1.0.
- Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

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[417] For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. This measure does not capture the significant differences between temporary evacuations and permanent displacement due to property destruction. However, this distinction is less relevant for events with zero displacement on either measure.

[418] See Appendix G of the SNRA draft Unclassified Documentation of Findings for references and additional discussion of the SNRA Psychological Distress metric.

The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.[419]

Environmental Impact

In 2011, the United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event in the first iteration of the SNRA. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as "the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources."
- The experts provided a best estimate of 'Moderate' for a pandemic scenario with severe social impacts and a second best estimate of 'Low' for a less severe pandemic scenario.
- The 2015 SNRA reports the 'Low' environmental impact judgment as the best estimate for the Pandemic event because the social impacts of the best estimate scenario, as defined by the best estimates on other consequence axes, correspond to the less severe pandemic scenario. The 2015 SNRA reports 'Moderate' as the second best judgment, because it describes the environmental impacts of a more severe pandemic scenario.
- Experts identified the consequences of a larger pandemic scenario as "Moderate" due to the potential for resources to be pulled from environmental protection activities, thereby allowing impacts to cascade and cause environmental consequences. If the pandemic were large enough, environmental protection could be deemphasized in order to divert resources towards higher priority response efforts, and consequences could be increased as service providers are afflicted with the pandemic (e.g., waste disposal efforts could be halted if workers require treatment).

Potential Mitigating Factors

Numerous medical and non-medical measures for mitigating the human consequences of an influenza pandemic, including social distancing, school closing, antiviral medications, antibiotics for secondary bacterial infections, and targeted vaccines, are known and would be expected to be deployed, at least in part. These measures' efficacy for those individuals who directly receive them is clearly indicated by the evidence in the literature. However, there is no consensus in the literature on what proportional or percentage reductions in total national fatalities and illnesses could be expected under the constraints and conditions of an actual pandemic.[420] Estimates of

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[419] SNRA 2011 draft Unclassified Documentation of Findings, p. 33.

[420] E.g. not everyone who is sick can afford going to the doctor or antiviral prescriptions; research and production times needed to mass produce vaccines targeted to the pandemic virus may delay their mass availability until after the pandemic's peak.

percentage reductions (mitigation effectiveness) in the literature range from 1.6%[421] to 96%[422] for fatalities and 6%[423] to 99%[424] for illnesses respectively.

The appropriate factor for converting the currently unmitigated consequence numbers to mitigated equivalents is not known. However, recent CDC studies of the 2009–10 H1N1 pandemic suggest that any adjustment for mitigation under real-world societal and economic conditions would not substantially shift the numbers reported here.[425]

Additional Relevant Information

The probability of impact due to a pandemic has two parts: the probability of a pandemic (any type) occurring, and then, once it has occurred, the severity of impact (essentially, the conditional probability that the "mild," "middle," or "worst case" scenario occurs).

- *Probability of a pandemic occurring:* From 1729 through 2009 there have been 8–12 influenza pandemics (including pandemics subsequently deduced to have been caused by influenza virus).[426] They have thus historically occurred with a frequency of once every 10 to 60 years.
- *Probability of severity* (probability of "mild," "middle," or "worst case" occurring once pandemic has started): The 1918 pandemic appears to have caused an exceptionally high case fatality rate. Such a pandemic could, in theory, reoccur but historically has only occurred once in approximately 8–12 pandemics. This historical frequency gives an approximately 10% chance that the next pandemic will be a 1918-type pandemic. Similarly, a "mild" pandemic, such as the 2009 pandemic, has only occurred once in 8–12 pandemics since 1700 and also has an approximate 10% probability of occurring. If one includes both the 1957 and 1968 pandemics as examples of "mild" impact pandemics, then the probability that such a scenario will occur rises to 30%. The probability of a "middle" scenario occurring is the residual after accounting for the probabilities of both "worst case" and "mild" scenarios (range for a "middle": 50%–80%).

Visualizing the time series of influenza pandemics, 1700–present

Quantitative study of mortality from historical influenza pandemics has focused almost entirely on the twentieth century. However, sufficient data on prior events exist for researchers to depict time series of historical pandemics over longer periods for mortality in selected populations.

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[421] CDC (2011, May 10). Ten Great Public Health Achievements—United States, 2001–2010. *Mortality and Morbidity Weekly Report (MMWR)* 60(19) 619-623, at http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6019a5.htm?s_cid=mm6019a5_w; CDC (2011, September 30), Notice to Readers: Revised Estimates of the Public Health Impact of 2009 Pandemic Influenza. *MMWR* 60(38) 1321, at http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6038a7.htm (accessed June 2013).

[422] Proportion of attack and mortality rates in the anticipated scenario to rates in the Baseline scenario, figure 3-1, p. 17. National Infrastructure Simulation and Analysis Center (NISAC) (2007, October 10). National Population, Economic, and Infrastructure Impacts of Pandemic Influenza with Strategic Recommendations. Office of Infrastructure Protection, U.S. Department of Homeland Security.

[423] CDC (2011), Ten Great Public Health Achievements, *op cit;* CDC (2011), Revised Estimates, *op cit*.

[424] NISAC (2007), *op cit*.

[425] CDC (2011, May 10, September 30) *op cit.*; Atkins et al (2011, September). Estimating effect of antiviral drug use during pandemic (H1N1) 2009 outbreak, United States. *Emerging Infectious Diseases* 17(9) 1591–1598; at http://wwwnc.cdc.gov/eid/article/17/9/11-0295_article.htm (accessed June 2013).

[426] Potter (2001), Taubenberger et al (2009), Patterson (1986), Dowdle (1999), *op. cit*. Different authors count different events as pandemic or non-pandemic events. However, but most events on different authors' lists overlap, as does the 8 to 12 total number with different authors' pandemic event counts when the 2009 H1N1 pandemic is included.

While differences in base population,[427] health, counting measures, and population age structures prevent precise comparisons, such estimates can be nonetheless arrayed together to get a rough picture of the historical variability of the influenza virus in terms of its effects on the human population (Figure 11).[428] The exceptional scale of the 1918–20 pandemic compared with other pandemics is immediately apparent.

[427] 1729–1890 estimates are for England and Wales; 1918–present are for the U.S. (sources below).

[428] The eight pandemics of natural origin are the list of Potter (2001), *op cit.* Note that these eight pandemics will differ from the pandemic lists of many of the sources from which the chart data come, especially those of older sources.

Note that uncertainties reported in the data sources below are suppressed in the Figure for clarity of presentation.

Pre-1918: Estimates for the population of England and Wales, Eichel, Otto R. (1922, December). The long-time cycles of pandemic influenza. *Journal of the American Statistical Association* 18(140) 446-454; available via JSTOR Early Journals Free Content at http://www.jstor.org/stable/2276917 (accessed June 2013). 1729–33 (90/100,000) is the sum of Eichel's lines for 1729 (30–45) and 1733 (45–60); 1781-82, for 1782 (15); 1832–33, for 1833 (45–60); 1889–90 (74/100,000), for 1889 (16) and 1890 (58). The midpoints of the dashed-line uncertainty ranges reported by Eichel were used as 'best estimates' (e.g. 37.5 + 52.5 = 90; 15; 52.5). Extrapolated to today's U.S. population without additional adjustments for factors increasing or decreasing fatality rates compared with the past, these pandemics would have equivalent fatalities: 1729-33, 276,300; 1781–82, 46,050; 1832–33, 161,200; 1889–90, 522,000.

1918-20, 1957-58, 1968-69: Historical fatalities, National Institutes of Health, 2011. *Timeline of human flu pandemics* [electronic resource]. National Institute of Allergy and Infectious Diseases, National Institutes of Health, January 14, 2011; at http://www.niaid.nih.gov/topics/flu/research/pandemic/pages/timelinehumanpandemics.aspx (accessed March 2013). U.S. population, for population fatality rate: United States population including Armed Forces abroad, Table I: National Center for Health Statistics (1999). *Vital Statistics of the United States: 1999 Mortality Technical Appendix*. At http://www.cdc.gov/nchs/products/vsus/ta.htm (accessed April 2013). Extrapolated to today's U.S. population without additional adjustments for factors increasing or decreasing fatality rates compared with the past, these pandemics would have equivalent fatalities: 1918, 2.0 million; 1957, 125,900; 1968, 52,200.

2009-10: Fatalities (12,470 total), best estimate, Centers for Disease Control (2010, May 4), Updated CDC estimates of 2009 H1N1 influenza cases, hospitalizations and deaths in the United States, April 2009–April 10, 2010 [electronic resource]: at http://www.cdc.gov/h1n1flu/pdf/CDC_2009_H1N1_Est_PDF_May_4_10_fulltext.pdf (accessed April 2013); Shresta et al (1999, January 1), Estimating the burden of 2009 pandemic influenza (H1N1) in the United States (April 2009–April 2010), *Clinical Infectious Diseases* 52(S1) S75-82; at http://cid.oxfordjournals.org/content/52/suppl_1/S75.full.pdf+html (retrieved April 2014).

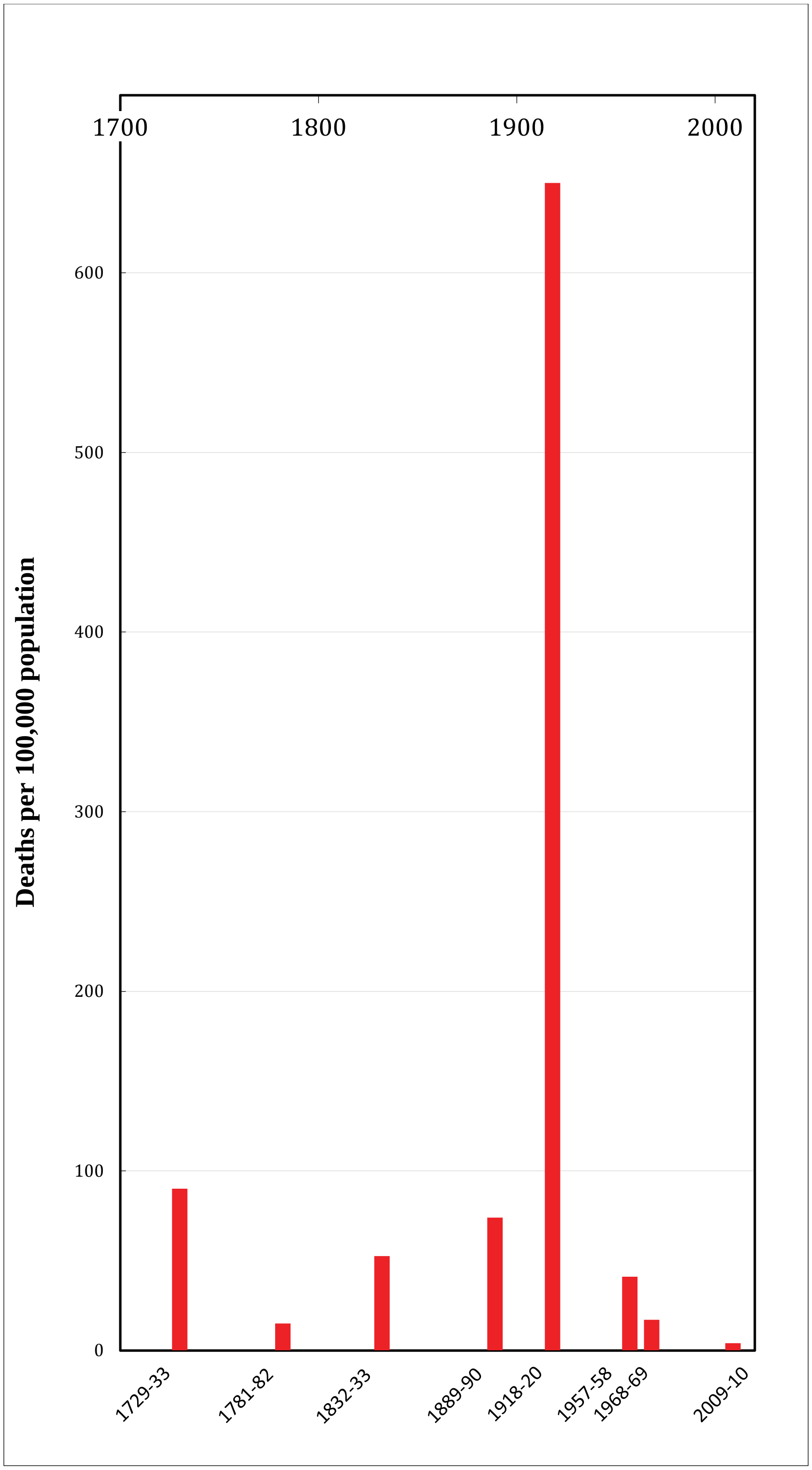

Figure 11: Influenza Pandemics 1700 - Present

Influenza pandemics: Historical range of impacts

Each of the population attack rate (25%) and the case fatality rate (0.2%) selected as the basis of the best estimate pandemic scenario in the SNRA represents the geometric midpoint of the corresponding range (attack rate 20%[429]–31.6%[430], CFR 0.02%[431]–2.0%[432]) observed in the influenza pandemics of the past century in the U.S. This suggests a logarithmic distribution on each axis of impact.

To represent a broader range of pandemic impacts beyond the comparatively narrow range of the SNRA Pandemic scenario and to permit comparisons and aggregations with other SNRA events, the uncertainty in each of these two parameters was represented by a log-uniform distribution over the historically observed intervals presented above. As fatalities represent the product of these two parameters (Table 14), the distribution of fatalities is given by the product of these two distributions (Table 15).[433]

Table 14: Fatalities,[434] Distribution Construction[435]

	Population Attack Rate				
CFR	**20.0%**	**22.4%**	**25.1%**	**28.2%**	**31.6%**
0.020%	12,280	13,754	15,411	17,315	19,402
0.036%	22,104	24,756	27,741	31,167	34,924
0.063%	38,682	43,324	48,546	54,542	61,118
0.11%	67,540	75,645	84,763	95,231	106,713
0.20%	122,800	137,536	154,114	173,148	194,024
0.36%	221,040	247,565	277,405	311,666	349,243
0.63%	386,820	433,238	485,459	545,416	611,176
1.12%	687,680	770,202	863,038	969,629	1,086,534
2.00%	1,228,000	1,375,360	1,541,140	1,731,480	1,940,240

429 The 2009 pandemic (19.9%), Reed et al (2013).

430 1918 pandemic, U.S., best estimate historical fatalities of 675,000 (NIH (2011), *op. cit.*) divided by case fatality rate of 2.04% (Reed et al (2013)), 33,088,000 illnesses; divided by 1918 U.S. population of 104,550,000 (Vital Statistics of the United States (1999), *op. cit.*).

431 2009 pandemic, U.S., 12,219 best estimate fatalities (CDC (2010)) divided by 61,093,000 estimated illnesses from 19.9% population attack rate (Reed et al (2013)).

432 1918 pandemic, U.S., 2.04% CFR (Reed et al (2013)).

433 Two log-uniform distributions, U(20%, 31.6%) × U(0.020%, 2.0%). Note that distributions such as these are not intended to represent known likelihoods of the occurrence of incidents of particular magnitudes: they are constructed to represent our uncertainty in the likely distribution of magnitudes for a hazard. In this case, since we do not know much about the true distribution other than the extremes which have been observed and our observation that more events have occurred between these extremes than at them, uniform distributions are the most accurate representation of our state of knowledge. The observation that events that have occurred between these extremes have tended to cluster nearer the lower end, and the span of orders of magnitude for CFR indicate that log-uniform distributions are a more appropriate model than linear uniform distributions.

434 Product times 2009 U.S. population of 307 million (for consistency with primary estimates).

435 Discretized (constructed in steps), 5 points for attack rate and nine points for CFR (an odd number of each was selected to ensure the central value [the SNRA best estimate] would be represented as a point in the set). Because the endpoints of the nominal ranges are included, the actual ranges are slightly broader than these (U(18.9%, 33.5%) × U(0.015%, 2.7%)).

Table 15: Pandemic, Modeled Distribution[436]

CFR	Attack rate	Fatalities	Illnesses	Direct economic loss (2011$ billion)	Probability of exceedance (fatalities)
20.0%	0.020%	12,300	61,400,000	54.3	0.989
22.4%	0.020%	13,800	68,800,000	60.9	0.967
25.1%	0.020%	15,400	77,200,000	68.3	0.944
28.2%	0.020%	17,300	86,500,000	76.6	0.922
31.6%	0.020%	19,400	97,000,000	85.9	0.900
20.0%	0.036%	21,800	61,400,000	56.8	0.878
22.4%	0.036%	24,500	68,800,000	63.7	0.856
25.1%	0.036%	27,400	77,200,000	71.4	0.833
28.2%	0.036%	30,800	86,500,000	80.0	0.811
31.6%	0.036%	34,500	97,000,000	89.7	0.789
20.0%	0.06%	38,800	61,400,000	62.4	0.767
22.4%	0.06%	43,500	68,800,000	70.0	0.744
25.1%	0.06%	48,800	77,200,000	78.4	0.722
28.2%	0.06%	54,700	86,500,000	87.9	0.700
31.6%	0.06%	61,400	97,000,000	98.6	0.678
20.0%	0.11%	69,100	61,400,000	72.4	0.656
22.4%	0.11%	77,400	68,800,000	81.2	0.633
25.1%	0.11%	86,800	77,200,000	91.0	0.611
28.2%	0.11%	97,300	86,500,000	102	0.589
31.6%	0.11%	109,000	97,000,000	114	0.567
20.0%	0.20%	123,000	61,400,000	89.6	0.544
22.4%	0.20%	138,000	68,800,000	100	0.522
25.1%	0.20%	154,000	77,200,000	113	0.500
28.2%	0.20%	173,000	86,500,000	126	0.478
31.6%	0.20%	194,000	97,000,000	142	0.456
20.0%	0.36%	218,000	61,400,000	119	0.433
22.4%	0.36%	245,000	68,800,000	134	0.411
25.1%	0.36%	274,000	77,200,000	150	0.389
28.2%	0.36%	308,000	86,500,000	168	0.367
31.6%	0.36%	345,000	97,000,000	188	0.344
20.0%	0.63%	388,000	61,400,000	170	0.322
22.4%	0.63%	435,000	68,800,000	190	0.300
25.1%	0.63%	488,000	77,200,000	213	0.278
28.2%	0.63%	547,000	86,500,000	239	0.256
31.6%	0.63%	614,000	97,000,000	268	0.233
20.0%	1.12%	691,000	61,400,000	257	0.211
22.4%	1.12%	774,000	68,800,000	288	0.189
25.1%	1.12%	868,000	77,200,000	323	0.167
28.2%	1.12%	973,000	86,500,000	362	0.144
31.6%	1.12%	1,090,000	97,000,000	406	0.122
20.0%	2.00%	1,230,000	61,400,000	408	0.100
22.4%	2.00%	1,380,000	68,800,000	457	0.078
25.1%	2.00%	1,540,000	77,200,000	513	0.056
28.2%	2.00%	1,730,000	86,500,000	575	0.033
31.6%	2.00%	1,940,000	97,000,000	644	0.011

436 Median (the SNRA best estimate) and approximate 5^{th} and 95^{th} percentile intervals are highlighted.

This model was constructed so that the uncertainties in our knowledge of the conditional distribution of pandemic impacts can be represented in calculations comparing or combining human pandemic risk with other risks in the SNRA, as opposed to the use of point estimates or a narrowly defined scenario. However, a surprising and somewhat disturbing outcome is how closely this model parallels the actual historical variability of the influenza virus, in terms of fatalities projected to the U.S. population of today, over its known 300-year history (Figure 12).

The historical data (projected to current U.S. population) of Figure 11 is depicted in Figure 12 as an exceedance curve in semi-logarithmic space. When viewed on a logarithmic scale, the 1918 pandemic appears less exceptional compared with the other historical influenza pandemics of natural origin of the past three centuries.[437]

While multiple factors affecting both likelihood and impacts substantially differ between the present day and the past, this comparative view can be useful for understanding the inherent variability of the influenza virus.

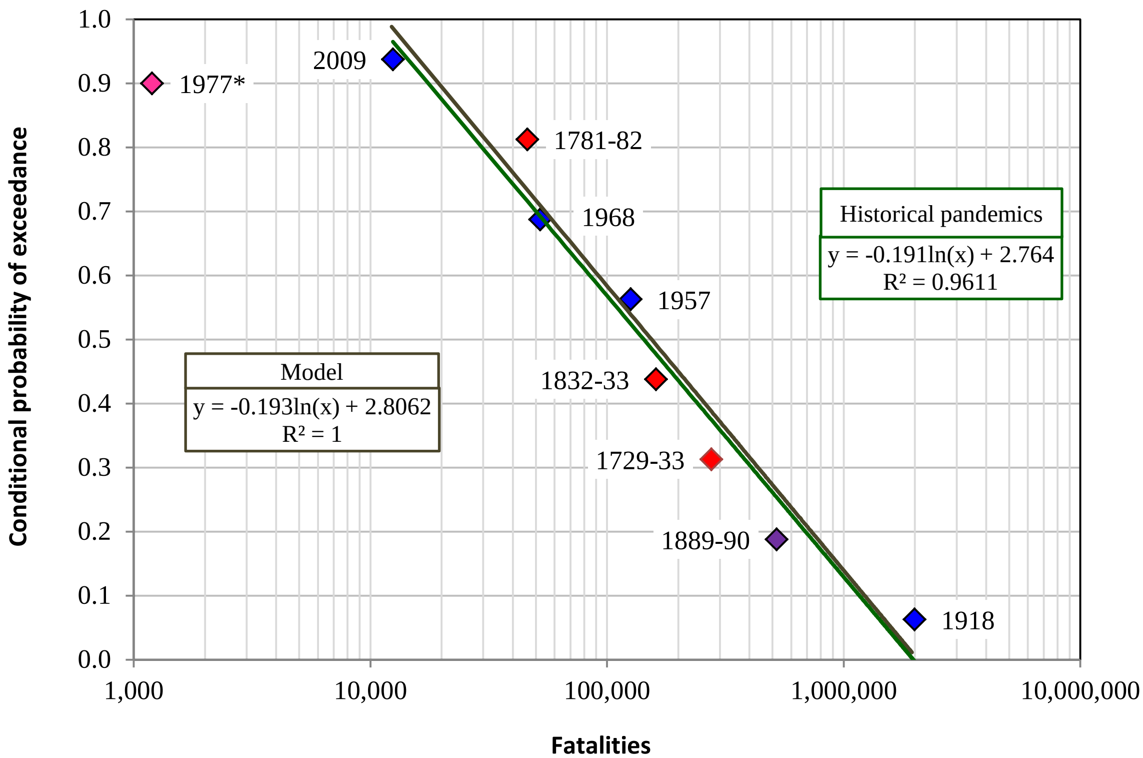

Figure 12: Fatalities, Historical and Modeled[438]

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[437] The logarithmic form of the best fit line, for both the theoretical and the historical distribution, is reflective of a single log-uniform distribution rather than a product. This is because the range for CFR (a power of 100 from end to end) is so much larger than the range of attack rates (a power of 2) that it effectively determines the shape of the product distribution.

[438] Historical incidents are identified by color to indicate data source or type. Blue, U.S. data 1918-present. Red, population fatality rates for England and Wales from Eichel (1922) op. cit., original source the English Bills of Mortality 1729-1833. Purple, 1889-90 pandemic, population fatality rates for U.S. and European cities, predominantly European, applied to U.S. population: mean population fatality rate of 170/100,000 reported for major European and U.S. cities, Valleron et al (2010, May 11), Transmissibility and geographic spread of the 1889 influenza pandemic, Proceedings of the National Academy of Sciences U.S.A. 107(19) 8778-81, including Supporting Information files: at http://www.pnas.org/content/107/19/8778.long (accessed April 2013); 1890 U.S. population, U.S. Census Office (1896), Report on Vital and

Social Statistics of the United States at the Eleventh Census: 1890, Part 1 – Analysis and Rate Tables, U.S. Department of the Interior: at http://www.cdc.gov/nchs/products/vsus/vsus_1890_1938.htm (accessed June 2013). The pink data point with astrix represents the accidental pandemic of 1977-78: Fatalities (860 total) in 1977-78 U.S. influenza season attributed to the 'frozen virus' A/USSR/90/77 (H1N1): Table 4, 1977 H1 excess fatalities (both age groups): Thompson et al (2009, February). Estimates of US influenza-associated deaths made using four different methods. Influenza and Other Respiratory Viruses 3(1) 37-49; at http://onlinelibrary.wiley.com/doi/10.1111/j.1750-2659.2009.00073.x/pdf (accessed April 2013). This is the only reference known to the SNRA project team which separates out fatalities attributed to each of the influenza virus strains circulating in 1977-78 (some other references appear to but in fact double count H1 and H2 fatalities). The returned virus primarily affected persons born after 1950, so mortality from H1N1 was low compared with the more lethal seasonal strain H3N2 (this pattern continued until a new H1N1 strain, directly descended from the 1918 virus, entered the human population in the 2009 pandemic).

For origin of A/1977/USSR, Chakraverty et al (1982, August), The return of the historic influenza A H1N1 virus and its impact on the population of the United Kingdom, Journal of Hygiene (London/Cambridge) 89(1) 89-100; Kendal et al, 1978, Antigenic similarity of influenza A (H1N1) viruses from epidemics in 1977-1978 to "Scandinavian" strains isolated in epidemics of 1950-1951, Virology 89 632-636; Kilbourne, Edwin D. (2006, January), Influenza pandemics of the 20th century, Emerging Infectious Diseases 12(1) 9-14; Nelson et al (2008), Multiple reassortment events in the evolutionary history of H1N1 influenza A virus since 1918, PLoS Pathogens 4(2) e1000012; Taubenberger et al (2006, January), 1918 influenza: the mother of all pandemics, Emerging Infectious Diseases 12(1) 15-22; Worobey, Michael (2008, April), Phylogenetic evidence against evolutionary stasis and natural abiotic reservoirs of influenza A virus, Journal of Virology 82(7) 3769-3774.

Combustible/Flammable Cargo Accident (Rail)

An accident involving fire or an explosion of combustible or flammable substances transported by rail occurs within the U.S., resulting in one fatality or greater.

Data Summary

Category	Description	Metric	Low	Best	High
Health and Safety	Fatalities	Number of Fatalities[439]	1	1	1
	Injuries and Illnesses	Number of Injuries or Illnesses[440]	0	20	52
Economic	Direct Economic Loss	U.S. Dollars[441]	$43,000	$900,000	$2.9 million
	Indirect Economic Loss	U.S. Dollars	See Discussion		
Social	Social Displacement	People Displaced from Home ≥ 2 Days	0	0	0
Psychological	Psychological Distress	Qualitative Bins	5	25	57
Environmental	Environmental Impact	Qualitative Bins	N/A		
LIKELIHOOD	Frequency of Events	Number per Year[442]	0.039	0.11	0.22

Note

The results for this analysis indicate an extremely low risk associated with combustible/ flammable cargoes transported by rail. However, this conclusion is tied to the assumptions which determine the scope of the event, the selection and interpretation of data, and the choice of results to be reported; and these limitations must be understood before using these results. The scoping of this hazard to only incidents resulting in fatalities may have resulted in an assessment that does not adequately address factors that affect risk. Additionally, the use of historic data depends upon the assumption that the future will resemble the past: with respect to combustible/ flammable rail cargo accidents, recent changes in the volume of cargo suggest that the use of historic data may not adequately describe current risk. Furthermore, the SNRA project team believes that the limitation of the current SNRA displacement metric to displacements of 48 hours or more may exclude information important to the characterization of this hazard.

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[439] Low, average, and high fatalities from the set of 1980-2014 U.S. historical combustible/flammable rail accidents resulting in one or more fatalities in Table 16.

[440] Low, average, and high from the set of 1980-2014 U.S. historical combustible/flammable rail accidents resulting in one or more fatalities in Table 16.

[441] Low, average, and high direct economic estimates from the set of 1980-2014 U.S. historical combustible/flammable rail accidents resulting in one or more fatalities in Table 16.

[442] Low, best, and high frequencies represent the 5th, mean, and 95th percentile of the uncertainty distribution for frequency, based upon four observations in 35 years and the assumption of a random (Poisson) process.

The SNRA project team believes that the effects of these recognized limitations (which are shared by other technological/accidental hazards in the SNRA) upon the final reported estimates may be significant. To better understand the risk from this hazard, the SNRA project team recommends further analysis that includes all factors included in the PHMSA data.

Overview

Recent rail accidents involving combustible/flammable cargoes such as Bakken crude oil have raised concerns about this hazard among many people in the United States.[443] Increases in the volume of Bakken crude oil transported by rail coupled with high profile accidents like the Lac-Mégantic, Quebec, Canada accident, have been major factors in driving this concern and risk perception.[444] Although the Lac-Mégantic accident falls outside of the scope of the SNRA because it occurred in Canada, the images associated with this accident still affect perception in the U.S. The Lac-Mégantic accident, which resulted in 47 fatalities, represents an actual worst-case scenario involving combustible/flammable rail cargoes.[445]

Five other dramatic accidents involving the rail transport of combustible substances occurred in 2014: although none resulted in fatalities, they further bolstered perceptions that rail shipments of combustible/flammable materials pose a risk of real risk.

However, as with other risks, the perception of risk often differs from the actual probability and likely impacts of risk.[446] For example, the Pipeline and Hazardous Materials Safety Administration (PHMSA) data from 1980 through 2014 that was leveraged for the 2015 SNRA contains only four accidents in the United States involving at least one fatality. Moreover, none of those incidents caused more than one fatality, or resulted in impacts on the other SNRA measures of consequence comparable to those of many other accidental and natural hazards studied in the SNRA.[447] Consequently, the relative risk of a fatal accident involving combustible/flammable cargoes may not necessarily match the perception of risk.

Prior to using results from the SNRA to inform a decision with significant impacts in the real world, it is important for end users to review the underlying data and fully understand its limitations.

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[443] Pipeline & Gas Journal. (2014). Rail transportation of oil: A growing congressional safety concern [Online document]. *Pipeline & Gas Journal, 241.* Retrieved from http://pipelineandgasjournal.com/rail-transportation-oil-growing-congressional-safety-concern; Nader: Bakken oil-related railroad accidents are "national emergency" [Web page]. Retrieved from http://kfgo.com/news/articles/2015/feb/18/nader-bakken-oil-related-railroad-accidents-are-national-emergency/.

[444] The train accident in Lac-Mégantic, Quebec, Canada resulted in 47 fatalities, and the destruction of 40 buildings and 53 vehicles. Transportation Safety Board of Canada. (2013). *Railway investigation report R13D0054: Runaway and main-track derailment*. Retrieved from http://www.tsb.gc.ca/eng/rapports-reports/rail/2013/r13d0054/r13d0054.pdf

[445] Ibid.

[446] Regarding perception, Pipeline & Gas Journal (2014), Nader (2015), *op. cit.* (footnote 443). As noted by the U.S. Department of Transportation, accident risk per shipment is extremely low: nearly 1 million shipments of HAZMAT shipments including Bakken crude oil occur in the U.S. every day without incident, indicating an extremely low probability of a serious accident resulting in a fatality, injury, environmental impact, or economic impact occurring for a shipment. Nader, R. (2015, February 18). US Department of Transportation. (2014, February 2). PHMSA's ongoing Bakken investigation shows crude oil lacking proper testing, classification: Pipeline and Hazardous Material Safety Administration issues proposed civil penalties to three companies [Web page]. Retrieved from http://www.dot.gov/briefing-room/phmsa%E2%80%99s-ongoing-bakken-investigation-shows-crude-oil-lacking-proper-testing

[447] 2012 – 2014 data was collected from the US Department of Transportation Pipeline and Hazardous Materials Safety Administration (PHMSA) website (https://hazmatonline.phmsa.dot.gov/IncidentReportsSearch/) using the Incidents Reports Database Search function. 1980 – 2011 data was archival data collected by RMA for the original SNRA.

Event Background

The recent advent of the shale oil boom in the United States and accidents involving rail cargoes of Bakken crude oil have raised concern over the hazards of such cargoes.[448] In 2013, over 462,000 barrels of oil where shipped by rail out of North Dakota, one of several states with crude oil production.[449] In the U.S., rail companies transported approximately 435,560 carloads of crude oil in 2013. From 2012 to 2014 (the last full year for data), four accidents occurred in the U.S. involving rail cargoes of crude oil.[450] However, accidents involving crude oil cargos from 1980 – 2014 represent approximately 0.09 percent of all incidents.[451] Alcohol N.O.S.[452] cargoes represented 0.8 percent of all incidents or 977 incidents out of over 13,000.[453] Additionally, alcohol N.O.S. and crude oil represent two of the approximately 180 different flammable or combustible commodities represented in the set of incidents reported to PHMSA in the 1980-2014 period included in the SNRA analysis.[454]

Aside from the type of cargo, the PHMSA data provided information on what failed (e.g. valve failed) that resulted in the release of the cargo. Three of the four events analyzed involved the failure of the container.[455] Three of the failures resulted from accident damage from a collision.[456]

Assumptions

All data used to develop the risk analysis came from the publically available PHMSA database. The PHMSA database includes incident information from several modes of transportation including aviation and rail. The scope of this report includes rail incidents involving cargoes with hazardous class noun names that include combustible, explosive, or flammable.[457] Cargoes that fall within the scope previously described include crude oil (e.g., Bakken crude), xylene, ethanol, etc.[458] In addition to the restrictions to rail and to specific cargoes, the scope of the SNRA Combustible/Flammable Cargo Accident (Rail) was limited to incidents involving at least one fatality related to the cargo.

Scope

The following are the parameters for data inclusion for the analysis:

1. Data set only includes incidents occurring within the U.S., U.S. territories, and possessions.[459]

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[448] Frittelli, J., Andrews, A., Parfomak, P. W., Pirog, R., Ramseur, J. L., & Ratner, M. (2014). U.S. rail transportation of crude oil: Background and issues for congress [Online document]. Retrieved from www.crs.gov

[449] Pumphrey, D., Hyland, L., & Melton, M. (2014). *Safety of crude oil by rail* [Online document]. Retrieved from http://csis.org/files/publication/140306_Pumphrey_SafetyCrudeOilRail_Web.pdf

[450] Ibid.

[451] PHMSA data for years 2012 – 2014 (https://hazmatonline.phmsa.dot.gov/IncidentReportsSearch/) expanded data set includes incidents without a fatality

[452] Alcohol Not Otherwise Specified

[453] PHMSA data for years 2012 – 2014 (https://hazmatonline.phmsa.dot.gov/IncidentReportsSearch/) expanded data set includes incidents without a fatality

[454] PHMSA data for years 2012 – 2014 (https://hazmatonline.phmsa.dot.gov/IncidentReportsSearch/) expanded data set includes incidents without a fatality

[455] PHMSA data for years 2012 – 2014 (https://hazmatonline.phmsa.dot.gov/IncidentReportsSearch/) as meets analytic scope.

[456] Ibid.

[457] Hazard class codes 1.1, 1.2, 1.4, all subclasses; 1.5, 1.7, 1.8, 1.9, 2, 2.1, 3, 4.1, 4.2, 4.4.

[458] PHMSA data for years 2012 – 2014 (https://hazmatonline.phmsa.dot.gov/IncidentReportsSearch/)

[459] Lands specified in the Homeland Security Act of 2002 as amended and the Stafford Act.

2. Incidents must include at least one fatality.
3. Direct economic estimates were converted to 2011 dollars to allow for comparison with the existing SNRA 2011 data set.
4. Displacement data must be from incidents with displacements of 48-hours or longer.
5. Incidents only involve rail as a means of transportation.
6. The analysis included incidents that use combustible, explosive, or flammable in the hazard noun name.[460]
7. To ensure data compatibility, to include but not limited to data collection methods and data collection standards, only PHMSA data is used.
8. Incidents only cover full years of data from 1980 to 2014.

Specific Assumptions

The following are assumptions used for this analysis:

1. The scope of the SNRA 2015 Combustible/Flammable Cargo Accident (Rail) event allows for a meaningful representation of the risk to the Nation from this hazard.
2. Factors not included in the analysis do not produce statistically significant affects that could change the analysis.
3. The SNRA metric for psychological distress is a valid and meaningful measure for comparison among hazards, within the order of magnitude precision and generic limitations of the SNRA.

Data Cleaning

Data cleaning involved two specific measures. First, data cleaning involved the elimination of multiple lines of data that did not contain unique quantitative data. Second, data cleaning also included removing records that did not include a cargo with noun names falling within the scope of the analysis.

Frequency

From 1980 to 2014, a span of 35-years, only four incidents occurred that resulted in at least one fatality (SNRA minimum threshold for inclusion of a risk) due to the cargo out of over 13,000 incidents. All four incidents involved different cargoes.

Low, best, and high annual frequency estimates represent the 5th, mean, and 95th percentile of the frequency distribution based upon an assumption of a Poisson (random and independently occurring) process and four observations in 35 years.[461] The resulting low, best, and high estimates of 0.039, 0.114, and 0.222 incidents per year for a fatal combustible/flammable cargo rail accident are relatively low in comparison with many other hazards in the SNRA, including

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[460] Hazard class codes 1.1, 1.2, 1.4, all subclasses; 1.5, 1.7, 1.8, 1.9, 2, 2.1, 3, 4.1, 4.2, 4.4.

[461] The distribution for the unknown frequency λ of the Poisson process given four observations in 35 years was represented by a gamma(4, 1/35) distribution.

chemical (toxic inhalational hazard) accidents, dam failures, and the majority of the SNRA natural hazards.

Health and Safety

The analysis of the four incidents resulted in an average of one fatality, given the occurrence of an incident resulting in any fatalities. Although the average (expected value) of the set was used as the best estimate for consistency with other hazards analyzed in the SNRA, for the Combustible/Flammable Cargo Accident (Rail) this value of one fatality was also the most likely value (mode) of the set. Injuries ranged from 0 to 52, with an average of 20.

Economic Impacts

Direct Economic Impacts

Direct economic impacts as defined in the SNRA include decontamination, disposal, and physical destruction costs including property (structure, contents, physical infrastructure and other physical property) and crop damage; one year's lost spending due to fatalities; medical costs; and business interruption directly resulting from the impacts of an event.

Direct economic impacts for the set of incidents meeting the threshold criteria of this SNRA event ranged from $42,500 to $2,886,612, with an average of $904,994, according to the measure of direct economic impact used by the SNRA.[462]

Indirect Economic Impacts[463]

Direct economic losses alone do not represent the full picture of the economic impacts to the Nation from a disaster or attack. Indirect and induced economic losses can be substantially larger than the direct economic losses that occur in the aftermath of an event.

- **Indirect economic impacts** include costs incurred by the suppliers and vendors in the associated expenditure sectors for the industries impacted by the direct costs. Indirect impacts also include positive offsets due to increased spending within sectors impacted by the direct costs.[464]
- **Induced economic impacts** include those incurred due to reduced spending by households with members employed in any of the directly or indirectly affected industries. Induced impacts can also include substitution effects or likely transfers of economic activity from one set of sectors to another set, such as avoidance of air or other travel or altered transportation mode preferences to other sectors following an attack on the commercial air transport sector.

Highly mature economic models exist for calculating estimates of indirect and induced economic losses for natural disasters, human and animal pandemics, technological accidents, terrorist attacks, and cyber events. However, there is at present no generally agreed or practical method for translating estimates produced by these disparate models into a single measure which can be

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[462] Note that the definition of direct economic impact is specific to the SNRA family of assessments, and should not be used for other purposes using different definitions without translation into the definition specific to that purpose unless the differences are insufficiently to affect a decision or communication using these estimates.

[463] The SNRA's taxonomy of indirect and induced economic impacts comes from the DHS Terrorism Risk Assessments and so is retained here for consistency across DHS assessments. However, both combined will be referred to as 'indirect economic impacts' where it is not expected to impede clarity.

[464] These may include the waste management, environmental consulting, mortuary services, and medical industries, among others.

meaningfully compared across all of the threats and hazards of the SNRA in a defensible fashion. Because such a measure would yield data of great value for multiple purposes beyond the context of the SNRA and similar assessments, it has been among the highest risk research priorities for DHS and its academic Centers of Excellence for over a decade. Should these efforts prove successful in coming years, the next iteration of the SNRA will include comparisons of total economic loss to the Nation across all of its threats and hazards.

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

For the limited data set of historical observations resulting in one or more fatalities, no incident resulted in a displacement of populations for 48-hours or longer.

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event.[465] The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs. A multiplicative factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.

- The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + ½\ D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement).
- In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement.
- The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long-term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA.
- Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

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465 See Appendix G of the SNRA draft Unclassified Documentation of Findings for references and additional discussion of the SNRA Psychological Distress metric.

The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

The Combustible/Flammable Cargo Accident (Rail) hazard event was added by the SNRA project subsequent to the 2011 iteration of the SNRA for which Event Familiarity Factors were elicited from subject matter experts. The SNRA project team assigned a *provisional* Event Familiarity Factor of 1.0 by analogy with other natural and accidental hazards in the existing SNRA, for the calculation of *provisional* psychological distress estimates. It must be stressed that this assignment has not been reviewed by the 2011 subject matter experts.

Environmental Impact

The SNRA environmental impact estimate, which was assessed in calendar year 2011 for the 23 original national-level events of the 2011 SNRA by subject matter experts from the U.S. Environmental Protection Agency (EPA), could not be assessed for the Combustible/Flammable Cargo Accident (Rail) hazard event which was added to the SNRA in calendar year 2015. A future iteration of the SNRA will assess the environmental impacts of this event on measures comparable with other SNRA threat and hazard events.

Discussion

Based upon the scope of the SNRA analysis and the specific data set selected by the SNRA project, the overall risk from a rail incident involving combustible/flammable cargoes is comparatively low on every measure of risk assessed in the SNRA, relative to other threats and hazards in the existing SNRA data set.

Combustible/flammable cargo rail accidents resulting in fatalities have historically occurred only once every ten years on average in the United States, within the 1980-2014 historical observation period of the SNRA analysis. None of the four incidents meeting this threshold resulted in mass fatalities. Additionally, none of the incidents resulted in consequences on any other impact scale, which would meet the minimum threshold of inclusion for any other existing hazard in the SNRA. Although any such assessment must be made in recognition of the significant limitations of the SNRA methodology when leveraging historical data – particularly in view of recent evidence in a neighboring country of this hazard's potential to cause catastrophic mass fatality accidents – the differences in risk across impact measures between this hazard and other SNRA hazards sharing the same data and methodological limitations and constraints are striking. Objectively, these differences are greater than the order of magnitude considered to be the minimum resolution for risk judgments in the SNRA.

Fatalities and Illnesses/Injuries

The data set of over 13,000 incidents indicates that fatalities due to the cargo as opposed to fatalities due to collisions are uncommon.[466] Additionally, injuries are relatively rare with only 149 out of over 13,000 incidents involving an injury.[467]

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[466] PHMSA data for years 2012 – 2014 (https://hazmatonline.phmsa.dot.gov/IncidentReportsSearch/) expanded to include events without a fatality.

[467] Ibid.

Psychological Distress

The methodological approach for psychological distress used in the SNRA represents a first attempt to include psychological consequences in a strategic, national-level risk assessment focused on national preparedness. While this approach is straightforward and transparent, it also has important limitations that should be considered when interpreting the psychological distress results:

- Additional analysis is required to verify and validate this approach, and the sensitivity of the results to the selection of weights in the formula should also be explored. Experts consulted about psychological consequences emphasized *extreme caution* in using the SNRA's measure of psychological distress, and the need for additional research.[468]
- Quantitative assessments of psychological factors generally involve an extreme level of complexity requiring specific controls. The methodological approach for psychological distress used in the SNRA does not include controls for factors such as preexisting psychological conditions, gender, age, culture, or other significant factors.
- The index approach currently does not include a component for translating economic losses into psychological distress. If estimates of homes destroyed and jobs lost (rather than overall direct economic losses) are obtained as consequence estimates for various national-level events, it would be possible to capture financial loss as part of the equation for psychological distress in future iterations of the SNRA.
- The current social displacement measure (counting people as displaced if they are forced to leave home for two or more days) does not differentiate between short term displacement (i.e., short term evacuation) and long term permanent displacement (i.e., the home is destroyed). Ideally, the psychological consequence index would differentiate these two types of displacement, because the long term displacement is much more impactful for "significant distress" and "prolonged distress" psychological consequences.
- The duration of distress is an important factor which is not considered in the current approach. Most people do recover over time, although individuals vary greatly in the speed with which they rebound.
- The psychometrics for the measure of psychological distress used in the SNRA is unknown.

The SNRA approach represents the first attempt to include psychological consequences in a DHS strategic, national-level risk assessment. However, the approach and inputs have not been extensively verified and validated by the broader community of academic researchers focused on psychosocial effects of disasters. As with all of the methodology and analysis introduced by the 2011 and 2015 iterations of the SNRA, the psychological distress estimates should be considered provisional pending full peer and stakeholder review.

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[468] The Department of Homeland Security and its partner organizations leveraged previously funded social and behavioral science research to better understand how to anticipate, prepare for, counteract, and mitigate the effects of terrorist acts, natural disasters, and technological accidents. Additional research is required to further explore psychosocial factors that enable resilience and affect recovery in individuals, organizations, communities, and at the societal level.

Social Displacement

The limitation of the SNRA combustible/flammable rail accident hazard event to only those incidents with a fatality and displacements of 48 or more hours resulted in no cases of social displacement by the measure used in the SNRA. Expanding the data set to include incidents without a fatality added only two incidents with displacement of 48 or more hours.[469] However, when the incident set parameters included all cases of displacement, only 139 of over 13,000 incidents included a displacement,[470] or less than 0.1 percent of all incidents.

Environmental Impact

Although the SNRA measure of environmental impact could not be assessed for the Combustible/Flammable Cargo Accident (Rail) event in the 2015 SNRA, the project team examined other measures and indicators of environmental impact. The SNRA project team used reports from the Congressional Research Service (CRS), the Center for Strategic & International Studies (CSIS), and PHMSA in the qualitative analysis.

The concentration of oil released in a relatively small area, when transported by rail, could result in a serious environmental impact.[471] Spills from rail cargoes for the analyzed data set range from 500 liquid gallons (LGA) to 31,856 LGA.[472] However, while large, these quantities pale in comparison to the Exxon Valdez spill (10.92 million LGA) and the largest pipeline spill (1.68 million LGA).[473] Although volume of spill represents only one factor that affects environmental impacts, it still provides a means for comparing effects. By this measure, the environmental impacts of rail spills in the historical data set used by the SNRA are small by comparison with historical spills from other forms of transportation.

Potential Mitigating Factors

Several factors could mitigate higher potential fatality and injury rates such as speed limits in more populous areas, which would mitigate catastrophic accidents. For example, the Lac-Mégantic accident occurred in part due to the train traveling in excess of 65 MPH into a corner rated for 35 MPH.[474] Thus, speed limits in populous areas may reduce fatality or injury risk for this hazard event.

Limitations and Other Recommendations

The limited scope of this assessment does not adequately address specific risks from specific cargoes. In addition, the lack of prior studies focused on specific cargoes limited the ability of the SNRA project team to compare different types of cargo. Different cargoes do present different specific hazards and risks. However, the SNRA analysis indicates that the transportation of any form of combustible/flammable cargo by rail presents comparatively low

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[469] PHMSA data for years 2012 – 2014 (https://hazmatonline.phmsa.dot.gov/IncidentReportsSearch/) expanded to include events without a fatality.

[470] Ibid.

[471] Congressional Research Service analysis. Frittelli, J., Andrews, A., Parfomak, P. W., Pirog, R., Ramseur, J. L., & Ratner, M. (2014). U.S. rail transportation of crude oil: Background and issues for Congress [Online document]. Retrieved from www.crs.gov

[472] PHMSA data for years 2012 – 2014 (https://hazmatonline.phmsa.dot.gov/IncidentReportsSearch/) as meets analytic scope.

[473] Pumphrey, D., Hyland, L., & Melton, M. (2014). Ibid. Energy Information Administration, U.S. Crude Oil Supply & Disposition (www.eia.gov) a barrel of oil is equal to 42 gallons.

[474] Transportation Safety Board of Canada. (2013). *Railway investigation report R13D0054: Runaway and main-track derailment*. Retrieved from http://www.tsb.gc.ca/eng/rapports-reports/rail/2013/r13d0054/r13d0054.pdf

risks on all SNRA impact measures, within the limitations of the SNRA method and the historic incident data set leveraged by the SNRA.

The SNRA does not indicate what variables may have been mitigating what may be an otherwise substantial, but unknown, risk from some very dangerous cargoes. The SNRA project team was unable, within the compressed timeframe of the 2015 SNRA, to locate sufficient data or prior analysis to indicate whether it is predominately a single variable (e.g., speed limits), or combinations of factors, that have mitigated the historic likelihood of catastrophic incidents by this modality.

Future research should include specific efforts into variable analysis to help develop an understanding of which variables mitigate hazards. Such an effort could help identify single points of failure if they exist. However, any effort to study the different variables would likely need to be a more complex analysis, using advanced statistical methods such as stepwise regression analysis.

Additional unknowns which the SNRA analysis indicated as important for further research:

- Risk factors such as speed limits, because of the potential to provide significant insight into risks associated with rail cargoes.
- Risk factors other than type of cargo, such as rail infrastructure.

As with all analysis and findings conducted for the SNRA, any further analytic efforts should include a scientific peer review process to mitigate potential bias, and ensure that the results are valid and reliable.

Table 16: PHMSA Data Set

Report Number	Date of Incident	Incident City	State	Commodity Short Name	Hazardous Class	Quantity Released (LGA)	Total Amount of Damages	Total Hazmat Fatalities	Non-Hazmat Fatalities	Total Hazmat Hosp Injuries	Total Hazmat Non-Hosp Injuries	Total Hazmat Injuries	Total Evacu-ated	Total Evacuation Hours	Major Artery Closed	Major Artery Hours Closed
I-1996030174	6/8/86	SAN ANTONIO	TX	BUTADIENES INHIBITED	FLAMMABLE GAS	31,856	0	1	0	0	0	0	0	0	No	0
X-2009070185	2/1/96	CAJON	CA	BUTYL-ACRYLATE	FLAMMABLE - COMBUSTIBLE LIQUID	500	300,000	1	0	2	50	52	50	0	No	0
I-1986070066	10/15/05	TEXARKANA	AR	PROPYLENE	FLAMMABLE GAS	22,736	26,542	1	0	20	1	21	1,012	17	Yes	34
I-2005120302	6/19/09	CHERRY VALLEY	IL	ALCOHOLS N.O.S.	FLAMMABLE - COMBUSTIBLE LIQUID	11,051	2,700,000	1	0	2	6	8	999	20	Yes	48

Transportation Systems Failure

Accidental conditions where a bridge failure occurs within the U.S., causing one fatality or greater.[475]

Data Summary

Category	Description	Metric	Low	Best	High
Health and Safety	Fatalities	Number of Fatalities[476]	1	8.6	47
	Injuries and Illnesses	Number of Injuries or Illnesses[477]	0	8.8	145
Economic	Direct Economic Loss	U.S. Dollars	$250,000[478]	$200 million[479]	$6.4 billion[480]
	Indirect Economic Loss	U.S. Dollars	See Discussion		
Social	Social Displacement	People Displaced from Home ≥ 2 Days	0[481]		
Psychological	Psychological Distress	Qualitative Bins	See Discussion		
Environmental	Environmental Impact	Qualitative Bins	N/A		
LIKELIHOOD	Frequency of Events	Number per Year[482]	0.17	0.57	2

475 The Transportation Systems Failure hazard event is intended to include within its scope the failure of tunnels and other highway and rail infrastructure causing loss of life. However, the SNRA 2015 event is effectively scoped to bridge failure because of data availability.

476 Low, average, and high fatalities from the set of U.S. historical bridge failure incidents in Table 19.

477 Low, average, and high injuries from the set of U.S. historical bridge failure incidents in Table 19.

478 DDP, generic cost estimate for state-federal bridge loss, NWS StormData preparation guide for reporting damages from natural disasters (p. B-2: Low end of $250K-$750K range selected for SNRA low estimate). National Weather Service (2007, August 17), Storm Data Preparation (Instruction 10-1605), National Oceanic and Atmospheric Administration; at http://www.nws.noaa.gov/directives/sym/pd01016005curr.pdf (retrieved 5 March 2014). This estimate does not include the other components of SNRA direct economic loss, such as business interruption.

479 Estimate is based on information from multiple sources:

(a) Padgett, J., DesRoches, R., Nielson, B., Yashinsky, M., Kwon, O., Burdette, N., and Tavera, E. (2008). "Bridge Damage and Repair Costs from Hurricane Katrina." J. Bridge Eng., 13(1), 6–14, January/February 2008; available at http://www.owlnet.rice.edu/~jp7/Padgett_JBE_Jan08_Bridge_Damage_and_Repair_Costs_from_Hurricane_Katrina_PUBLISHED.pdf

(b) WSDOT, "I - 5 Skagit River Bridge – Estimate of the Direct Cost of Closure", Accessed 3/18/2015, available at http://www.wsdot.wa.gov/NR/rdonlyres/983F3385-A349-4372-9493-1C21E033DEC0/0/SkagitRiverBridge_DirectCost_1082013.pdf.

(c) Minnesota DOT (2007, September 4), "Economic Impacts of the I-35W Bridge Collapse," available at http://www.dot.state.mn.us/i35wbridge/rebuild/pdfs/economic-impacts-from-deed.pdf (checked 15 April 2015).

(d) Pioneer Press, "The Design for the I-35W Replacement Bridge is Unveiled," available at http://www.twincities.com/ci_7122021, accessed March 18, 2015

480 Based upon the replacement cost of the Oakland Bay Bridge. Cuff, Dennis (2014, September 8). Cost of Bay Bridge demolition rises amid complication. *Oakland Tribune*. [$6.4 billion cost was for replacement: demolition cost estimate cited in article, $271 million.] Bay Area Toll Authority (2015). Bridge facts: San Francisco-Oakland Bay Bridge [dynamic resource]: http://bata.mtc.ca.gov/bridges/sf-oak-bay.htm (retrieved 13 April 2015).

481 Social displacement was assumed to be zero for the Transportation Systems Failure national-level event.

482 Low, best, and high frequencies represent the inverse of the longest inter-arrival time (gap) between incidents, the average number of incidents per year, and the largest number of incidents occurring in any one year from the set of U.S. historical bridge failure incidents in Table 19.

Event Background

The Strategic National Risk Assessment (SNRA) Transportation Systems Failure hazard event was originally developed by the DHS National Protection and Programs Directorate (NPPD) for the 2012-13 Homeland Security National Risk Characterization (HSNRC) project.[483] The original HSNRC data and analysis were expanded and revised for the 2015 SNRA by project staff from Argonne National Laboratory and FEMA.

Transportation infrastructure is broadly distributed, but the health of the overall system can be monitored by the state of disrepair and trends of failures of bridges, tunnels, road segments, and other assets. Bridges and tunnels are necessary means to overcome physical obstacles. By necessitating greater convergence of traffic in these locations, bridges and tunnels become critical nodes or choke points in networks. However, roadways can also operate as critical nodes when they provide sole or primary access to an area, connect to critical facilities, or when there is a lack of sufficient redundancy within the network.

Infrastructure owners and operators often struggle to fund and implement proper maintenance and repairs to the structures and assets that compose transportation systems, leading to an increasing risk of infrastructure failure. The Nation's transportation network includes reliance on key infrastructure nodes such as bridges and tunnels, which are aging. In some cases these nodes are at risk due to conditions exceeding design specifications, and in others due to external threats and hazards. The more aware owners and operators are of the critical nature of their key nodes, the more likely they are to maintain them appropriately. However, the general system decline and lack of resources suggests a broader trend toward increasing infrastructure failure.[484]

Transportation system failures can disrupt supply chains, resulting in unexpected costs to repair or rebuild damaged components. They can also increase transportation costs to those normally using the disrupted facility due to increased congestion or detouring, and often entail delays for emergency response and other important services. In rare instances these infrastructures can come under extreme loads or other unforeseen conditions (e.g., design errors), that create situations where high numbers of casualties could occur from their catastrophic failure.

Bridges, tunnels, and roadway culverts represent a subset of transportation infrastructure assets that, as identifiable network nodes and through interaction with the surrounding environment, are at a greater risk to acute failures that can cause broader disruption or impact to the transportation system. A background summary of bridge, tunnel, and culvert transportation failures are summarized below.

Bridge Failures

Bridge failures represent a subset of all transportation risk; however, there is a larger amount of data on highway bridge condition and failures compared with other transportation infrastructure, which better enables a national-level assessment of associated risks. The National Bridge Inventory (NBI) maintains condition and inspection data on individual bridges for all roadway

[483] The HSNRC was a collaborative effort of the DHS analytic enterprise to expand the 2011 SNRA risk knowledge base to additional threats and hazards, and to adapt the SNRA to the information needs of DHS strategic planning.

[484] One advocacy group assessed that the number of bridges older than 50 years was 95,150 in 1990 and 199,584 in 2010, and would be 383,060 by 2030 and 542,170 by 2050. Transportation for America (2011), "The Fix We're In For: The State of Our Nation's Bridges," Washington, DC. Accessed 3/18/2015 http://t4america.org/docs/bridgereport/bridgereport-national.pdf.

bridges in the United States. There is no national database of highway bridge failures; however, a review of 92 failures[485] has categorized causes of bridge failure as indicated in Table 17. This failure database was statistically analyzed in conjunction with the NBI to estimate that annually, 128 bridges fail in the United States. It should be noted, however, that this is a statistically determined number, and includes all bridge failures (i.e., from major roadways to low-volume roads), some of which may have little consequence. Most failures are a result of flooding or scour (a hydraulic-related failure of bridge foundation supports) as well as truck or vehicle collisions. Deterioration, fatigue, fire, soil bearing, and bridge overload have also resulted in bridge failures.

Databases of condition and inspection information to the NBI are not broadly available for railway bridges. Although rail bridges are of systemic and economic importance, they are primarily privately owned facilities, and therefore, national data is not maintained in a central location. The potential for high casualty counts resulting from rail bridge accidents may be attributable to passengers trapped in trains, as well as momentum of the train following the incident.

The Bridge Forum Bridge Collapse Database, maintained by the Cambridge University Department of Engineering, contains 25 U.S. road, rail, and pedestrian bridge failures that resulted in one or more fatalities from 1964 through 2007 (Table 18).[486] This database has been updated with information from multiple data sources, and has been used to provide a basis for the frequency, fatality, and injury estimates in the 2015 SNRA.

[485] Reproduced from Table 2, p. 27: Cook, W. (2014, May 1). "Bridge Failure Rates, Consequences, and Predictive Trends." Doctoral Dissertation, Department of Civil & Environmental Engineering, Utah State University, Logan, UT: at http://digitalcommons.usu.edu/etd/2163/ (checked 13 April 2015).

[486] Imhof, Daniel, and University of Cambridge (2012). BridgeForum Bridge Failure Database [electronic resource]. Structures Group, University of Cambridge Department of Engineering, adapted from Imhof, Daniel (2005), Risk Assessment of Existing Bridge Structures [dissertation], abstract at http://www-civ.eng.cam.ac.uk/abstract/Imhofabs.html. Database at http://www.bridgeforum.org/dir/collapse/country/United%20States.html (accessed December 13, 2012). The 25 incidents causing fatalities are a subset of 71 U.S. bridge failure incidents from 1964-2007 in total in these sources.

Table 17: Bridge Failure Study, Percentages of Failure Causes

Cause of Failure	Partial Collapse	Total Collapse	Total Count	Percentage of Total
Hydraulic Total	21	27	48	52.17%
Hydraulic	–	2	2	2.17%
Flood	8	18	26	28.26%
Scour	12	7	19	20.65%
Ice	1	–	1	1.09%
Collision Total	17	1	18	19.57%
Collision	14	1	15	16.30%
Auto/Truck	3	–	3	3.26%
Overload	3	8	11	11.96%
Deterioration Total	4	2	6	6.52%
Deterioration	–	1	1	1.09%
Steel deterioration	2	1	3	3.26%
Concrete deterioration	2	–	2	2.17%
Fire	3	–	3	3.26%
Construction	1	1	2	2.17%
Fatigue-steel	1	–	1	1.09%
Bearing	–	1	1	1.09%
Soil	1	–	1	1.09%
Miscellaneous	1	–	1	1.09%
Total	52	40	92	100.00%

Tunnel Failures[487]

In the United States, there are about 337 highway tunnels as compared to over 600,000 highway bridges. As with bridges, many of these tunnels are choke points or critical nodes in the Nation's highway transportation network that have completely unique design, construction, and operational requirements. Tunnel structures are designed to withstand environmental impacts from the soil or seabed through which they pass; however, a failure of a tunnel could result in hundreds of casualties and billions of dollars in reconstruction cost. The greatest threats to tunnel users are fire and chemical spills, resulting from the closed environment of tunnels. Therefore, life safety and evacuation are the most important considerations for risk reduction. There have been a number of tunnel incidents in the United States that resulted in casualties, but these incidents have not been as catastrophic as compared to those in other countries. Tunnel owners must conduct systematic reviews to understand their facilities and vulnerabilities, and develop protection and life safety strategies.

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[487] Transportation Research Board (TRB), National Academies (2006). "TCRP Report 86/NCHRP Report 525, Transportation Security, Volume 12: Making Transportation Tunnels Safe and Secure," National Academies Press, Washington, D.C. At http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_525v12.pdf (checked 13 April 2015).

There is no national dataset or study that presents tunnel failure risks or vulnerabilities in the United States. Global studies have been conducted;[488] however, variability in international design and safety practices relating to construction, operation, and management suggest that global trends in tunnel failures may not accurately represent or be predictive of such failures in the United States.

Culvert Failures

The number of culverts in the United States is significantly greater than the number of bridges, and most of these are roadway culverts that are owned and maintained by state Departments of Transportation (DOT), state Departments of Natural Resources, and local counties or municipalities. Culverts are water runoff control devices designed to constrict or control surface water runoff to allow it to pass under roadways, railways, or other similar systems. Culverts range in size from small pipes several inches in diameter to large structures that may be dozens of feet wide. They are distinct from bridges in that they contain structure on all sides of the opening (although some newer "open-bottomed" culverts omit structure on the bottom of the opening to preserve streambeds), and can be constructed of concrete, galvanized steel, aluminum, timber, or other materials. As with bridges and tunnels, however, the flooding, failure, or washout of a roadway culvert results in closure of, or disruption to, the overlying roadway.

The cost and length of time to replace or repair a road culvert is significantly less than bridges and tunnels; therefore, the aggregate risks associated with disruption may be comparatively less than that for bridges. Road culvert failures typically occur during extreme weather events, heavy rains, and flooding. They frequently are a result of overwhelmed capacity, poor maintenance, or some combination thereof. Numerous state DOTs maintain inventories of culvert condition and inspection data; however, such practices are not nationally standardized and are documented with a widely ranging level of detail, if at all.[489],[490]

Data Scope

The SNRA transportation systems failure data set includes historical incidents of automotive, rail, and pedestrian bridge collapses in the United States. Bridge failures represent a subset of all mass transportation risk. However, there is a larger amount of data on bridge failures compared with tunnel and other transportation infrastructure, and bridges were considered sufficiently representative of a larger trend of changing conditions in critical infrastructure for the purposes of informing preparedness planning decisions at a strategic level.

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[488] For example, "Catalog of Notable Tunnel Failure Case Histories (Up to October 2012)," Presented by Mainland East Division, Geotechnical Engineering Office, Civil Engineering and Development Department, Hong Kong: at http://www.cedd.gov.hk/eng/publications/geo/doc/HK%20NotableTunnel%20Cat.pdf (accessed 16 March 2015).

[489] Wall, T.A. (2013) "A Risk-Based Assessment Tool To Prioritize Roadway Culvert Assets for Climate Change Adaptation Planning," Doctoral Dissertation, School of Civil & Environmental Engineering, Georgia Institute of Technology, Atlanta, GA: at https://smartech.gatech.edu/handle/1853/50393 (checked 13 April 2015).

[490] FHWA (2014). "Culvert and Storm Drain Management Case Study: Vermont, Oregon, Ohio, and Los Angeles County." United States Department of Transportation, Washington, D.C.

Assumptions

- Transportation-related infrastructure such as tunnels, roadway culverts, navigation locks, and railway systems are all potential points of system vulnerability and failure. However, due to lack of national-level data to serve as a basis for a nationally-consistent risk assessment, these systems are excluded and the focus is redirected exclusively to bridges. Additionally, focus is given to major roadway bridges (i.e., those located on main highway and roadway networks), and excludes bridges such as those on undeveloped roads (e.g., logging, forest access) or private property.
- The SNRA social displacement measure (persons, other than response personnel and those hospitalized, with homes destroyed or who are prevented from returning home for more than two days) is used in this analysis. Other measures, such as whether or not a transportation system component provides sole-access to a community or facility, or network redundancy can be useful alternative metrics for social displacement, but are excluded here due to lack of available national-level data.
- Aging infrastructure, whose construction techniques and materials are now considered substandard in the U.S., are considered part of the failing transportation infrastructure system if they had continued to be used at the time of their failure.
- Economic impacts are highly varied and dependent on the context of the particular bridge failure and its cascading effects. There is no basis to make such an estimate in this assessment for the more minor failures in an unclassified estimate. Therefore, direct costs reflected in the quantitative estimates, and a discussion of other relevant factors, including broader and indirect economic impacts, are provided in the final section.
- While there is no broad consensus as to what items to include in a list of U.S. bridge failures—the factors that most directly contributed to those risks, or in the analysis of their impacts—the resources consulted and discussed here provide a sufficient basis upon which to form an estimate and inform further consideration, but not a comprehensive and complete study of those failures, contributing factors, or impacts.

Frequency

Low, best, and high estimates of annual frequency represent the inverse of the longest interarrival time (longest gap between incidents, six years, 1995-2001), the average number of incidents per year, and the maximum number of incidents occurring in any one year of the incidents in Table 19.

Health and Safety

Low, best, and high estimates of fatalities and injuries represent the lowest, average, and highest fatalities and injuries from the set of incidents in Table 19.

Direct Economic Loss

Direct economic impacts as defined in the SNRA include decontamination, disposal, and physical destruction costs including property (structure, contents, physical infrastructure and other physical property) and crop damage; one year's lost spending due to fatalities; medical costs; and business interruption directly resulting from the impacts of an event.

The historical incident database (Table 18) did not report economic damage information. Low, best, and high estimates for the SNRA 2015 Transportation Systems Failure hazard event are based upon literature data and analyst judgment.

The low estimate of direct economic loss is based on a generic cost estimate for state-federal bridge loss for reporting damages from natural disasters.[491] This estimate does not include the other components of SNRA direct economic loss, such as business interruption.

For the best estimate of direct economic loss, cost information available for three recent events—bridges affected by Hurricane Katrina, the I-35W Bridge, and the I-5 Skagit River Bridge—was used to compute an average cost including the impact on transportation costs, and economic output, where available.[492] Because these estimates include costs in addition to physical damage, their degree of approximation to the SNRA direct economic loss metric (which includes a component for direct business interruption but not other second-order costs) is unknown. The SNRA project team made the assumption that the resulting average would be a reasonable approximator to an average cost of catastrophic bridge failures resulting in loss of life, within the order of magnitude precision of the SNRA.

The cost for replacing the Oakland Bay Bridge was used as the high estimate for direct economic loss.[493] Note that this estimate excludes the impact on transportation costs, output, and employment, and therefore, underestimates both direct and total economic loss from this event.

Social Displacement

The impacts of transportation network disruptions on travel behavior are a function of the geographic scope of the disruption, the existence of alternate routes, network redundancy, capacity utilization, and congestion, and restoration time. Depending on the level of disturbance, travelers may consider options such as shifting work schedules, telecommuting, or public transportation.

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

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[491] National Weather Service (2007, August 17), Storm Data Preparation (Instruction 10-1605), National Oceanic and Atmospheric Administration; at http://www.nws.noaa.gov/directives/sym/pd01016005curr.pdf (retrieved 5 March 2014). Page B-2: Low end of $250K-$750K range selected for SNRA low estimate.

[492] Estimate is based on information from multiple sources:

(a) Padgett, J., DesRoches, R., Nielson, B., Yashinsky, M., Kwon, O., Burdette, N., and Tavera, E. (2008). "Bridge Damage and Repair Costs from Hurricane Katrina." J. Bridge Eng., 13(1), 6–14, January/February 2008; available at http://www.owlnet.rice.edu/~jp7/Padgett_JBE_Jan08_Bridge_Damage_and_Repair_Costs_from_Hurricane_Katrina_PUBLISHED.pdf

(b) WSDOT, "I - 5 Skagit River Bridge – Estimate of the Direct Cost of Closure", Accessed 3/18/2015, available at http://www.wsdot.wa.gov/NR/rdonlyres/983F3385-A349-4372-9493-1C21E033DEC0/0/SkagitRiverBridge_DirectCost_1082013.pdf.

(c) Minnesota DOT (2007, September 4), "Economic Impacts of the I-35W Bridge Collapse," available at http://www.dot.state.mn.us/i35wbridge/rebuild/pdfs/economic-impacts-from-deed.pdf (checked 15 April 2015).

(d) Pioneer Press, "The Design for the I-35W Replacement Bridge is Unveiled," available at http://www.twincities.com/ci_7122021, accessed March 18, 2015

[493] Cuff, Dennis (2014, September 8). Cost of Bay Bridge demolition rises amid complication. *Oakland Tribune*. [$6.4 billion cost was for replacement: demolition cost estimate cited in article, $271 million.] Bay Area Toll Authority (2015). Bridge facts: San Francisco-Oakland Bay Bridge [dynamic resource]: http://bata.mtc.ca.gov/bridges/sf-oak-bay.htm (retrieved 13 April 2015).

The historical incident database (Table 18) did not include information on persons displaced. The SNRA project team made the assumption that no persons were separated from their homes for more than two days for any of these incidents.

Psychological Distress

Psychological consequences for the SNRA focus on significant distress and prolonged distress, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event.[494] The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs. A multiplicative factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.

- The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\,Fat + Inj + \frac{1}{2}\,D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement).
- In words, this formula suggests that there are five significantly distressed persons for each life lost; one for each person injured; and one for each two people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement.
- The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long-term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA.
- Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

The Transportation System Failure national-level event was added by the SNRA project subsequent to the 2011 iteration of the SNRA for which Event Familiarity Factors were elicited from subject matter experts. The SNRA project team assigned a *provisional* Event Familiarity Factor of 1.0 by analogy with the SNRA Dam Failure event, for the calculation of *provisional* psychological distress estimates. It must be stressed that this assignment has not been reviewed by the 2011 subject matter experts.

Environmental Impact

In general, the direct environmental impacts of a bridge collapse would be limited to localized debris and disturbance of contaminants in a riverbed. In special cases, where environmentally

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[494] See Appendix G of the SNRA draft Unclassified Documentation of Findings for references and additional discussion of the SNRA Psychological Distress metric.

volatile or hazardous material is transported over the bridge (either by vehicles or by co-located infrastructure such as fuel pipelines), direct environmental impacts would be greater. Indirect environmental impacts related to additional emissions related to increased congestion and detouring as a result of disruption, and direct impacts to the surrounding environment related to replacement activities could also occur. However, these are significantly variable and contextual, and thus difficult to reasonably quantify.

The environmental impact estimate, which was assessed for the 23 original national-level events of the 2011 SNRA by subject matter experts from the U.S. Environmental Protection Agency (EPA), could not be assessed for the transportation systems failure event added to the SNRA in calendar year 2015. A future iteration of the SNRA will assess the environmental impacts of this event.

Potential Mitigating Factors

The aging of the Nation's transportation infrastructure is a risk that can be addressed through proactive inspection, maintenance, repair and replacement of deteriorating assets. However, this would require significant investment at the Federal, state and local levels, and therefore such activities will have to be prioritized based on criticality, risk, available funds, and other factors. A recent Federal requirement that state DOTs engage in risk-based asset management[495] to better strategically plan for transportation infrastructure investment and improvement may ensure more effective use of existing funding, but expanded funding may also be required for effective mitigation of risk. Additionally, complementary action may be taken for enhanced contingency, response, and emergency preparedness planning. In the event of a transportation system failure, better emergency preparedness and response planning will enable agencies to more immediately respond to and mitigate direct impacts, and better contingency planning (e.g., establishing detouring and rerouting plans around higher risk assets) can mitigate indirect costs associated with disruption to the transportation system and supply chain, and associated congestion.

Additional Relevant Information

There is not a comprehensive database for bridge, tunnel, or culvert failures in the U.S. There is also a lack of consensus on how to define a failure, with some studies excluding failures due to natural disasters.[496]

The SNRA does not quantitatively assess trends or other measures of how the current national risk picture may be changing. However, engineering design principles, coupled with NBI bridge inspection data do provide potential indicators of increased vulnerability or risk of failure among bridges in the United States. These are summarized below.

Bridge Condition Indicators Related to Increased Risk of Failure

Scour-Critical Bridges: Scour refers to the "removal of a streambed or bank area by stream flow; erosion of streambed or bank material due to flowing water; often considered as being localized around piers and abutments of bridges."[497] Scour critical bridges are those that either have

[495] Moving Ahead for Progress in the 21st Century Act (MAP-21), U.S. Public Law 112-141 – July 6, 2012

[496] Wardhana, Kumalasari and Hadpriono, Fabian C., "Analysis of Recent Bridge Failure in the United States," Journal of Performance of Constructed Facilities, 2003, Vol 17(3), pp. 144-150.

[497] FHWA (2012). "Bridge Inspector's Reference Manual." United States Department of Transportation, Washington, D.C.

insufficient information regarding the construction of the bridge's substructure (i.e., bridge foundation)[498] or that are known to have a substructure or foundation element that has structural issues or is determined to be unstable due to scouring. Scour-critical bridges are not necessarily substandard and do not note a specific defect for the structure; they are simply structures that should be monitored during high water events as they may be more susceptible to settlement and foundation failure if scouring of the stream or river would occur during a high water event.

Fracture-Critical Bridges: These are bridges that do not contain redundant supporting elements, and if key supports fail, the bridge would be in danger of partial or complete collapse.[499] Fracture criticality does not necessarily mean that a bridge is inherently unsafe, but rather that the design lacks redundancy and, therefore, may be at greater risk to threats that could damage fracture critical members of the structure.

Functionally Obsolete Bridges: These are bridges built to design standards that are no longer in use. For example, they may not have adequate lane widths, shoulder widths, or vertical clearances to serve current traffic demand. These bridges are not inherently unsafe and are not automatically rated as structurally deficient; however, in some cases they may have different operational or management requirements (e.g., imposing weight or clearance restrictions).

Structurally Deficient Bridges: These are bridges "where significant load carrying elements are found to be in poor or worse condition due to deterioration and/or damage, or the adequacy of the waterway opening provided by the bridge is determined to be extremely insufficient to the point of causing intolerable traffic interruptions" (i.e., the deck is frequently overtopped by water during floods). These structures are classified as structurally deficient if the deck, superstructure, substructure, or a culvert is rated in "poor" condition (0 to 4 on the NBI rating scale).[500]

Fatalities, Injury and Illness Related to Bridge Failures

The deadliest failure of a bridge used for automobile transportation in the United States since 1960 was the collapse of the Silver Bridge over the Ohio River in 1967, which killed 46 people and injured at least nine. The bridge collapsed due to the failure of a single fracture-critical structural bridge member due to fatigue. Another recent major failure of a fracture-critical bridge was the collapse of the I-35W Bridge in Minneapolis in 2007, which killed 13 people with 145 injured. The failure in this latter case was the result of a structural member gusset plate that was constructed thinner than was specified in the original design and ripped along a line of rivets. A truss railroad bridge in Mobile, Alabama, in 1993 failed leading to 47 deaths and 103 injuries. This failure was caused when an assembly of heavy barges had collided with the bridge just eight minutes prior to the failure, causing displacement of a bridge span and deformation of the rails.

Economic Impact Studies of Bridge Failures

Little analysis has been conducted of the economic impacts from bridge failures, and the economic impacts of such incidents are highly contextual. They must consider the full range of

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[498] Marathon County Highway Department (2015), "Scour Critical Bridges." Accessed 3/17/2015 < http://www.co.marathon.wi.us/Departments/HighwayDepartment/LocalGovernmentInformation/ScourCriticalBridges.aspx>

[499] AASHTO (Undated) "Subcommittee on Transportation Communications: Bridge Terms Definitions." Accessed 3/17/2015 <http://www.iowadot.gov/subcommittee/bridgeterms.aspx#f>

[500] MDOT (2015) "Structurally Deficient." Accessed 3/17/2015. At http://www.michigan.gov/mdot/0,4616,7-151-9618_47418-173622--,00.html>

systemic impacts of the incident. The National Infrastructure Simulation and Analysis Center (NISAC) conducted an analysis of the consequences of the failure of the I-35W Bridge in Minneapolis, Minnesota, in 2007.[501] The estimated cost for reconstruction ranged from $40 million to $180 million, pending decisions about whether only damaged sections would need to be replaced, or the entire bridge. The broader economic impacts were not assessed, but the cascading impacts to infrastructure provide insights into the source of economic losses that might result from the loss of a significant bridge. For example, the primary economic impact of the loss of the I-35W bridge was assessed to be the increased commuting times and transportation delays related to the 140,000 cars/day that would need to be rerouted. Changes for trucking would create minor increases in transit time for goods shipments going through the Twin Cities metropolitan area. While there were negligible impacts to the water and wastewater infrastructures in this incident, bridge infrastructures frequently include co-located water pipelines, power lines, fiber-optic cables, and sometimes fuel pipelines, which could be damaged in such an event. There were no such complications in the collapse of the I-35W Bridge. However, the failure of a bridge that included damage to these other infrastructures would have had a much more significant multi-sector systemic impact than what was observed in I-35W.

The Minnesota DOT (MNDOT) analyzed the impact of the loss of the bridge on road users and the Minnesota economy. The increased cost to road users totaled $400,000 per day in terms of longer travel times and higher operating costs for auto ($247,000) and commercial truck traffic ($153,000). These increased transportation costs were assessed to have a direct impact on businesses in the Minneapolis area. The economic costs in terms of state gross domestic product were estimated to be $113,000 per day, with a total impact of $60 million over the 2007- 2008 restoration period.[502] MNDOT estimated that the total replacement project would cost $393 million dollars.[503]

The 26-day closure of the I-5 Skagit River Bridge in Washington State was estimated by the Washington State DOT to have had a direct economic impact on travel costs of $8.3 million.[504] The analysis included estimates for increases in variable operating costs and travel times due to rerouting of traffic during bridge restoration. The total cost of the bridge replacement was $20.7 million, with $8.1 million for the temporary bridge, $8.5 million for the new permanent bridge, and $4.1 million for additional repair work to other parts of the bridge

The significant damage to highway bridges along the coastal region of Louisiana, Mississippi, and Alabama caused by the combination of high winds, rain, and storm surge in Hurricane Katrina led to an estimated cost to repair or replace the damaged bridges at over $1 billion. Much of the bridge damage from Katrina is attributable to storm surge resulting in damage to mechanical and electrical equipment on movable spans and displacement of bridge decks in traditional fixed spans. The average repair/replacement cost for bridges damaged in Hurricane Katrina was estimated to be $14 million, ranging from $1,000 for minor repairs to mechanical

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[501] National Infrastructure Simulation and Analysis Center, "Impacts of the I35W Bridge Failure (Preliminary Analysis)", August 3, 2007

[502] Minnesota DOT (2007, September 4), "Economic Impacts of the I-35W Bridge Collapse," available at http://www.dot.state.mn.us/i35wbridge/rebuild/pdfs/economic-impacts-from-deed.pdf (checked 15 April 2015).

[503] Pioneer Press, "The Design for the I-35W Replacement Bridge is Unveiled," available at http://www.twincities.com/ci_7122021, accessed March 18, 2015.

[504] WSDOT, "I - 5 Skagit River Bridge – Estimate of the Direct Cost of Closure", Accessed 3/18/2015. http://www.wsdot.wa.gov/NR/rdonlyres/983F3385-A349-4372-9493-1C21E033DEC0/0/SkagitRiverBridge_DirectCost_1082013.pdf.

systems for movable bridges in Louisiana, to an estimated $276 million for repairs to US-90 in Mississippi.[505] Table 18 shows the estimated cost by extent of bridge damage.

The repair costs to bridges with more minor damage from Hurricane Katrina amounted to less than $10,000; however, there was significant variation in the repair cost for bridges that were in the extensive and complete damage state, ranging from $25,000 to nearly $276 million. Repair costs are a function of many different factors including size of bridge, how many of the spans were collapsed, whether or not the bridge was salvageable or required replacement, as well as the level of damage to and cost for repair of the submerged electrical and mechanical systems.[506]

Table 18: Estimated Bridge Repair or Replacement Cost Following Hurricane Katrina[507]

Bridge Damage	Number of Bridges	Minimum	Average	Maximum
Slight-Moderate	19	$1,000	$374,737	$6,000,000
Extensive	20	$25,000	$1,893,250	$7,700,000
Complete	5	$1,500,000	$116,880,000	$276,000,000
Total	44	$1,000	$14,304,205	$276,000,000

[505] Padgett, J., DesRoches, R., Nielson, B., Yashinsky, M., Kwon, O., Burdette, N., and Tavera, E. (2008). ”Bridge Damage and Repair Costs from Hurricane Katrina.” *Journal of Bridge Engineering* 13(1), 6–14, January/February 2008.

[506] Ibid.

[507] Ibid.

Table 19: Major Bridge Failures (SNRA Data Set)

Event	Year	Fatal	Injured	Displaced > 2 Days
Lake Pontchartrain Bridge	1964	6	0	0*
Silver Bridge (Ohio River)	1967	46	9	0*
Sidney-Lanier Bridge (Brunswick, GA)	1972	10	0	0*
Motorway Bridge (Pasadena, CA)	1972	6	0	0*
Lake Pontchartrain Bridge	1974	3	0	0*
21-Span Pass Manchac Bridge (LA)	1976	2	2	0*
Sunshine Skyway Bridge (St. Petersburg, FL)	1980	35	0	0*
Multiple Span (East Chicago, Indianapolis)	1982	13	18	0*
Syracuse Bridge (NY)	1982	1	5	0*
Connecticut Turnpike Bridge (Greenwich)	1983	3	3	0*
Walnut St. Viaduct (Denver, CO)	1985	1	4	0*
El Paso Bridge (TX)	1987	1	7	0*
Oakland Bay Bridge (San Francisco, CA)	1989	1	0	0*
Truss Bridge (Mobile, AL)	1993	47	0	0*
Truss Bridge (Concord, NH)	1993	2	7	0*
Interstate 5 (Coalinga, CA)	1995	7	0	0*
3-Span 3-Girder (Clifton)	1995	1	0	0*
Queen Isabella Causeway (TX)	2001	8	0	0*
Marcy Bridge (Utica-Rome Expressway)	2002	1	9	0*
Highway 14 Overpass (TX)	2002	1	1	0*
Imola Avenue Bridge (Napa, CA)	2003	1	7	0*
Interstate 70 Bridge (Denver, CO)	2004	3	0	0*
Shelby (NC)	2004	1	2	0*
35-West Bridge (Minneapolis, MN) [508]	2007	13	145	0*
MacArthur Maze[509]	2007	1	0	0*

[508] Fatality and injury data for the significant I-35W bridge collapse (2007) were obtained from Hao, S. (2010), I-35W bridge collapse, *Journal of Bridge Engineering* (September/October 2010) 608-609, at http://suhao-acii.com/files/I35W_note.pdf (retrieved January 2013).

[509] Waters, Lew (2014). Bridge collapses in the U.S. from 1940 to 2013. Internet resource (not academic or peer reviewed). At http://lewwaters.files.wordpress.com/2013/06/bridge-collapses-in-the-u-s-from-1940-to-2013.pdf (retrieved 15 April 2014).

Winter Storm

A winter storm event occurs resulting in direct economic losses of $1 billion or greater.[510]

Category	Description	Metric	Low	Best	High
Health and Safety	Fatalities	Number of Fatalities	0[511]	50[512]	270[513]
	Injuries and Illnesses	Number of Injuries or Illnesses[514]	0	1,700	14,000
Economic	Direct Economic Loss	U.S. Dollars[515]	$1 Billion	$3.1 Billion	$9 Billion
	Indirect Economic Loss	U.S. Dollars	N/A		
Social	Social Displacement	People Displaced from Home ≥ 2 Days	N/A		
Psychological	Psychological Distress	Qualitative Bins	N/A		
Environmental	Environmental Impact	Qualitative Bins	N/A		

LIKELIHOOD	Frequency of Events	Number of Events per Year	0.125	0.56	2

Event Background[516]

The Strategic National Risk Assessment (SNRA) Winter Storm national-level event was originally developed by the DHS Office of Policy for the 2012–13 Homeland Security National Risk Characterization (HSNRC) project.[517] The original HSNRC data and analysis were expanded and revised for the 2015 SNRA by project staff from Argonne National Laboratory and the Federal Emergency Management Agency (FEMA).

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510 For the purposes of the SNRA, the Winter Storm event includes snow storms, ice storms, freezes and other periods of extremely and exceptionally cold temperatures, and heavy snowfalls, but excludes snowmelt induced flooding which is counted in the SNRA Flood event.

511 Minimum fatalities of the 19 billion dollar winter storm events in Table 21.

512 Average number of fatalities in the 19 winter storm events in Table 21.

513 Highest number of fatalities in the 19 winter storm events in Table 21.

514 Estimated from NCDC Billion Dollar Disaster List, which does not report injuries or illnesses, by applying injury/fatality ratios from NCDC StormData events corresponding to the winter storm events of the primary data set. See Injuries for details.

515 Low, average, and high reported direct economic loss of the 19 winter storm events in Table 21, converted from reported (2014) dollars to 2011 dollars.

516 This section is substantially adapted from National Weather Service (2008, June), *Winter storms: the deceptive killers*, at http://www.nws.noaa.gov/om/winter/resources/Winter_Storms2008.pdf; National Weather Service (2003), *All about winter storms*; at https://web.archive.org/web/20040214012848/http://www.nws.noaa.gov/om/brochures/wintstm.htm (retrieved January 2014); Chapter 7, Federal Emergency Management Agency (1997), Multi-Hazard Identification and Risk Assessment (MHIRA): A Cornerstone of the National Mitigation Strategy: FEMA Mitigation Directorate, at https://www.fema.gov/media-library/assets/documents/7251?id=2214 (retrieved April 2013); and Federal Emergency Management Agency (2013, April 26). Emergency preparedness: secondary hazards associated with severe winter weather. Trend analysis, Lessons Learned Information Sharing (LLIS), at https://www.llis.dhs.gov/content/emergency-preparedness-secondary-hazards-associated-severe-winter-weather (retrieved January 2014).

517 The HSNRC was a collaborative effort of the DHS analytic enterprise to expand the 2011 SNRA risk knowledge base to additional threats and hazards, and to adapt the SNRA to the information needs of DHS strategic planning. The HSNRC title for this event is Extreme Cold/Winter Weather.

The 2015 SNRA considered winter storms, including blizzards, snow storms, and ice storms, together with freezes and other periods of unusual and extremely cold temperatures hazardous to life and agriculture, within the scope of this event.[518]

Extreme cold and winter weather events produce extremely high winds that can create blizzard conditions with wind driven snow, drifting, and dangerous wind chills. Heavy snow accumulations can immobilize a region and paralyze a city, strand motorists, stop the flow of supplies, and disrupt emergency services. Heavy snows can also create the opportunity for avalanches in mountainous regions. Heavy ice accumulations can bring down trees, utility poles and lines and communication towers. Extreme cold temperatures can cause potentially life-threatening conditions such as hypothermia and frostbite. These below-freezing temperatures can damage vegetation and crops and cause water pipes to burst. The melting of significant snow accumulations and ice flow can produce major widespread flooding of rivers and low areas, resulting in potential environmental impacts and substantial damage to property, businesses, transportation infrastructure, and farmland.

Winter storms can be snowstorms and other types of weather associated with winter storms that can be extremely hazardous. These include storms with strong winds, ice storms, extremely cold temperatures, and heavy snow.

- **Storms with strong winds:** Winter storms can be accompanied by strong winds creating blizzard conditions with blinding wind-driven snow, severe drifting, and dangerous wind chill. Strong winds with these intense storms and cold fronts can knock down trees, utility poles, and power lines. Storms near the coast can cause coastal flooding and beach erosion as well as sink ships at sea.
- **Ice storms:** Heavy accumulations of ice can bring down trees and topple utility poles and communication towers. Ice can disrupt communications and power for days while utility companies repair extensive damage. Even small accumulations of ice can be extremely dangerous to motorists and pedestrians. Bridges and overpasses are particularly dangerous because they freeze before other surfaces.
- **Extreme cold:** Exposure to cold can cause frostbite or hypothermia and become life-threatening. Infants and elderly people are most susceptible. What constitutes extreme cold varies in different parts of the country.
    - In the South, near freezing temperatures are considered extreme cold. Freezing temperatures can cause severe damage to citrus fruit crops and other vegetation. Pipes may freeze and burst in homes that are poorly insulated or without heat.
    - In the north, below zero temperatures may be considered as “extreme cold.” Long cold spells can cause rivers to freeze, disrupting shipping. Ice jams may form and lead to flooding.
- **Heavy snow storms:** Heavy snow can immobilize a region and paralyze a city, stranding commuters, closing airports, stopping the flow of supplies, and disrupting emergency and medical services. Accumulations of snow can cause roofs to collapse and knock down trees

[518] Snowmelt-induced flooding is treated within the scope of the SNRA Flood event (SNRA 2011 draft Unclassified Documentation of Findings 131–-133).

and power lines. Homes and farms may be isolated for days and unprotected livestock may be lost. In the mountains, heavy snow can lead to avalanches. The cost of snow removal, repairing damages, and the loss of business can have severe economic impacts on cities and towns.[519]

Winter storms are known to spawn other natural hazards, such as severe thunderstorms, tornadoes, and extreme winds. These effects disrupt commerce and transportation and often result in loss of life due to accidents or hypothermia. Vulnerable populations such as the elderly and homeless may have adverse health effects if exposed to the elements for extended periods of time. In addition to the impacts on transportation, power transmission, communications, agriculture, and people, severe winter storms can cause extensive coastal flooding, erosion, and property loss.

Winter storms and blizzards originate as mid-latitude depressions or cyclonic weather systems, sometimes following the meandering path of the jet stream.[520] A blizzard combines heavy snowfall, high winds, extreme cold, and ice storms. The origins of the weather patterns that cause severe winter storms, such as snowstorms, blizzards, and ice storms are primarily from four sources in the continental United States.

- In the northwestern states, cyclonic weather systems from the North Pacific Ocean or the Aleutian Island region sweep in as massive low-pressure systems with heavy snow and blizzards.
- In the Midwestern and Upper Plains states, Canadian and Arctic cold fronts push ice and snow deep into the interior region and, in some instances, all the way down to Florida.
- In the Northeast, lake-effect snowstorms develop from the passage of cold air over the relatively warm surfaces of the Great Lakes, causing heavy snowfall and blizzard conditions.
- The eastern and northeastern states are affected by extra-tropical cyclonic weather systems in the Atlantic Ocean and Gulf of Mexico that produce snow, ice storms, and occasional blizzards.

Nearly the entire United States, except the extreme southern states, Hawaii, Puerto Rico, the U.S. Virgin Islands, and the U.S. Pacific territories is considered at risk for severe winter storms. The degree of exposure depends on the normal severity of local winter weather. In particular, Alaska, the Northeast, and the upper Midwest tend to be more susceptible than others to severe winter storms. Generally, these regions are more prepared for severe winter weather. Areas where such weather is rare, such as the extreme South, are disrupted more severely than are regions that experience severe weather more frequently.

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[519] Adapted from National Weather Service (2008, June). *Winter storms: the deceptive killers*, at http://www.nws.noaa.gov/om/winter/resources/Winter_Storms2008.pdf; and National Weather Service (2003) All about winter storms; at https://web.archive.org/web/20040214012848/http://www.nws.noaa.gov/om/brochures/wintstm.htm (retrieved January 2014).

[520] Bryant, Edward (1991), Natural Disasters: Cambridge University Press, New York; as cited by FEMA (1996).

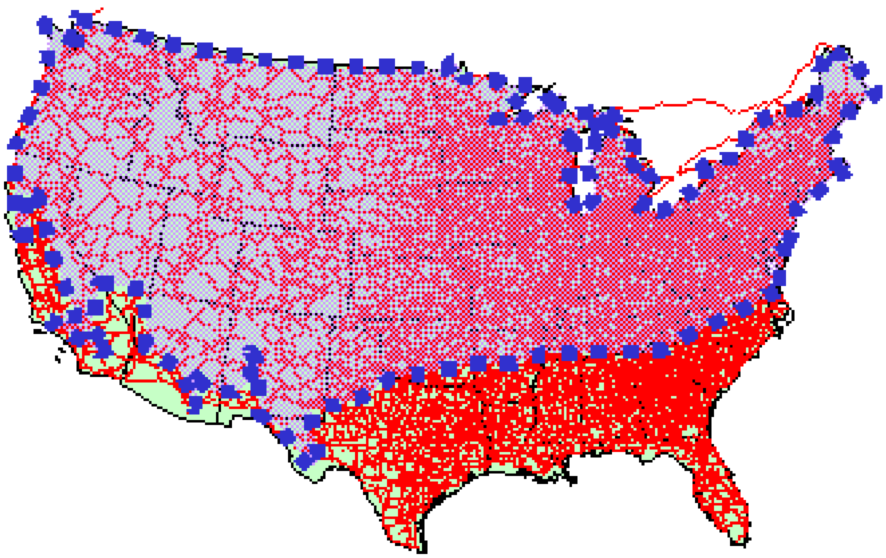

Figure 13: Extent of the Continental United States Receiving 5 or more Inches Annual Snowfall[521]

However, experience has shown that no area can fully prepare for severe winter storms. The past two decades have seen many severe winter events forecast days in advance and for which individuals and communities made substantial preparation, but which nonetheless paralyzed multi-state regions for a week or more.

Heavily populated areas are particularly impacted when severe winter storms disrupt communication and power due to downed distribution lines. Snow and ice removal from roads and highways is difficult when accumulations build faster than equipment can clear. Debris associated with heavy icing may impact utility systems and transportation routes.

Secondary and cascading hazards from severe winter storms may include:

- **Power outages:** Power outages can negatively impact response operations by forcing emergency operations centers to operate on standby power and generators. Power outages can also hinder distribution of food, water, and fuel supplies, cause chaos in transportation and response coordination facilities such as airports and train stations, and lead to loss of lives in hospitals and nursing homes.
- **Downed trees and power transmission lines:** In addition to being a hazard in themselves, downed trees and power lines are underlying causes of other secondary hazards such as power outages, road closures, debris removal issues, and restoration challenges.
- **Responder communications issues:** Winter storm emergencies can increase response operations' need for key communication systems such as landlines and battery powered radios at the same time as burdening and disrupting them.

[521] U.S Department of Transportation Federal Highway Administration (FHWA) (2013, July 2). *Snow and Ice* [electronic resource]. FHWA Road Weather Management Program Office of Operations: at http://ops.fhwa.dot.gov/weather/weather_events/snow_ice.htm (retrieved January 2014).

- **Phone service outages:** These include landline outages due to downed telephone wires and drained batteries for wireless personal communication devices due to extended power outages.
- **Road closure:** In most cases, road closure is due to snow and ice built up on primary and secondary roads, but roads may also be closed due to downed trees or tree branches, utility poles, and electrical lines. Over 70 percent of U.S. roads are located in snowy regions that annually receive more than 5 inches average snowfall. Further, approximately 70 percent of the U.S. population lives in these regions. Each year, state and local agencies spend more than $2.3 billion on snow and ice control operations. In addition to their direct effects on the local population and economy, road closures can hinder response operations.[522]
- **Public transportation closure:** Snow clearing operations, downed trees and wires, landslides, and overall dangerous conditions can impede public transit.
- Need for **public shelters and warming centers:** Demand for shelters usually increases significantly during larger-scale, prolonged events. Shelters provide cots, food, water, and sometimes shower facilities, and serve as places to gather information, charge electronics, and pick up supplies. Local communities frequently rely on non-governmental organizations to establish and manage shelters. However, communities may not always have a sufficient number of pre-identified sheltering locations, and temporary ad-hoc shelters established as a result often lack emergency power and trained personnel.

  Extensive power outages combined with extreme cold temperatures can also necessitate the opening of designated warming stations. Warming stations provide temporary relief from the cold and can be used to distribute hot meals, provide information, and stage transportation to overnight shelters. Schools, churches, libraries, and public and private community centers can serve as warming stations. Warming station management can include challenges such as ensuring sufficient staffing, understanding roles and responsibilities, having safe transportation to and from the stations, having emergency power, and coordinating delivery of supplies.
- **School, government, and public services closure:** Dangerous weather conditions, snow accumulation, and loss of power are the most frequent reasons determining school closure. However, schools may also be closed in order to be used as emergency shelters. Snow and ice storms affecting the National Capital Region can force closure of Federal Government offices in the Washington, DC area, affecting the entire country.
- **Water distribution issues:** Power loss and burst pipes can cause issues with water distribution and force families to seek alternative shelter to flooded homes or homes without water. Other challenges include providing water to shelters, distribution points, and livestock. Public education on water safety and maintaining or restoring water systems is especially important for winter storms, as power outages can prevent customers from following boil-water and other safety notices. In the aftermath of especially widespread or destructive storms, the state National Guard may be called on to provide water buffaloes for portable

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[522] DoT FHWA (2013), *Snow and Ice*, as cited in FEMA (2013). Snow, sleet, and ice cause 580,000 crashes, 180,000 injuries, and 2,200 deaths on U.S. roadways each year. DoT FHWA (2013), *Snow and Ice*, and DoT FHWA (2013, July 2), *How do weather events impact roads?* [electronic resource], FHWA Road Weather Management Program Office of Operations, http://www.ops.fhwa.dot.gov/weather/q1_roadimpact.htm (retrieved January 2014) (cited figures include snow, sleet, slush, and ice related accidents only).

water distribution points, in addition to distributing other essential items and assisting in emergency operations and critical infrastructure restoration.

The primary data source for the SNRA Winter Storm event is the Billion-Dollar Disaster List of the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center (NCDC).[523] Between the years of 1980 and 2013, there were 19 winter storm, ice storm, freeze, and cold wave incidents identified by NOAA as meeting the billion-dollar threshold of the SNRA event (Table 21).[524] There were 945 fatalities and $58 billion dollars' damage ($2011) as a result of these extreme events.

Snow flooding incidents were not included within the SNRA Winter Storm data set to avoid double counting with the SNRA Flood event which includes these incidents within its scope.[525] In addition, flood caused fatalities and economic impacts were subtracted from the reported total fatalities and economic impacts of the January 1996 Blizzard/Flood incident prior to calculations.[526]

Assumptions

The threshold for this event was set at $1 billion of direct economic loss. This difference from the $100 million direct economic loss per occurrence threshold used for other SNRA natural hazards was intentional. While the majority of other SNRA natural hazard incidents are exceptional events by their inherent nature, the regular recurrence of winter storms and freezes as a normal feature of the national risk background required a higher threshold than other hazards in order to capture only those incidents which are exceptions to the norm.

- The Billion-Dollar Disaster List of the NOAA NCDC was used for the identification of extreme cold, freeze, and winter storm events from 1980 to 2013.

Frequency

Low, best, and high estimates of annual frequency represent the inverse of the longest time between incidents in the data set (1/8 years), the average frequency (19 incidents in 34 years, 01/01/1980–12/31/2013), and the maximum number of incidents in 1 year (2).

Fatalities

Low, best, and high estimates of fatalities per occurrence are the minimum (0), average, and maximum fatalities reported by the Billion-Dollar Disaster List.

Injuries

The Billion Dollar Disaster List (BDL[527]) does not report injury estimates. Proxy estimates of persons injured were constructed from raw data reported to the NCDC StormData database for

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[523] National Climatic Data Center (2015). Billion-dollar U.S. weather/climate disasters 1980-2013: http://www.ncdc.noaa.gov/billions/overview.

[524] An additional incident from 2014 is reported, but final cost estimates in the primary source were not yet available for 2014 incidents at the conclusion of the SNRA 2015 analysis (April 2015). For this reason, the observation period used as the basis for the frequency estimates of the SNRA Winter Storm event is limited to 1980–2013.

[525] Snowmelt induced floods can have catastrophic impacts of their own: the SNRA project team identified nine such incidents among the incidents reported on the Billion Dollar List.

[526] See footnotes to this incident, Table 21.

[527] Note that this is a convenience abbreviation used here: it is not a term used outside of the context of the SNRA.

winter storm/ice storm/freeze incidents[528] corresponding in temporal and spatial scope to those reported by BDL from 1993 onward.[529] Where both sources reported non-zero fatalities, the totals from StormData records were substantially lower than those of BDL, indicating underreporting or a distinction between direct and indirect fatalities.[530],[531] The SNRA project team made the assumption that winter storm, ice storm, and cold wave injuries would generally scale to fatalities (both direct and indirect), while fatalities and injuries from a freeze event would, unless reported otherwise, generally be zero as freeze events primarily damage crops.

- Where StormData reported injuries and both sources reported fatalities, the BDL/StormData fatality ratio for each incident was applied to the StormData reported injuries to estimate total injuries.
- Where StormData reported injuries but BDL did not report fatalities, the average BDL/StormData fatality ratio (6.46) was applied to the StormData reported injuries to estimate total injuries.
- Where StormData did not report injuries but BDL reported fatalities, the average StormData injury/fatality ratio (26.5) was applied to the BDL fatality estimates to estimate total injuries. These incidents included all incidents prior to 1993.[532]

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[528] Blizzard, Extreme Cold/Wind Chill, Frost/Freeze, Heavy Snow, Ice Storm, Lake-Effect Snow, Winter Storm, Winter Weather, Winter Weather/Mix.

[529] Incidents having beginning dates between the dates specified by BDL. Spatial scope of selection is indicated in the above table. StormData reports for the specified hazards begin 1/1/1993.

[530] Although both are NCDC products, BDL uses StormData reporting as one of many inputs. Smith et al (2013, June), U.S. billion-dollar weather and climate disasters: Data sources, trends, accuracy and biases; *Natural Hazards* 67(2) 387–410: at http://www.ncdc.noaa.gov/billions/docs/smith-and-katz-2013.pdf (retrieved 18 January 2014).

[531] StormData preparers report both direct and indirect fatalities and injuries, but only direct fatalities and injuries are represented in the numerical fields. A direct fatality or injury is defined as a fatality or injury directly attributable to the hydro-meteorological event itself, or impact by airborne/falling/moving debris—the weather event or its debris are the active agent of harm. Indirect fatalities injuries occur in the vicinity or aftermath of a weather event, but are not directly caused by the event. Examples of direct fatalities and injuries include exposure, hypothermia, and injuries from collapsed roofs under heavy snow. Examples of indirect injuries and fatalities include heart attacks from overexertion, vehicle accidents, and carbon monoxide poisoning caused by improvised or improperly vented heating devices. Pp. 9–10, and sections on hazard classes listed in footnote 528: National Weather Service (2007, August 17), Storm Data Preparation (Instruction 10-1605), National Oceanic and Atmospheric Administration; at http://www.nws.noaa.gov/directives/sym/pd01016005curr.pdf (retrieved 5 March 2014). Indirect fatalities and injuries usually make up the largest proportion of fatalities and injuries from winter storm, cold weather, and ice storm events. FEMA (2013); Iqbal et al (2012, September), National carbon monoxide poisoning surveillance framework and recent estimates, *Public Health Reports* 127(5) 486-96; at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3407848/pdf/phr127000486.pdf (retrieved 7 October 2014); Hamilton, Janice (1998, February 24), Quebec's Ice Storm '98: "all cards wild, all rules broken" in Quebec's shell-shocked hospitals, *Canadian Medical Association Journal [CMAJ/JAMC]* 158(4) 522–524.

[532] A ratio of 40 persons ill per fatality from expert estimation/rule of thumb alternatively could be applied. Changnon, Stanley A. (1999, February). January 1999 Blizzard: Impacts of the New Year's 1999 Blizzard in the Midwest. National Climatic Data Center, National Oceanic and Atmospheric Administration: at http://www.ncdc.noaa.gov/oa/climate/extremes/1999/january/blizzard99.html (retrieved 13 April 2014).

Table 20: Injury Estimates Construction

Begin Date	Type	StormData Fatal	BDL Fatal	Under-count ratio	StormData Injured	Injured (adjusted)	Included/Excluded
3/11/1993	Blizzard	36	270	7.5	428	3,200	All but TX
1/17/1994	Cold Wave	0	70		0	1,850[533]	All
2/8/1994	Ice Storm	1	9	9	1600	14,400	Listed states
1/1/1996	Blizzard	33	154	4.7	186	870	All
1/5/1998	Ice Storm	2	16	8	2	16	Listed states
12/20/1998	Freeze	2	0		0	0	CA only
1/1/1999	Winter Storm	15	25	1.7	91	150	All
1/13/1999	Winter Storm	0	0		75	480[534]	Listed states + DC
1/11/2007	Freeze	0	1		0	0	CA only
4/4/2007	Freeze	0	0		0	0	Listed states
2/1/2011	Blizzard	1	36	36	0	950[535]	All
	Total	90			2,382		
			Average	**6.46**			

Economic Impacts

Direct Economic Impacts

Direct economic impacts as defined in the SNRA include decontamination, disposal, and physical destruction costs including property (structure, contents, physical infrastructure and other physical property) and crop damage; one year's lost spending due to fatalities; medical costs; and business interruption directly resulting from the impacts of an event. The direct economic loss estimates of the BDL were used for the 2015 SNRA without modification because of the close similarity of its direct economic loss estimation methodology with that of the SNRA.[536]

In performing these disaster cost assessments, the NCDC gathers the statistics from a wide variety of sources.[537] The total estimated costs of these events are the costs in terms of dollars that would not have been incurred had the event not taken place. Insured and uninsured losses are

533 Applying average StormData ratio 26.5 injuries/fatality to BDL fatalities to estimate total injuries (StormData reported 0 injured).

534 Applying average fatality undercount ratio of 6.46 (90 reported StormData fatalities/581 reported BDL fatalities) to reported StormData injuries.

535 Applying average StormData ratio 26.5 injuries/fatality to BDL fatalities to estimate total injuries (StormData reported 0 injured).

536 Smith et al (2013, June). U.S. billion-dollar weather and climate disasters: Data sources, trends, accuracy and biases. *Natural Hazards* 67(2) 387-410. At http://www.ncdc.noaa.gov/billions/docs/smith-and-katz-2013.pdf (retrieved 18 January 2014).

537 In 2012, NCDC reviewed its methodology how it develops Billion-dollar Disasters and examined possible inaccuracy and biases in the data sources and methodology used in developing the loss assessments. As a result NCDC temporarily rounded their loss estimates to the nearest billion dollars while implementing the newest research to define uncertainty and confidence intervals surrounding these loss estimates. The current methodology for the production of this loss data set is described in Smith et al (2013). This document highlights its strengths and limitations including sources of uncertainty and bias. The Insurance Services Office/Property Claims Service, the U.S. Federal Emergency Management Agency's National Flood Insurance Program and the U.S. Department of Agriculture's crop insurance program are key sources of quantified disaster loss data, among others. The methodology uses a factor approach to convert from insured losses to total direct losses, one potential limitation.

included in damage estimates. Sources include the National Weather Service, FEMA, U.S. Department of Agriculture, other U.S. Government agencies, individual state emergency management agencies, state and regional climate centers, media reports, and insurance industry estimates.[538] Given the threshold of $1 billon events, the best estimate was $3 billion with low and high estimates at $1 billion and $9 billion dollars, respectively.

Indirect Economic Impacts[539]

Direct economic losses alone do not represent the full picture of the economic impacts to the Nation from a disaster or attack. Indirect and induced economic losses can be substantially larger than the direct economic losses that occur in the aftermath of an event.

- Indirect economic impacts include costs incurred by the suppliers and vendors in the associated expenditure sectors for the industries impacted by the direct costs. Indirect impacts also include positive offsets due to increased spending within sectors impacted by the direct costs.[540]
- Induced economic impacts include those incurred due to reduced spending by households with members employed in any of the directly or indirectly affected industries. Induced impacts can also include substitution effects or likely transfers of economic activity from one set of sectors to another set, such as avoidance of air or other travel or altered transportation mode preferences to other sectors following an attack on the commercial air transport sector.

Highly mature economic models exist for calculating estimates of indirect and induced economic losses for natural disasters, human and animal pandemics, technological accidents, terrorist attacks, and cyber events. At present, there is no generally agreed upon or practical method for translating estimates produced by these disparate models into a single measure which can be meaningfully compared across all of the threats and hazards of the SNRA in a defensible fashion. Because such a measure would yield data of great value for multiple purposes beyond the context of the SNRA and similar assessments, it has been among the highest risk research priorities for the Department of Homeland Security (DHS) and its academic Centers of Excellence for over a decade. Should these efforts prove successful in coming years, the next iteration of the SNRA will include comparisons of total economic loss to the Nation across all of its threats and hazards.

Social Displacement

The impacts of extreme cold/winter weather in North American climate regions are comparatively minor, in the sense of permanent disruption to life for most individuals and communities. Impacts generally include closed business and schools along with decreased travel. With the exception of homes destroyed by collapsed roofs or storm-induced flooding, long-term social displacement resulting from this threat is rare.

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538 National Climatic Data Center; http://www.ncdc.noaa.gov/billions/overview.

539 The SNRA's taxonomy of indirect and induced economic impacts comes from the DHS Terrorism Risk Assessments and so is retained here for consistency across DHS assessments. However, both combined will be referred to as 'indirect economic impacts' where it is not expected to impede clarity.

540 These may include the waste management, environmental consulting, mortuary services, and medical industries, among others.

The SNRA 2015 'Risk summary sheet instructions and template' incorrectly notes that mortuary offsets were included in the direct economic impact metric of the 2011 SNRA. These offsets were accounted for in the calculations for indirect and induced costs, for those National-level Events having calculated estimates for those costs.

The SNRA project team was not able to find defensible estimates for persons displaced from home for 2 or more days corresponding to the historical data set of winter storm events used for the other impact estimates. Determining such estimates is a priority for the next update of the SNRA.

Psychological Consequences

The SNRA metric of psychological distress uses the fatality, injury/illness, and social displacement estimates as inputs (SNRA 2011 draft Unclassified Documentation of Findings, Appendix G). As social displacement estimates could not be determined for the Extreme Cold/Winter Weather event, the psychological distress consequence measure could not be calculated.

Environmental Impact

The environmental consequence estimate, which was assessed for the 23 original national-level events of the 2011 SNRA by subject matter experts from the U.S. Environmental Protection Agency (EPA), could not be assessed for the winter weather event which was added to the SNRA in calendar year 2015. A future iteration of the SNRA will assess the environmental impacts of this event.

Potential Mitigating Factors

Mitigation efforts to reduce the frequency severity of extreme cold/winter weather are related to a reduction in the burning of hydrocarbons through a decreased global dependence on fossil fuels. These mitigation efforts are focused on reduced occurrence and decreased severity rather than individual measures that can be taken to reduce extreme cold/winter weather mortality (e.g., limiting exposure to the elements, using safer heating devices). At present, emergency planning efforts to ensure vulnerable populations are cared for during extreme cold/winter weather events will limit health-related illnesses and fatalities from exposure.

Table 21: Extreme Cold/Winter Weather Events[541]

Begin Date[542]	End Date	Fatal	Inj-ured[543]	Cost $B (2014)	Description
01/08/1982	01/16/1982	85	2,250	2	Midwest/Southeast/Northeast Winter Storm/Coldwave - January 1982: Winter storm and coldwave affect numerous states (AL, AR, CT, DE, FL, GA, IA, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, MO, MS, NC, ND, NH, NJ, NY, OH, OK, PA, RI, SC, TN, TX, VA, VT, WI, WV) across the Midwest, Southeast and Northeast.
12/24/1983	12/25/1983	0	0	5	Florida Freeze - December 1983: Severe freeze central/northern Florida.
01/19/1985	01/22/1985	150	4,000	2	Winter Damage, Cold Wave - January 1985: Extreme cold and winter storms in the Southeast, South, Southwest, Northeast, Midwest, and North.

[541] Winter Storm and Freeze events as reported by the Billion Dollar Disaster List of NOAA's National Climatic Data Center (NCDC). NCDC (2015). Billion-dollar U.S. weather/climate disasters 1980–2013: at http://www.ncdc.noaa.gov/billions/events [dynamic resource: table represents data current as of 3 April 2015]. This table reflects the 2014 dollars reported by the NOAA source. The final SNRA estimates in the Data Table summary are converted to 2011 dollars for comparison with existing SNRA events (CPI 2014–2011, 0.950).

[542] Dates as reported by Web version (4/3/2015) of Billion Dollar Disaster List (static pdf version, http://www.ncdc.noaa.gov/billions/events.pdf [retrieved 3 April 2015] does not list exact dates for all incidents).

[543] Proxy estimates constructed from corresponding incidents 1993–2011 in the StormData database and ratios between BDL and StormData reported fatalities to account for underreporting and differing reporting of direct/indirect fatalities and injuries.

Begin Date[542]	End Date	Fatal	Inj-ured[543]	Cost $B (2014)	Description
01/20/1985	01/22/1985	0	0	3	Florida Freeze - January 1985: Severe freeze central/northern Florida.
12/21/1989	12/26/1989	100	2,700	1	Winter Damage, Cold Wave, Frost - December 1989: Northeast, Southeast hit by winter storms.
12/23/1989	12/25/1989	10	270	4	Florida Freeze - December 1989: Severe freeze damages citrus crops across central/northern Florida.
12/18/1990	12/25/1990	0	0	6	California Freeze - December 1990: Severe freeze in the Central and Southern San Joaquin Valley caused the loss of citrus, avocado trees, and other crops in many areas. Several days of subfreezing temperatures occurred, with some valley locations in the teens.
12/10/1992	12/13/1992	19	500	4	Nor'easter - December 1992: Slow-moving storm batters northeast U.S. coast, New England hardest hit.
03/11/1993	03/14/1993	270	3,200	9	Storm/Blizzard - March 1993: Storm of the Century hits entire eastern seaboard with tornadoes (FL), high winds, and heavy snows (2–4 feet).
01/17/1994	01/20/1994	70	1,859	2	Winter Damage, Cold Wave - January 1994: Winter storm affects Southeast and Northeast.
02/08/1994	02/13/1994	9	14,400	5	Southeast Ice Storm - February 1994: Intense ice storm with extensive damage in portions of TX, OK, AR, LA, MS, AL, TN, GA, SC, NC, and VA.
01/01/1996	01/31/1996	154[544]	870	4[545]	Blizzard [Blizzard/Flood] - January 1996: Very heavy snowstorm (1–4 feet) over Appalachians, Mid-Atlantic, and Northeast [followed by severe flooding in parts of same area due to rain and snowmelt].
01/05/1998	01/09/1998	16	16	2	Northeast Ice Storm - January 1998: Intense ice storm hits Maine, New Hampshire, Vermont, and New York, with extensive forestry losses.
12/20/1998	12/28/1998	0	0	4	California Freeze - December 1998: A severe freeze damaged fruit and vegetable crops in the Central and Southern San Joaquin Valley. Extended intervals of sub 27°F temperatures occurred over an 8-day period.
01/01/1999	01/04/1999	25	150	1	Winter Storm - January 1999: South, Southeast, Midwest, Northeast affected by damaging winter storm.
01/13/1999	01/16/1999	0	480	1	Central and Eastern Winter Storm - mid-January 1999: Winter storm affecting the Central and Eastern states including IL, IN, OH, MI, WV, VA, MD, PA, NJ, NY, MA, CT, VT, NH and ME.
01/11/2007	01/17/2007	1	0	2	California Freeze - January 2007: Widespread agricultural freeze— for nearly 2 weeks in January, overnight temperatures over a good portion of California dipped into the 20s, destroying numerous agricultural crops; with citrus, berry, and vegetable crops most affected.
04/04/2007	04/10/2007	0	0	2	Spring Freeze - April 2007: Widespread severe freeze over much of the east and Midwest (AL, AR, GA, IL, IN, IA, KS, KY, MS, MO, NE, NC, OH, OK, SC, TN, VA, WV), causing significant losses in fruit crops, field crops (especially wheat), and the ornamental industry. Temperatures in the teens/20s accompanied by rather high winds nullified typical crop-protection systems.
02/01/2011	02/03/2011	36	950	2	Groundhog Day Blizzard - February 1–3, 2011: A large winter storm impacted many central, eastern and northeastern states. The city of Chicago was brought to a virtual standstill as between 1 and 2 feet of snow fell over the area.

[544] Flood fatalities are backed out to avoid double counting with the SNRA Flood event. Of the 187 total fatalities reported by NCDC, 154 were reported as due to blizzard and winter conditions, and 33 as due to flooding. Lott et al (1996, April). The winter of '95–96: a season of extremes. Pp. 3–4. National Oceanic and Atmospheric Administration, National Climatic Data Center, technical report 96-02: at http://www1.ncdc.noaa.gov/pub/data/techrpts/tr9602/tr9602.pdf (retrieved 13 April 2014).

[545] Lott et al (1996) do not split out flood economic damages. The direct economic losses reported from the corresponding incident in the SNRA flood data set (flood risk summary sheet [SNRA 2011 draft Unclassified Documentation of Findings p 133], snowmelt flood VA-NY start date 1/18/1996: USD2011 $475,800,500 inflated to 2014 dollars [$500, 843,000] rounded to nearest billion to maintain one significant figure of primary NCDC source used for this summary sheet) were subtracted from the NCDC reported $5 billion total damage to avoid double counting with the SNRA flood event.

Drought

A drought occurs in the U.S. resulting in direct economic losses greater than $1 billion.

Category	Description	Metric	Low	Best	High
Health and Safety	Fatalities	Number of Fatalities	0[546]		
	Injuries and Illnesses	Number of Injuries or Illnesses			
Economic	Direct Economic Loss	U.S. Dollars[547]	$2 Billion	$8.7 Billion	$38 Billion
Social	Social Displacement	People Displaced from Home ≥ 2 Days	0[548]		
Psychological	Psychological Distress	Qualitative Bins	0[549]		
Environmental	Environmental Impact	Qualitative Bins	N/A		
Likelihood	Frequency of Events	Number of Events per Year[550]	0.50	0.63	1.0

This table shows the minimum, average, and maximum values for frequencies and consequences associated with the direct impacts of national-level droughts.[551] The event set evaluated was from 1980 to 2014 and contained a total of 22 droughts that met the $1 billion threshold. This analysis did not specifically include consideration for climate scenarios often associated with drought events (e.g. heat waves, reduction in precipitation and snowpack).

Event Background

The Strategic National Risk Assessment (SNRA) Drought National-level Event was originally developed by the DHS Office of Policy for the 2012-13 Homeland Security National Risk Characterization (HSNRC) project, a cooperative effort of the DHS analytic enterprise, to expand the 2011 SNRA risk knowledge base to additional threats and hazards relevant to

[546] There are no significant human health implications resulting from a drought in the United States. To avoid double counting of impacts between hazard events, for drought and heat wave incidents which overlapped in time or which were reported together in historical data sets the SNRA counted human fatalities and injuries under the Heat Wave event, while direct economic losses were counted under the Drought event. As both property damage (e.g. damage to physical infrastructure) and crop damage were reported by the primary data sources used for these events in the 2015 SNRA as combined totals, this raises the possibility of over-reporting the direct economic losses for Drought. Non-crop damages to physical infrastructure by heat events can be substantial. However, previous DHS analysis conducted for the 2013 Homeland Security National Risk Characterization (HSNRC) Drought National-level Event indicated that these property damage costs were generally insignificant in comparison to the economic value of lost crops which were orders of magnitude greater.

[547] Low, best, and high estimates for direct economic loss are the historical minimum, average, and maximum for the event set. Adjusted from 2014 dollars of NCDC source to 2011 dollars for comparison with existing SNRA events.

[548] See text for further description.

[549] No reported human health or displacement impacts. (The SNRA Psychological Distress Index is calculated from fatality, injury/illness, and displacement estimates. For Drought/Heat Wave events, non-economic impacts were reported under the Heat Wave event.)

[550] Historical lowest, average, and maximum number of events per year (calculated from interarrival times).

[551] Direct economic loss data was gathered from the National Oceanic and Atmospheric Administration (NOAA)'s National Climatic Data Center (NCDC).

national preparedness. The HSNRC data and analysis were updated and revised by Argonne National Laboratory in support of the 2015 SNRA.

The National Weather Service (NWS) defines drought as a deficiency in precipitation over an extended period, usually a season or more, resulting in a water shortage causing adverse impacts on vegetation, animals, and/or people. Drought is a temporary aberration from normal climatic conditions; thus it can vary significantly from one region to another.[552] It is a normal, recurrent feature of climate that occurs in virtually all climate zones. However, drought conditions can be caused by human interaction with the natural world.

Drought characteristics include large-scale drying trends in precipitation, streamflow, and soil moisture fields. The impacts of a drought result from the interplay between the natural event (less precipitation than expected) and the demand people place on the water supply.

While droughts and heat waves can occur at the same time, they are separate meteorological events and have been assessed independently in the SNRA. For further information on heat waves, please see the Heat Wave Risk Assessment.

The duration of droughts can vary greatly. For instance, there are cases when drought conditions develop relatively quickly and lasts a very short period of time, exacerbated by extreme heat and/or wind, and there are other cases when drought spans multiple years, or even decades.

Drought differs from other natural hazards in at least two significant ways:

- The onset and end of a drought can be difficult to determine. The effects of a drought can accumulate slowly, and may linger even after the apparent termination of an episode.
- Unlike most natural hazards, drought impacts are less obvious, and are spread over a larger geographic area.

During severe droughts, agricultural crops do not mature, wildlife and livestock are undernourished, land values decline, and unemployment increases. Droughts can cause a shortage of water for human and agricultural consumption, hydroelectric power, recreation, and navigation. Water quality may decline and the number and severity of wildfires may increase.[553]

Assumptions

- For the purpose of the SNRA, a national-level drought is defined as a drought producing direct economic loss in excess of $1 billion dollars.
- A 35-year time period, from Jan 1, 1980 to Dec 31, 2014, was used to estimate the interarrival rates/frequencies and consequences for droughts exceeding the $1 billion threshold. A full list of aggregated drought events used for this report is located in Table 22. The Data Summary table reports the maximum, average, and minimum frequency with which such droughts occurred in the United States, and the maximum, average and minimum

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[552] National Weather Service (2008, May). Drought: Public Fact Sheet. At http://www.nws.noaa.gov/om/brochures/climate/DroughtPublic2.pdf (retrieved December 2012).

[553] This section is substantially adapted from Chapter 15 of Federal Emergency Management Administration (1997), Multi-Hazard Identification and Risk Assessment (MHIRA): A Cornerstone of the National Mitigation Strategy. FEMA Mitigation Directorate. At https://www.fema.gov/media-library/assets/documents/7251?id=2214 (retrieved April 2013).

consequences for fatalities, injuries, and direct economic losses associated with droughts in the data set.

- Mean global drought conditions were not directly considered in this assessment. The focus of this analysis was limited to the climatic regions within the contiguous United States.

Frequency

For purposes of the SNRA, drought risk is based on historical weather and climate disasters reported by the National Oceanic and Atmospheric Administration (NOAA)'s National Climatic Data Center (NCDC) for the Billion Dollar Disaster List.[554] The best-estimate frequency is the average frequency of occurrence of droughts in the selected 35-year period. The low frequency is the inverse of the longest interarrival time in the data set (the longest number of years that two droughts are spaced apart); the high frequency is the inverse of the shortest interarrival time in the data set (the shortest number of years that two incidents are spaced apart).

Health and Safety

There were no fatalities or illness/injuries directly linked to the droughts in this data set.[555] In the developed world, widespread drought-related deaths are rare in the modern era. However, increasing drought conditions in developed countries such as the United States can have significant direct and indirect impact to food supplies which may put populations at risk.[556]

Economic Impacts

Direct Economic Impacts

Direct economic impacts as defined in the SNRA include decontamination, disposal, and physical destruction costs including property (structure, contents, physical infrastructure, and other physical property) and crop damage; one year's lost spending due to fatalities; medical costs; and business interruption directly resulting from the impacts of an event. The direct economic loss estimates of the Billion Dollar Disaster List were used for the 2015 SNRA without modification because of the close similarity of its direct economic loss estimation methodology with that of the SNRA.[557]

In performing these disaster cost assessments, NCDC gathers the statistics from a wide variety of sources.[558] The total estimated costs of these events are the costs in terms of dollars that would not have been incurred had the event not taken place. Insured and uninsured losses are included

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[554] NCDC (2015). Billion-dollar U.S. weather/climate disasters 1980-2013. NOAA: at http://www.ncdc.noaa.gov/billions/events.

[555] To avoid double counting of impacts between hazard events, for drought and heat wave incidents which overlapped in time or which were reported together in historical data sets the SNRA counted human fatalities and injuries under the Heat Wave event, while direct economic losses were counted under the Drought event.

[556] Franke, R. W.; Chasin B. H. Seeds of famine: Ecological destruction and the development dilemma in the West African Sahel. Rowman/Allanheld: Towtowa, New Jersey, 1980.

[557] Smith et al (2013, June). U.S. billion-dollar weather and climate disasters: Data sources, trends, accuracy and biases. *Natural Hazards* 67(2) 387-410. At http://www.ncdc.noaa.gov/billions/docs/smith-and-katz-2013.pdf (retrieved 18 January 2014).

[558] In 2012, NCDC reviewed its methodology how it develops Billion-dollar Disasters and examined possible inaccuracy and biases in the data sources and methodology used in developing the loss assessments. As a result, NCDC temporarily rounded their loss estimates to the nearest billion dollars while implementing the newest research to define uncertainty and confidence intervals surrounding these loss estimates. The current methodology for the production of this loss dataset is described in Smith et al (2013), *op. cit.* This document highlights its strengths and limitations including sources of uncertainty and bias. The Insurance Services Office/Property Claims Service, the FEMA National Flood Insurance Program and the U.S. Department of Agriculture's crop insurance program are key sources of quantified disaster loss data, among others. The methodology uses a factor approach to convert from insured losses to total direct losses, one potential limitation.

in damage estimates. Sources include the NWS, the Federal Emergency Management Agency (FEMA), U.S. Department of Agriculture, other U.S. government agencies, individual state emergency management agencies, state and regional climate centers, media reports, and insurance industry estimates. [559]

For the NCDC source list, economic drought damages were inflated to a 2014 dollar value using average changes in the Consumer Price Index. In total, 22 droughts exceeding the $1 billion threshold are aggregated in the findings of this report. Low, best, and high estimates for direct economic loss are the historical minimum, average, and maximum for the event set, adjusted to 2011 dollars for comparison with the existing SNRA data set.[560]

The total loss for the 22 events was $201 billion (see Table 22 for a full breakdown of cost per event). The historical high for economic losses was the 1988 drought at $38 billion [2014 $40 billion], which was rated as one of the nation's worst in the past 100 years. The 1988 drought impacted large portions of the U.S. with very severe losses to agriculture and related industries. Barge traffic on the lower Mississippi River was stopped during June and July 1988 as a result of record low flows caused by drought conditions throughout most of the Mississippi Basin. [561] Five separate drought events (1993, 1996, 2005, 2006, and 2014) all reported the historical low for economic loss at $2 billion. The average economic consequence is $8.7 billion [2014 $9.1 billion] per event. The largest gap between drought events of two years occurred twice during the event set—between 1980 and 1983, and again between 1993 and 1996.

Indirect Economic Impacts[562]

Direct economic losses alone do not represent the full picture of the economic impacts to the Nation from a disaster or attack. Indirect and induced economic losses can be substantially larger than the direct economic losses that occur in the aftermath of an event.

- *Indirect economic impacts* include costs incurred by the suppliers and vendors in the associated expenditure sectors for the industries impacted by the direct costs. Indirect impacts also include positive offsets due to increased spending within sectors impacted by the direct costs. [563]
- *Induced economic impacts* include those incurred due to reduced spending by households with members employed in any of the directly or indirectly affected industries. Induced impacts can also include substitution effects or likely transfers of economic activity from one set of sectors to another set, such as avoidance of air or other travel or altered transportation mode preferences to other sectors following an attack on the commercial air transport sector.

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[559] NCDC (2015). Billion-dollar disaster list, Overview: http://www.ncdc.noaa.gov/billions/overview.

[560] CPI-U 2014-2011, 0.950.

[561] Chagnon, Stanley A. (1989, September). The 1988 drought, barges, and diversion. *Bulletin of the American Meteorological Society* 70(9) 1092-1104: available at http://journals.ametsoc.org/doi/abs/10.1175/1520-0477%281989%29070%3C1092%3ATDBAD%3E2.0.CO%3B2 (accessed on March 25, 2015).

[562] The SNRA's taxonomy of indirect and induced economic impacts comes from the DHS Terrorism Risk Assessments and so is retained here for consistency across DHS assessments. However, both combined will be referred to as 'indirect economic impacts' where it is not expected to impede clarity.

[563] These may include the waste management, environmental consulting, mortuary services, and medical industries, among others.

The SNRA 2015 'Risk summary sheet instructions and template' incorrectly notes that mortuary offsets were included in the direct economic impact metric of the 2011 SNRA. These offsets were accounted for in the calculations for indirect and induced costs, for those National-level Events having calculated estimates for those costs.

Highly mature economic models exist for calculating estimates of indirect and induced economic losses for natural disasters, human and animal pandemics, technological accidents, terrorist attacks, and cyber events. However, there is at present no generally agreed or practical method for translating estimates produced by these disparate models into a single measure which can be meaningfully compared across all of the threats and hazards of the SNRA in a defensible fashion. Because such a measure would yield data of great value for multiple purposes beyond the context of the SNRA and similar assessments, it has been among the highest risk research priorities for DHS and its academic Centers of Excellence for over a decade. Should these efforts prove successful in coming years, the next iteration of the SNRA will include comparisons of total economic loss to the Nation across all of its threats and hazards.

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. By this measure, social displacement was assessed to be zero as a result of national level droughts. [564]

Note that there are limitations to this measure of social displacement, as permanent migration due to job loss or lack of opportunities from a hazard such as drought are not captured through this measure. For instance, during the Dust Bowl in the 1930's, millions of people migrated from the drought areas, often heading west, in search of work. [565]

Psychological Impacts

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs. [566]

Fatalities and injuries associated with historical heat wave/drought events were counted under the Heat Wave event by definition, and as noted above the assessed displacement was zero. As the SNRA psychological distress index is derived from the human health and displacement impact estimates, this measure reflects *de minimus* psychological distress impacts for the SNRA 2015 Drought event.

Environmental Impacts

The environmental consequence estimate, which was assessed for the 23 original national-level events of the 2011 SNRA by subject matter experts from the U.S. Environmental Protection Agency (EPA), could not be assessed for the Drought event which was added to the SNRA in

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[564] For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. To estimate social displacement for the SNRA, U.S. drought data from the Emergency Events Database (EM-DAT) maintained by the World Health Organization Collaborating Centre for Research on the Epidemiology of Disasters with support from the United States Agency for International Development, provides estimates of the "total number affected" by disaster events. The data from EM-DAT suggest that there were no displacements as a direct result of drought events.

[565] Reported by the National Drought Mitigation Center, http://drought.unl.edu/DroughtBasics/DustBowl/DroughtintheDustBowlYears.aspx.

[566] See Appendix G of the SNRA draft Unclassified Documentation of Findings for references and additional discussion of the SNRA Psychological Distress metric.

calendar year 2015. A future iteration of the SNRA will assess the environmental impacts of this event.

Potential Mitigating Factors

According to the National Drought Mitigation Center, studies over the past century have shown that meteorological drought is never the result of a single cause. It is the result of many causes, often synergistic in nature.

Scientists do not know how to predict drought a month or more in advance for most locations. Predicting drought depends on the ability to forecast two fundamental meteorological parameters, precipitation and temperature. Historical record reinforces that climate is inherently variable, and anomalies of precipitation and temperature may last from several months to several decades. How long they last depends on air–sea interactions, soil moisture and land surface processes, topography, internal dynamics, and the accumulated influence of dynamically unstable weather systems at the global scale. [567]

Additional Relevant Information

Although a variety of weather related phenomena have the potential to cause great economic and personal losses in the US, drought has historically had the greatest impact on the largest number of people. On a broad scale, the 1980's and 1990's were characterized by unusual wetness with short periods of extensive droughts, the 1930's and 1950's were characterized by prolonged periods of extensive droughts with little wetness, and the first decade of the 2000's saw extensive drought and extensive wetness.

Table 22: Drought Events[568]

Event	Begin Date	End Date	Summary	Direct Economic Loss ($ B) ($2014)[569]
Western Drought 2014	01/01/2014	12/31/2014	Historic drought conditions affected the majority of California for all of 2014 making it the worst drought on record for the state. Surrounding states and parts of Texas and Oklahoma also experienced continued severe drought conditions. This is a continuation of drought conditions that have persisted for several years.	$2
Western/Plains Drought/Heatwave Spring-Fall 2013	03/01/2013	11/30/2013	The 2013 drought slowly dissipated from the historic levels of the 2012 drought, as conditions improved across many Midwestern and Plains states. However, moderate to extreme drought did remain or expand into western states (AZ, CA, CO, IA, ID, IL, KS, MI, MN, MO, ND, NE, NM, NV, OK, OR, SD, TX, UT, WA, WI, WY). In comparison to 2011 and 2012 drought conditions, the U.S. experienced only moderate crop losses across the central agriculture states.	$11

567 National Drought Mitigation Center is based in the School of Natural Resources at the University of Nebraska-Lincoln; http://drought.unl.edu/Home.aspx.

568 Table based on information reported by NOAA's National Climactic Data Center (NCDC). This table reflects the 2014 dollars reported by the NOAA source. The final SNRA estimates in the Data Summary table are converted to 2011 dollars for comparison with existing SNRA events (CPI 2014-2011, 0.950).

569 Costs adjusted to 2014 dollars: Cost estimates are rounded to nearest billion-dollars. Ongoing research is seeking to define uncertainty and confidence intervals around the cost of each event.

Event	Begin Date	End Date	Summary	Direct Economic Loss ($ B) ($2014)[569]
U.S. Drought/ Heatwave 2012	01/01/2012	12/31/2012	The 2012 drought is the most extensive drought to affect the U.S. since the 1930s. Moderate to extreme drought conditions affected more than half the country for a majority of 2012. The following states were affected: CA, NV, ID, MT, WY, UT, CO, AZ, NM, TX, ND, SD, NE, KS, OK, AR, MO, IA, MN, IL, IN, GA. Costly drought impacts occurred across the central agriculture states resulting in widespread harvest failure for corn, sorghum and soybean crops, among others. The associated summer heatwave also caused 123 direct deaths, but an estimate of the excess mortality due to heat stress is still unknown.	$31
Southern/Plains/ Southwest Drought Spring-Summer 2011	03/01/2011	08/31/2011	Drought and heat wave conditions created major impacts across Texas, Oklahoma, New Mexico, Arizona, southern Kansas, and western Louisiana. In Texas and Oklahoma, a majority of range and pastures were classified in "very poor" condition for much of the 2011 crop growing season.	$13
Southwest/Great Plains Drought 2009	01/01/2009	12/31/2009	Drought conditions occurred during much of the year across parts of the Southwest, Great Plains, and southern Texas causing agricultural losses in numerous states (TX, OK, KS, CA, NM, AZ). The largest agriculture losses occurred in TX and CA.	$4
U.S. Drought 2008	01/01/2008	12/31/2008	Severe drought and heat caused agricultural losses across a large portion of the U.S. Record low lake levels also occurred in areas of the southeast.	$8
Western/Eastern Drought/Heatwave Summer-Fall 2007	06/01/2007	11/30/2007	Severe drought with periods of extreme heat over most of the southeast and portions of the Great Plains, Ohio Valley, and Great Lakes area, resulting in major reductions in crop yields, along with very low stream-flows and lake levels. Includes states of ND, SD, NE, KS, OK, TX, MN, WI, IA, MO, AR, LA, MS, AL, GA, NC, SC, FL, TN, VA, WV, KY, IN, IL, OH, MI, PA, NY.	$3
Midwest/Plains/ Southeast Drought Spring-Summer 2006	03/01/2006	08/31/2006	Rather severe localized drought causes significant crop losses (especially for corn and soybeans) in the states of AR, IL, IN, MO, OH, and WI.	$2
Midwest Drought Spring-Summer 2005	03/01/2005	08/31/2005	Rather severe localized drought causes significant crop losses (especially for corn and soybeans) in the states of AR, IL, IN, MO, OH, and WI.	$2
Western/Central Drought/Heatwave Spring-Fall 2003	03/01/2003	11/30/2003	2003 drought across western and central portions of the U.S. with losses to agriculture.	$6
U.S. Drought Spring-Fall 2002	03/01/2002	11/30/2002	Moderate to extreme drought over large portions of 30 states, including the western states, the Great Plains, and much of the eastern U.S.	$11
Western/Central/ Southeast Drought/ Heatwave Spring-Fall 2000	03/01/2000	11/30/2000	Western/Central/Southeast Drought/Heatwave.	$7
Eastern Drought/ Heat Wave	06/01/1999	08/31/1999	Very dry summer and high temperatures, mainly in eastern U.S., with extensive agricultural losses.	$3

Event	Begin Date	End Date	Summary	Direct Economic Loss ($ B) ($2014)[569]
Summer 1999				
Southeast Drought/ Heat Wave Summer 1998	06/01/1998	08/31/1998	Severe drought and heat wave from Texas/Oklahoma eastward to the Carolinas.	$6
Southern Plains Drought Spring-Summer 1996	03/01/1996	08/31/1996	Severe drought in agricultural regions of southern plains--Texas and Oklahoma most severely affected.	$2
Southeast Drought/ Heat Wave Summer 1993	06/01/1993	08/31/1993	Drought and heat wave across Southeastern U.S.	$2
U.S. Drought Spring-Summer 1991	03/01/1991	08/31/1991	Drought conditions over parts of the West, Central and eastern U.S. most affected the states IL, IN, KS, MN, OH, OR, PA, SD, and WA.	$5
Northern Plains Drought Summer-Fall 1989	6/1/1989	11/30/1989	Severe summer drought over much of the northern plains with significant losses to agriculture.	$4
U.S. Drought/ Heatwave Summer 1988	6/1/1988	8/31/1988	1988 drought across a large portion of the U.S. with very severe losses to agriculture and related industries. Combined direct and indirect deaths (i.e., excess mortality) due to heat stress estimated at 5,000.	$40
Southeast Drought/ Heatwave Summer 1986	6/1/1986	8/31/1986	Severe summer drought in parts of the southeastern U.S. with severe losses to agriculture.	$4
Southeast Drought Summer 1983	6/1/1983	8/31/1983	1983 flash drought in the southeastern U.S. with losses to agriculture, most notably corn and soybeans.	$6
Central/Eastern Drought/Heatwave Summer-Fall 1980	6/1/1980	11/30/1980	Central and eastern U.S. drought/heat wave caused damage to agriculture and other related industries. Combined direct and indirect deaths (i.e., excess mortality) due to heat stress estimated at 10,000.	$29

Climate Change

Scientific evidence indicates that the climate is changing[570] and significant economic, social, and environmental consequences can be expected as a result. Climate change is becoming an increasingly significant factor in assessing and managing risks and vulnerabilities to extreme events. Over the last 50 years, much of the U.S. has seen increases in prolonged periods of excessively high temperatures, heavy downpours, and in some regions, severe floods and droughts.[571] These changes have further cascading effects on human health, water supply, agriculture, and energy and transportation infrastructure. Recognizing how climate change may alter hazard trends is the first step to protect against, mitigate the effects of, respond to, and recover from both typical and catastrophic events.

Climate Change Impacts on Natural Hazard Risk

Long-term, independent records from weather stations, satellites, ocean buoys, tide gauges, and many other data sources all confirm that the Nation, like the rest of the world, is in the midst of a long-term warming trend.[572] Although the warming trend is clear, the exact quantitative risk of climate change is difficult to estimate due to natural climatic variations.[573] The Third National Climate Assessment (NCA3), was produced by a team of more than 300 experts, guided by a 60-member Federal Advisory Committee, and extensively reviewed by the public and experts, including federal agencies and a panel from the National Academy of Sciences. The NCA3 comprises the best available scientific data on the potential impacts of climate change in the U.S. and summarizes the status of the current scientific consensus on various aspects of climate change.

Climate change presents a challenge to individuals throughout the Nation, however, its impacts will vary across the U.S. The NCA3 describes eight regions and their anticipated changes in climate-related hazards:

- In the Northeast, communities will be affected by heat waves, more extreme precipitation events, and coastal flooding due to sea level rise and storm surge.
- In the Southeast and Caribbean, decreased water availability, exacerbated by population growth and land use change, will cause increased competition for water in addition to growing risks associated with extreme events such as hurricanes.
- In the Midwest, an increased occurrence of extreme events such as heat waves, droughts, and floods is anticipated.
- In the Great Plains, rising temperatures will lead to increased demand for water and energy, as well as impacts on agricultural practices.

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[570] U.S. Third National Climate Assessment (NCA3), "*Climate Change Impacts in the United States The Third National Climate Assessment*," U.S. Global Change Research Program, May 2014 http://nca2014.globalchange.gov/report , Pg. 1

[571] NCA3 Highlights," *Climate Change Impacts in the United States: The Third National Climate Assessment: Highlights."*. http://nca2014.globalchange.gov/Highlights, Pg. 24

[572] NCA3

[573] NCA3, Pg. 28

- In the Southwest, drought and increased warming will increase the risk of wildfires and competition for scarce water resources.
- In the Northwest, changes in the timing of streamflow due to earlier snowmelt will reduce the supply of water in the summer, causing far-reaching ecological and socioeconomic consequences.
- In Alaska, rapidly receding summer sea ice, shrinking glaciers, and thawing permafrost cause damage to infrastructure and major changes to ecosystems.
- In Hawai'i and the Pacific Islands, increasingly constrained fresh water supplies, coupled with increased temperatures, will stress both people and ecosystems and decrease food and water security.[574]

Historical risk profiles for hazards may no longer serve as effective planning tools for identifying and addressing future risks. Climate change has the potential to affect the frequency, intensity, and/or geographic range of many natural hazards. However, due to the complexity of climatological forecasting and the plethora of anticipated impacts, not all projections are backed by equally strong scientific evidence. Some are backed by scientific consensus and a comprehensive body of supporting data; others are supported by limited studies, or are the subject of ongoing scientific debate. Table 24 identifies key natural hazards that will potentially be affected by climate change, and how, as well as the degree of scientific confidence behind each anticipated or observed change in hazard characteristic, according to the NCA3.

Table 23: Climate Change Impacts Table Legend

Hazard	Identifies the hazard for which there is either a projected future or an observed historical shift in frequency, intensity, or range of impact.
"Very High" to "Low"	Indicates the degree of scientific confidence that climate change has/will affect the given hazard characteristic.[575] Note: Some of the projected hazard increases/shifts have differing degrees of scientific confidence in different regions. This is noted in the qualitative description when applicable.
Qualitative description for each hazard	Provides additional information as to whether the shift is projected (future) vs. observed (current), or regional vs. national in nature. Also provides the source page number from NCA3, or NCA3 Highlights, for each statement.

[574] NCA3 Highlights, Pg 8

[575] "**Very High**" - High scientific consensus due to established theory, multiple sources, consistent results, well documented and accepted methods, etc.

"**High**" - Medium scientific consensus due to several sources, some consistency, methods vary and/or documentation limited, etc.

"**Medium**" - Competing schools of thought due to suggestive evidence, few sources, limited consistency, models incomplete, methods emerging, etc.

"**Low**" - Inconclusive evidence due to limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.; disagreement or lack of opinions among experts.

Table 24: Climate Change Impacts on Natural Hazards in the U.S.

<table>
<tr><th>Hazard Characteristic:</th><th>Increase in Frequency</th><th>Increase in Intensity</th><th>Shift in Geographic Range of Impacts</th></tr>
<tr><td>Wildfire</td><td>Very High Confidence</td><td>Very High Confidence</td><td></td></tr>
<tr><td colspan="4">
Hotter and drier weather and earlier snowmelt may result in wildfires in the west starting earlier in the spring, lasting later into the fall, and burning more acreage. (NCA3 Pg 1)
There is very high confidence that western forests in the United States will be affected increasingly by large and intense fires that occur more frequently. Wildfires will increase substantially in response to warming and also in conjunction with other changes such as an increase in the frequency and/or severity of drought and amplification of pest and pathogen impacts. (192)
Eastern forests are less likely to experience immediate increases in wildfire unless/until a point is reached at which warmer temperatures, concurrent with seasonal dry periods or more protracted drought, trigger wildfires. (192)
Excessive wildfire destroys homes, exposes slopes to erosion and landslides, threatens public health, and causes economic damage. (468)
</td></tr>
<tr><td>Floods</td><td>Regional Trends</td><td>Regional Trends</td><td></td></tr>
<tr><td colspan="4">
Increasing heavy precipitation events will contribute to flash floods and urban floods, while rising sea levels will contribute to increasing tidal and storm-related flooding. (75)
Confidence is very high that sea level will continue to rise; medium confidence that the rise will be in the range of one to four feet by 2100, (66)
Rates of sea level rise are not uniform along U.S. coasts and can be exacerbated locally by land subsidence or reduced by uplift. (582)
Detailed hydrologic models of rivers that simulate response to projected precipitation and temperature changes from climate models have only recently begun to emerge in peer-reviewed literature. Confidence in current estimates of future changes in flood frequencies and intensities is overall judged to be low [nationally], due to the impact of future development and the need to conduct individual projections for each river basin. (107)
Confidence is high that there have been regional trends in floods and droughts. (65)

Northeast: Very High confidence for sea level rise and increasing coastal flooding as well as heat waves; High confidence for more intense precipitation events and riverine flooding. (393)
Midwest: There is Medium confidence that, in the absence of substantial adaptation actions, the enhancement in extreme precipitation and other tendencies in land use and land cover result in a projected increase in flooding. (439)
Southwest: There is Very High confidence the sea level will continue to rise and that this will entail major damage to coastal regions in the Southwest. There is also very high confidence that flooding and erosion in coastal areas are already occurring even at existing sea levels and damaging some areas of the California coast during storms and extreme high tides. (485)
Northwest: There is High confidence in the projections of increased [coastal] erosion and inundation. (509)

</td></tr>
</table>

<table>
<tr><th>Hazard Characteristic:</th><th>Increase in Frequency</th><th>Increase in Intensity</th><th>Shift in Geographic Range of Impacts</th></tr>
<tr><td>Drought</td><td>High Confidence</td><td>High Confidence</td><td></td></tr>
<tr><td colspan="4">
▪ The number of extremely hot days is projected to continue to increase over much of the U.S., especially by late century. (39)
▪ Higher temperatures cause increased rates of evaporation, which may result in a decrease of surface water and soil moisture, and lead to drought conditions even when there is no decrease in precipitation. (Highlights 24)
▪ Potential secondary impacts include an increase in wildfire severity and frequency (32), a reduction in energy generation capacity in areas that rely on hydropower (85), and a decrease in water quality due to higher relative concentrations of contaminants in surface water. (78)
▪ Confidence is judged to be medium-high that short-term (seasonal or shorter) droughts are expected to intensify in most U.S. regions. Confidence is high that longer-term droughts are expected to intensify in large areas of the southern U.S. (107)
▪ Confidence is high that the length of dry spells is projected to increase in most areas, especially the southern and northwestern portions of the contiguous U.S. (106)
▪ Confidence is judged to be medium-high that short-term (seasonal or shorter) droughts are expected to intensify in most U.S. regions. Confidence is high that longer-term droughts are expected to intensify in large areas of the Southwest, southern Great Plains, and Southeast. (107)
</td></tr>
<tr><td>Extreme Heat</td><td>High Confidence</td><td>High Confidence</td><td></td></tr>
<tr><td colspan="4">
▪ Climate change has increased the probability of heat waves. Prolonged (multi-month) extreme heat has been unprecedented since the start of reliable instrumental records in 1895. (NCA 3 Highlights Pg 24)
▪ The national number of heat waves in 2011 and 2012 was almost triple the long-term average. (Highlights 24)
▪ Heat waves sharply increase risks of power outages and fatalities from heat stroke and related conditions, particularly in urban areas. (NCA 3 Pg 224)
▪ High confidence that heat waves everywhere are projected to become more intense in the future. (64)
▪ High confidence that heat waves have become more frequent and intense, especially in the West. (64)
</td></tr>
<tr><td>Heavy Precipitation</td><td>High Confidence</td><td>High Confidence</td><td></td></tr>
<tr><td colspan="4">
▪ Over the last three to five decades, the heaviest rainfall events have become heavier and more frequent, and the amount of rain falling on the heaviest days has also increased. (Highlights 25)
▪ High confidence that heavy downpours are increasing, and will continue to increase, in most regions of the U.S., with especially large increases in the Midwest and Northeast. (64)
▪ High confidence that further increases in the frequency and intensity of extreme precipitation events are projected for most U.S. areas, including in regions where total precipitation is projected to decrease, such as the Southwest. (37)
▪ Secondary impacts may include increases in flash flooding, erosion and landslides, as well as associated infrastructure stresses.
</td></tr>
</table>

Hazard Characteristic:	Increase in Frequency	Increase in Intensity	Shift in Geographic Range of Impacts
Hurricanes	Medium Confidence	Medium Confidence	
▪ Although there are many contributing factors that make hurricanes difficult to predict, most models project an overall increase in the frequency of the strongest (Category 4 and 5) hurricanes by the end of the century. (41) ▪ Rising sea levels along the Atlantic and Gulf coasts will make coastal areas even more vulnerable to storm surge. (401) ▪ Overall, medium confidence that hurricane intensity and rainfall rates are projected to increase as the climate continues to warm. (65)			
Winter Storms	Medium Confidence	Medium Confidence	Medium Confidence
▪ There is evidence of an increase in both winter storm frequency and intensity since 1950 in the northern and eastern parts of the U.S., but they have been less frequent since 2000. (43) ▪ Confidence is high that cold waves have become less frequent and intense across the Nation. (64) ▪ Confidence is medium that winter storms have increased slightly in frequency and intensity, and that their tracks have shifted. (65)			
Tornadoes	Low	Low	
▪ A recent study suggests a projected increased in the conditions favorable for severe thunderstorms, but more studies are required. (43) ▪ Low confidence in increasing trend in intensity and frequency of tornadoes, hail and damaging thunderstorms. (65)			

Other Considerations

As climate change alters the natural hazard risk environment, cascading risk and vulnerability effects on public health, natural resources, infrastructure, and society are likely. The social and health-related impacts of climate change will likely be more concentrated in communities that already face economic or health-related challenges,[576] but may substantially affect the capacity of communities as a whole to prepare for, respond to, and recover from increasing threats from natural hazards. Below are examples of climate change-related effects that can increase vulnerability to extreme events.

Natural Resources Effects: Climate change, combined with other stressors, is overwhelming the capacity of ecosystems to buffer the impacts from extreme events like droughts, floods, and storms.[577] Salt marshes, reefs, mangrove forests, and barrier islands provide an ecosystem service of defending coastal ecosystems and infrastructure against storm surges. Losses of these natural features to sea level rise and other causes render coastal ecosystems and infrastructure more vulnerable to catastrophic damage during or after extreme events.

Infrastructure Effects: Much of the Nation's infrastructure, including buildings and energy, transportation, water, and sanitation systems, is outdated and/or in need of upgrades. This existing infrastructure is expected to become "more stressed in the next decades – especially when the impacts of climate change are added to the equation."[578] Increased exposure to hazards due to climate change may lead decision makers and planners to consider how climate change will affect their new and existing infrastructure systems, assets, and networks across the lifespan of those structures. Anticipated impacts include a reduction in the reliability and capacity of transportation infrastructure and systems, which are critical to lifesaving response efforts and disaster recovery.[579] Additionally, urban infrastructure systems are highly interdependent, so a failure in one sector may have "cascading effects across affected urban economies."[580]

While it may be obvious that infrastructure faces challenges nationwide, infrastructure exposure to natural hazards is a nationwide concern and requires further analysis and investment in order to mitigate risks of disruption. The Department of Homeland Security (DHS) National Protection and Programs Directorate (NPPD) conducted an in-depth analysis of infrastructure exposure[581] to natural hazards in the contiguous U.S. The preliminary analysis reveals where existing infrastructure systems are exposed to natural hazards and where that exposure may shift due to climate change.[582] Even without adjusting for climate change, the Nation's infrastructure is exposed to a range of natural hazards such as landslides, hurricanes, earthquakes, tornados, and

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[576] NCA 228-229

[577] NCA3, Pg. 217

[578] NCA3, Pg. 283

[579] NCA3 Highlights, Pg. 40

[580] NCA3, Pg. 283

[581] DHS NPPD commissioned the RAND Corporation to conduct analysis on infrastructure exposure to natural hazards. As of April 2015, the data, methods, analysis, and findings are being documented and will be reviewed by representatives from across the interagency.

[582] For the purposes of this analysis, permanent inundation, tidal flooding, coastal surge, extreme temperatures, drought, and wildfires were considered to be impacted by climate change. Earthquakes, landslides, tornadoes, tsunamis, ice storms, riverine flooding, and hurricane winds were not considered related to climate change, as there is not sufficient data to support a nationwide evaluation of how the hazard could be expected to change.

wildfire. While additional analysis is required to quantify the vulnerability of specific infrastructure systems to climate-related hazards, understanding infrastructure exposure is an important step in planning for adapting to the impacts of climate change.

Water Insecurity: Changes in water availability have the potential to drive "critical climate-related conflicts and relief challenges across the globe."[583] Climate change is projected to reduce water availability and increase demand in the American Southwest and Southeast.[584] This will create water management challenges, including potential competition between sectors and/or land owners. The agricultural sector is currently responsible for around 70 percent of freshwater consumption. There is also the potential, as water becomes a scarcer resource for water infrastructure to become an increasingly attractive target for terrorism.

Sea Level Rise: Global sea level has risen by about eight inches since reliable record keeping began in 1880. It is projected to rise another one to four feet by 2100. [585] This rise will not be constant throughout the U.S., but will be impacted by coastal uplift and subsidence as well as any movement of the Atlantic jet stream. For example, in the same period of 1880 to present, the relative sea level rise was approximately one foot in the Northeast.[586] Since 1992, the rate of global sea level rise measured by satellites has been roughly twice the rate observed over the last century, indicating a potential increase in the rate of sea level rise.

Health Effects: Increasing heat waves, worsening air quality, and more favorable growing conditions for common allergens may increase the strain on health systems due to increasing chronic heat-, respiratory-, and allergy-related conditions.[587] The Department of Health and Human Services (HHS) Climate Change Adaptation Plan[588] identifies several effects that climate change can have on public health. These impacts will likely be most severe among individuals and communities that already face economic or health-related challenges. Individuals with asthma are especially vulnerable to health consequences associated with extreme heat, wildfires, and mold outbreaks from flood events. Asthma prevalence (the percentage of people who have ever been diagnosed with asthma and still have asthma) increased nationwide from 7.3% in 2001 to 8.4% in 2010.[589] Heat waves can also worsen specific health concerns not traditionally associated with heat, such as cardiovascular disease and respiratory disease, leading to spikes in hospitalizations during extreme heat events.[590] Finally, the changing climate may impact the geographic range and lengthen the active season of tropical disease-carrying vectors such as mosquitoes.[591]

Food Insecurity: During the next century, the predicted higher incidence of extreme weather will influence agricultural productivity. Near-term climate change effects on agriculture include the potential for increased soil erosion through extreme precipitation events, as well as regional

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[583] National Research Council "*Climate and Social Stress*," Pg. 98

[584] NCA3, Pg. 87

[585] NCA3, Pg. 66

[586] NCA3, Pg. 370

[587] NCA3, Pg. 222

[588] *HHS Climate Change Adaptation Plan*. U.S. Department of Health and Human Services. 2012. http://www.hhs.gov/about/sustainability/adaptation-plan.pdf

[589] NCA3, Pg. 222

[590] NCA3, Pg. 224

[591] NCA3, Pg. 225

and seasonal changes in the availability of water resources for both rain-fed and irrigated agriculture.[592] According to the U.S. Department of Agriculture (USDA) Climate Change Adaptation plan, pressures associated with climate change, including "weeds, diseases, and insect pests, together with potential changes in timing and coincidence of pollinator lifecycles, will affect growth and yields."[593] In addition to impacting crop agriculture, climate change can "affect animal agriculture in four primary ways: (1) feed-grain production, availability, and price; (2) pastures and forage crop production and quality; (3) animal health, growth, and reproduction; and (4) disease and pest distributions."[594]

In response to the above pressures, food prices are expected to rise.[595] Historically, food insecurity rises with rising food prices, and the NCA3 notes that in such situations, "people cope by turning to nutrient-poor but calorie-rich foods, and/or they endure hunger, with consequences ranging from micronutrient malnutrition to obesity."[596] Additionally, Americans with specific dietary patterns, such as Alaska Natives, will confront shortages of key foods.[597]

Mass Migration/Social Displacement: Climate change could displace many socially vulnerable individuals and lead to significant social disruptions in some coastal areas.[598] There is evidence that tribal communities in Alaska, coastal Louisiana, the Pacific Islands, and other coastal locations are already being forced to relocate due to sea level rise, coastal erosion, melting permafrost, and/or extreme weather events.[599] A recent National Research Council report notes that climate change may contribute to "temporary or permanent displacement of a population following some type of climate event or other disruptive event, such as a tsunami… temporary or permanent relocation of a population from an area threatened by flooding or inundation; and temporary or permanent movement from one region or country to another for economic opportunity."[600] Such events are impossible to predict, but Hurricane Katrina demonstrated the potential of major climate-related disasters to permanently displace large portions of an impacted population.[601] Hurricane Katrina also demonstrated the challenges that may face the migrants, such as establishing themselves in a new community, finding employment, and accessing services. The receiving communities also face challenges, as their infrastructure, labor market, commerce, natural resources, and governance structures need to absorb a sudden population growth.[602]

Economic Effects: Climate change has the potential to affect resources and response capabilities at all levels of government. There has been a sizeable upward trend in the number of storm events causing large financial and other losses in the U.S.,[603] though this trend can be attributed to

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[592] USDA Climate Change Adaptation Plan, Pg. 9
[593] USDA Climate Change Adaptation Plan Pg. 10
[594] USDA Climate Change Adaptation Plan
[595] NCA3, Pg. 228
[596] NCA3, Pg. 228
[597] NCA3, Pg. 228
[598] NCA3, Pg. 591
[599] NCA3, Pg. 317
[600] National Research Council "*Climate and Social Stress,*" Pg. 112
[601] NCA3, Pg. 401
[602] NCA3, Pg. 545
[603] NCA3, Pg. 65

increases in both storm activity and development. In 2012, the warmest year on record for the U.S., the Nation experienced 11 climate-related disasters resulting in over $110 billion in damages.[604]

In addition to the economic toll of disaster response, the underlying drivers of local economies could be significantly altered as climate zones suitable for agricultural production and climate-driven tourism shift.[605] The nation's ports are located in already-vulnerable coastal locations, and increasingly exposed to sea level rise and related hazards.[606] This is not just a concern for coastal communities, but has far-reaching implications for the economy of the Nation as whole as ports are deeply interconnected with inland areas through the goods imported and exported each year.[607] If additional mitigation actions are not taken, the potential economic toll from climate-related disasters could be huge.

Even the necessary mitigation efforts could have significant economic impact, however. There have been no comprehensive, nation-wide estimates of the total necessary mitigation investment, though there have been sector- and region-specific estimates. A water sector-specific study estimated the nationwide climate change adaptation costs for wastewater systems alone would fall between $123 billion and $252 billion by 2050.[608] A Gulf Coast-specific study estimated that investing approximately $50 billion for adaptation over the next 20 years could lead to approximately $135 billion in averted losses over the lifetime of adaptive measures.[609]

Abrupt Climate Change Impacts: An additional climate change consideration is the rate at which the change might occur. Most changes are anticipated to occur gradually, allowing time to implement adaptation measures. However, the National Research Council report *Abrupt Impacts of Climate Change: Anticipating Surprises,* notes that the possibility also exists, however that" some changes will be abrupt, perhaps crossing a threshold or "tipping point" to change so quickly that there will be little time to react."[610] These 'abrupt' changes could occur over decades or years or could accelerate the rate at which other hazards are affected.[611]

Concluding Thoughts

Climate change will act as a hazard amplifier for many current threats and hazards, or introduce hazards to new communities. The impacts of climate change may strain the reliability of critical infrastructure and availability of key resources, forcing the whole community to reconsider current and future resource needs. Its consequences may cascade into a number of areas that are not directly weather related, effecting population shifts, public health problems, and local economies. In other words, although a changing climate is not a threat or hazard unto itself, its impacts can stress capabilities across all five mission areas – prevention, protection, mitigation,

[604] *The President's Climate Action Plan*. Executive Office of the President. 2013. http://www.whitehouse.gov/sites/default/files/image/president27sclimateactionplan.pdf
[605] NCA3. Pgs. 334-339
[606] NCA3, Pg. 589
[607] NCA3, Pg. 590
[608] NCA3, Pg. 588
[609] NCA3, Pg. 589
[610] "*Abrupt Impacts of Climate Change: Anticipating Surprises*" by the National Research Council
[611] "*Abrupt Impacts of Climate Change: Anticipating Surprises*" by the National Research Council

response, and recovery – and should be considered throughout risk analyses and future decision making processes.

Infrastructure Exposure to Natural Hazards and Climate Change

The quantitative risk of climate change is difficult to estimate because of the uncertainty that exists. Science does provide insight into the direction in which certain risks are trending. Regions across the U.S. will experience different impacts and need to plan according to their specific challenges. In the *National Climate Assessment*, the U.S. Global Change Research Program highlighted how regions across the U.S. could face different hazards. The *National Climate Assessment* analyzed data on how the Nation has seen rainfall events become heavier and more frequent in parts of the U.S., primarily in the Northeast, Midwest, and upper Great Plains, and these rainfall events have increased flooding in those regions.[612] As an example, in areas of the country where precipitation is expected to decrease, such as the Southwest, projections suggest there will be increased heavy precipitation. In addition to heavier precipitation, the *National Climate Assessment* analyzed hurricanes and concluded that hurricane-associated storm intensity and rainfall rates are projected to increase as the climate continues to warm.[613] The Southwest region of the U.S. is expected to be more prone to drought, wildfires, and heat waves, while the Northeast can expect heat waves, heavy downpours, and sea level rise to challenge their region. These various hazards will impact the country in different, sometimes unprecedented ways, and may have catastrophic impacts on their populations and infrastructure. Based on the climate science available today, which underpins the *National Climate Assessment* and is agreed upon by the Intergovernmental Panel on Climate Change (IPCC), DHS conducted a preliminary analysis that reveals where infrastructure systems are exposed to natural hazards and how that exposure is expected to change based on climate change.[614] While additional analysis is required to determine the level of vulnerability that specific infrastructure systems have or will have to climate-related hazards, understanding infrastructure exposure is an important step in planning for adapting to the impacts of climate change.

DHS developed a way to analyze and visualize infrastructure exposure to natural hazards and understand how that exposure may change due to climate change. The DHS National Protection and Programs Directorate (NPPD) conducted an in-depth, nationwide[615] analysis of this exposure[616]. While the preliminary findings are currently being reviewed by the interagency, this analysis reaffirms the work done by the *National Climate Assessment* and reflects the most current climate science. The analysis not only visualizes how infrastructure exposure to climate change and non-climate related hazards may shift, but also allows decision makers to estimate exposure to multiple hazards as well as various intensities. For the purpose of the analysis, DHS used subject matter expertise and expert judgments to identify a set of hazards that could affect critical infrastructure. Recognizing that any hazard event could have a major impact on a specific

[612] U.S. Global Change Research Program, 2015, p. 36
[613] U.S. Global Change Research Program, 2015, p. 41
[614] For the purpose of this analysis, permanent inundation, tidal flooding, coastal surge, extreme temperatures, drought, and wildfires were considered to be impacted by climate change. Earthquakes, landslides, tornadoes, tsunamis, ice storms, riverine flooding, and hurricane winds were not considered related to climate change, as there is insufficient data to support a nationwide evaluation of how these hazards could be expected to change.
[615] Due to the scoping for this analysis, DHS focused on the contiguous United States. Additional analysis would be required to incorporate Alaska, Hawaii, and the U.S. Territories.
[616] DHS NPPD commissioned the RAND Corporation to conduct analysis on infrastructure exposure to natural hazards. As of March 2015, the data, methods, analysis, and findings are being documented and will be reviewed by representatives from across the interagency.

community or region, for the purpose of this national level analysis, DHS NPPD classified the hazards into low and high categories based on their relative magnitude.

Table 25: Classification of Hazards Analyzed

Low Magnitude Hazards	High Magnitude Hazards
▪ Landslides ▪ Drought (400-600 Index) ▪ Extreme Heat (120° F daily max) ▪ Hurricane Wind (Category 2) ▪ Ice Storms (Category 4) ▪ Coastal Flooding (1 ft. depth) ▪ Earthquakes (0.34 ground acceleration) ▪ Wildfire (Moderate) ▪ Tornado (EF3)	▪ Drought (600-800 Index) ▪ Extreme Heat (130° F daily max) ▪ Hurricane Wind (Category 4) ▪ Ice Storms (Category 5) ▪ Coastal Flooding (6 ft. depth) ▪ Earthquakes (0.64 ground acceleration) ▪ Wildfire (Very High) ▪ Riverine Flood ▪ Tsunami ▪ Tornado (EF5)

Even without adjusting for climate change, the Nation's infrastructure is exposed to a range of low intensity natural hazards. The map in Figure 14 visually depicts, by county areas across the U.S., where infrastructure[617] is exposed to at least two assessed hazards from the category of low intensity hazards.[618] While it may be obvious that infrastructure faces challenges nationwide, infrastructure exposure to natural hazards is a nationwide concern and requires further analysis and investment in order to mitigate risks of disruption.

[617] The infrastructure data is found in HSIP Gold. The sectors considered in this analysis include chemical, communications, energy, transportation, water, wastewater, and dams.
[618] Subject matter experts determined infrastructure exposure by first identifying which types of infrastructure were vulnerable to which types of hazards (e.g., power transmission lines are vulnerable to high winds), and then identifying where they are co-located. This data does not include mitigation efforts, such as burying electric power transmission lines to mitigate tornado exposure.

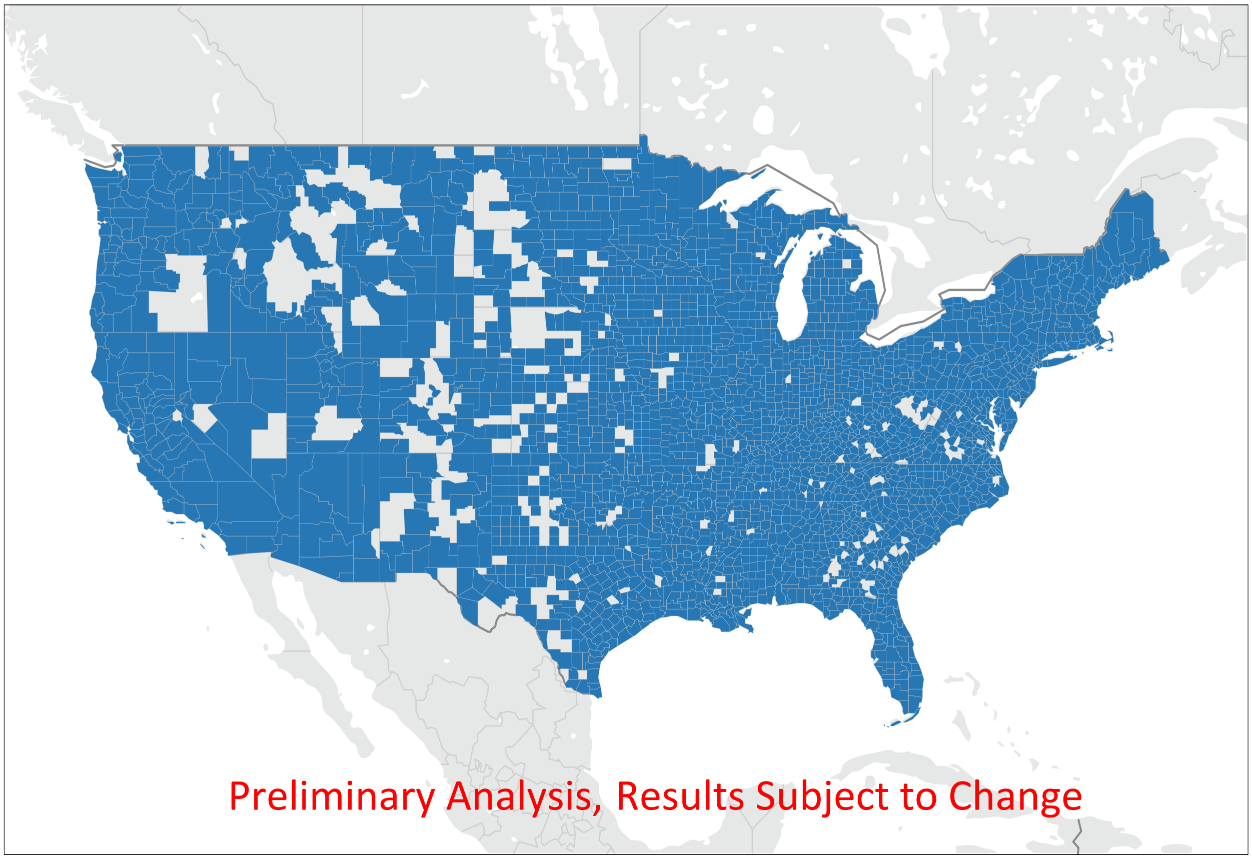

Figure 14: Infrastructure Exposure to Relatively Frequent Natural Hazards. This map illustrates that in 2015, most counties across the U.S. contain infrastructure that is exposed to hazards in the low magnitude category (see Table 25 for additional details) that occur relatively frequently within the U.S. (>1% chance of occurrence per year). These represent relatively common hazards.

Perhaps more significantly than viewing exposure to less severe hazards, DHS can use this analysis to determine where infrastructure is most likely to be exposed to high intensity hazards. This can be used as an indicator for where infrastructure is most likely to be exposed to more significant events that may require a National response. Based on this analysis, infrastructure in the Mid-Atlantic, Midwest, New England, and the West Coast is most likely to be exposed to these severe hazards.

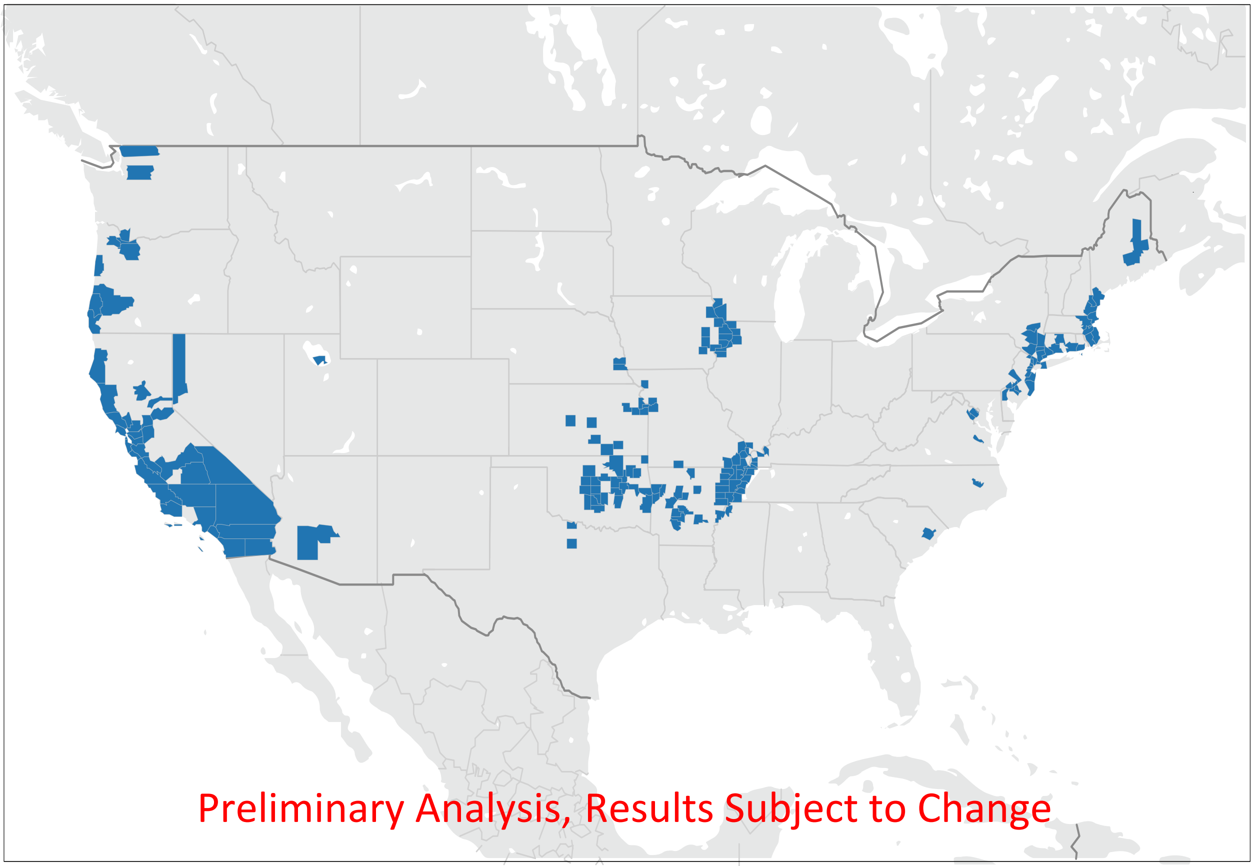

Figure 15: Infrastructure Exposure to High Magnitude, Relatively Infrequent Hazards. This map illustrates that in 2015, a few concentrated regions across the U.S. contain infrastructure that is exposed to multiple[619] hazards in the high magnitude category (see Table 25 for additional details) that occur relatively infrequently (<0.1% chance of occurrence per year), particularly in the Midwest, New England, and the West Coast.

This infrastructure exposure is a challenge today. Much of the Nation's infrastructure is outdated and needs to be upgraded. While the U.S. is trying to find ways to encourage infrastructure investment to address these challenges, experts estimate that the country would need to invest $3.6 trillion in the Nation's infrastructure by 2020 to bring it up to date.[620] Modern, efficient infrastructure is essential to the growth, health, and prosperity of the Nation and the direct cost of a disruption could cost billions of dollars. Hurricane Sandy caused an estimated $1 billion in damage to the power and gas lines in New Jersey alone, and ended up causing an estimated $65 billion in damages and economic loss across the region.[621] Hurricane Sandy demonstrated the widespread catastrophic damage that can occur when a large storm hits a densely populated and highly interconnected region.

[619] Three or more

[620] American Society of Civil Engineers, 2013

[621] Hurricane Sandy Rebuilding Task Force, 2013, p. 21

In addition to preparing for today's realities, the Nation must prepare for natural hazards that will be exacerbated by climate change. As regions make choices about their infrastructure and consider how to strategically invest their scarce resources, decision makers should consider how climate change will affect their new and existing infrastructure systems, assets, and networks across the lifespan of those structures. To support this, DHS conducted preliminary analysis on how hazard exposure changes according to a variety of/multiple future climate scenarios. Using representative concentration pathway (RCP) scenarios accepted by the Intergovernmental Panel on Climate Change's Fifth Assessment Report, DHS modeled how different climate futures could alter the frequency and severity of natural hazards, and how these changes, in turn, could expose infrastructure in new and different ways.[622] In addition, DHS leveraged the work done by NOAA to evaluate potential sea level rise scenarios, which inform analysis on permanent inundation, tidal flooding, and coastal surge.

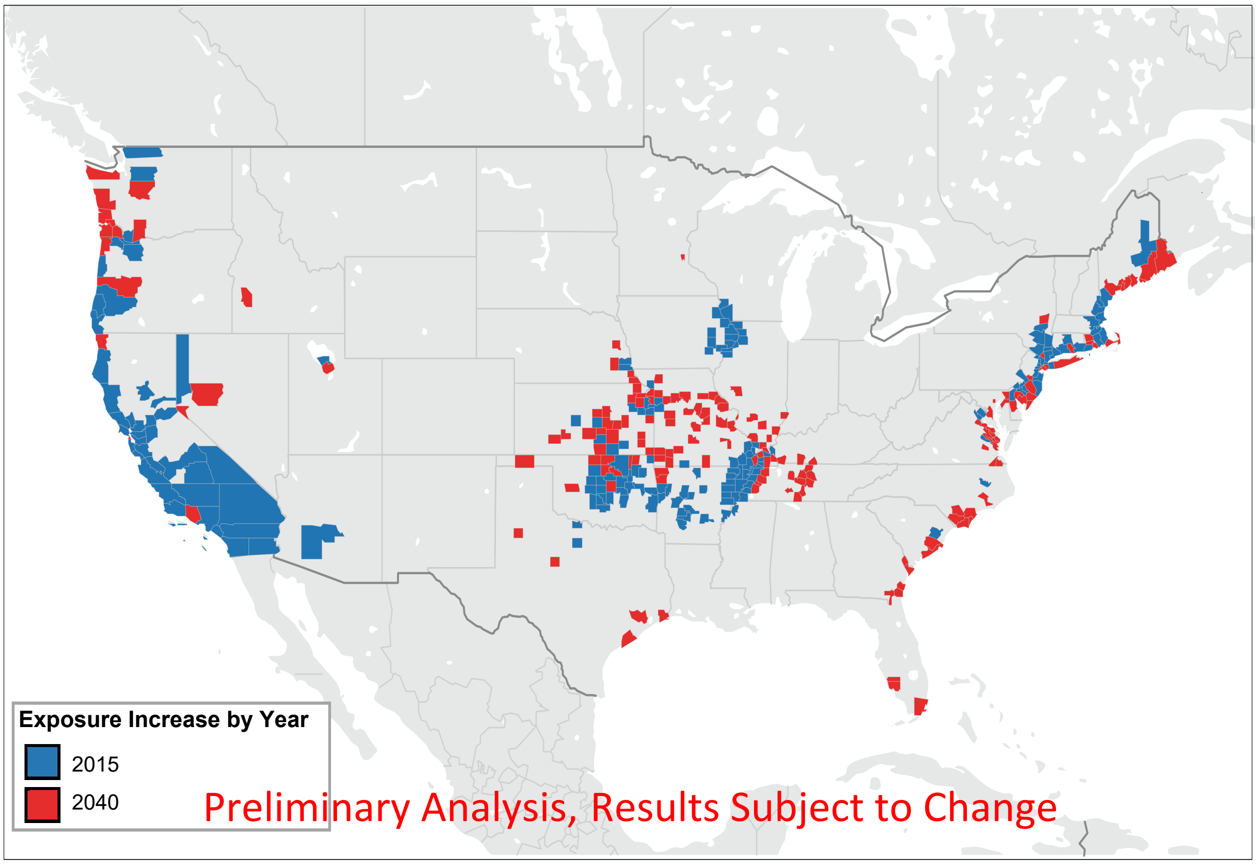

Figure 16: Infrastructure Exposure to High Magnitude, Relatively Infrequent Hazards Using a Pessimistic Climate Scenario. This map illustrates that, under a pessimistic climate scenario, by 2040 there could be an expansion of areas in the U.S. that contain infrastructure exposed to multiple[623] hazards in the high magnitude category (see Table 25 for additional details) that occur relatively infrequently (<0.1% chance of occurrence per year), particularly in the Midwest and along the coasts.

[622] Additional information on the models and the definitions for pessimistic, median, and optimistic climate scenarios used for analysis will be included in the forthcoming technical report. As of March 2015, the report is being finalized by the RAND Corporation on behalf of DHS NPPD. The report will document the data, methods, and analysis and will be reviewed by representatives from across the interagency.
[623] Three or more

Figure 16 depicts how new concentrations of exposure emerge as a result of climate change scenarios, particularly in the Pacific Northwest, California, the Midwest, the Southeast, and New England. It is important to note that the specific hazards vary across the regions. The Southeast, for instance, is vulnerable to coastal flooding and permanent inundation, whereas the Midwest is more likely to be affected by drought and extreme heat. These different hazards pose their own unique challenges and could require different plans for mitigating the effects. Evaluating the vulnerability and risk to infrastructure in Charleston, South Carolina will involve different variables than the infrastructure in Tulsa, Oklahoma. Likewise, the resources required to respond and recover from disasters in various regions could differ as well. It is important to understand where the hazards are expected to change so the Nation can prepare accordingly.

It is also important to note that the preliminary analysis reflects similar patterns of exposure when selecting a less pessimistic climate scenario, albeit over a longer timeframe. Whereas the model in the High RCP scenario depicted in Figure 16 reflects the changes in exposure in the year 2040, the analysis also reflects similar results for a less aggressive model in the year 2065, depicted in Figure 17. Considering the lifespan of infrastructure can be 50 to 100 years, the longer timeframe in this analysis still represents a significant finding and suggests the geographic clusters identified under a pessimistic model will be similarly exposed under less pessimistic scenarios.

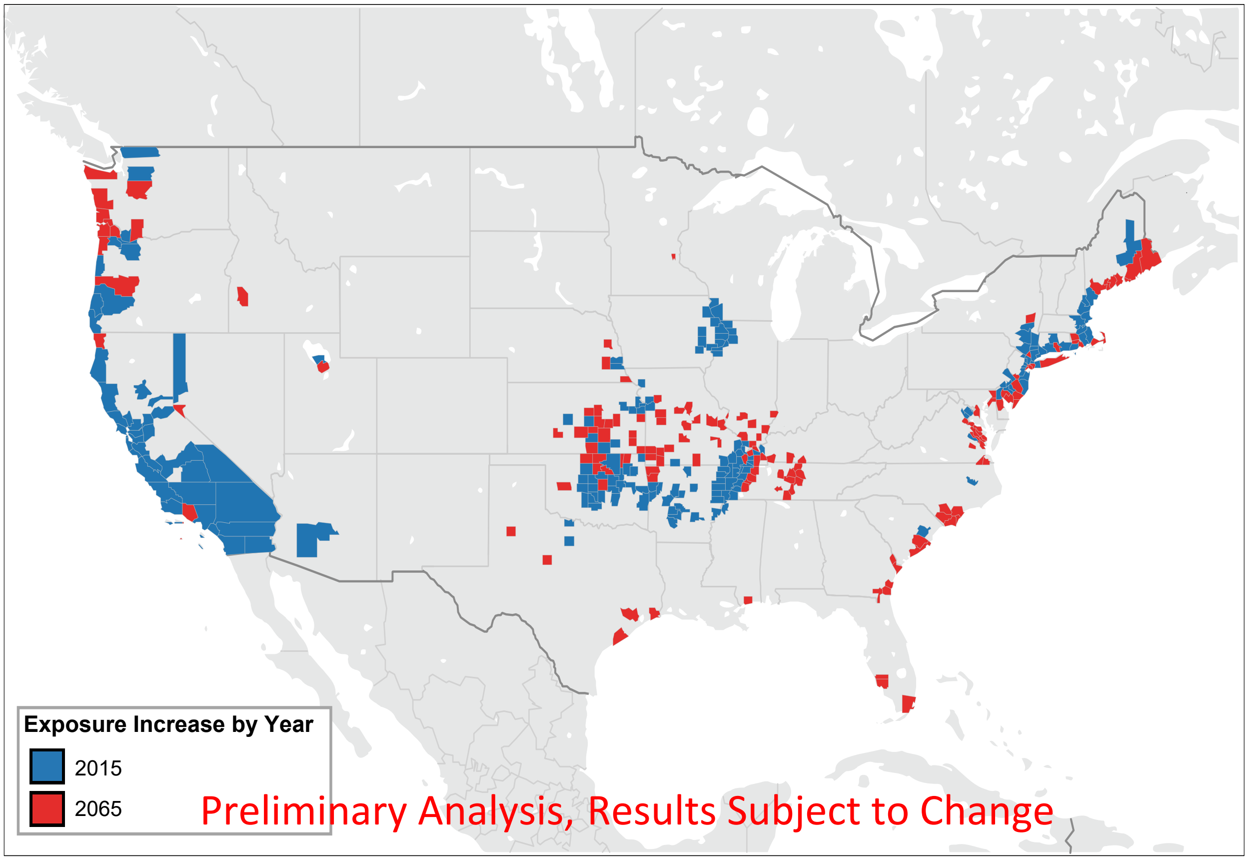

Figure 17: Infrastructure Exposure to High Magnitude, Relatively Infrequent Hazards Using the Median Climate Scenario. This map illustrates that under the median climate scenario, by 2065 there could be an expansion of areas in the U.S. that contain infrastructure exposed to multiple[624] hazards in the high magnitude category (see Table 25 for additional details) that occur relatively infrequently (<0.1%chance of occurrence per year), particularly in the Midwest and along the coasts.

As cities and regions grow and adapt to changing conditions, the supporting infrastructure will be stressed in new and more extreme ways. This groundbreaking preliminary analysis allows DHS NPPD to visualize infrastructure clusters and estimate how the exposure will change over time. At this point in time, DHS is not able to say precisely where and when a catastrophic hazard will strike. However, by better understanding the exposure of infrastructure to climate change, DHS NPPD and our partners can help decision makers incorporate climate vulnerability considerations into decisions, invest in critical infrastructure security and resilience, and prepare the Nation to adapt to climate change.

[624] Three or more

Drivers and Evolving Threats

Certain threats and hazards frequently appeared in documents across governmental, intergovernmental, non-profit, and academic sources as growing issues for the United States as a whole and the world in the near-term and long-term. The list of evolving threats included in the SNRA emerged from a variety of sources. We examined data sets used to prepare the National Preparedness Report over the past three years. The majority of the sources included in the NPR data sets stretched from 2011 to 2014. Another group of sources used for the SNRA evolving threats list were government documents. Reports from the Department of Homeland Security, the White House, the Department of Health and Human Services, the Congressional Research Service, the Government Accountability Office, testimonies from House and Senate committees, the Department of Agriculture, the National Intelligence Council, and the U.S. Census Bureau provided additional insight beyond the information included in the NPR data sets. In addition to government reports, the list of evolving threats grew from information in peer reviewed academic journals and books as well as reports from non-profits and intergovernmental organizations such as the United Nations.

Critical Infrastructure

The country's critical infrastructure provides essential services that underpin American society in sectors such as transportation, communication, energy, and health care.[625] Over the next 15-20 years, aging transportation, communication, energy, and health care infrastructure poses significant risk due to potential cascading impacts of failures and harm to the Nation's long term economic competitiveness.[626] The scale of the Nation's critical infrastructure makes it vulnerable to a diversity of risks. Severe weather events; terrorists and other actors seeking to cause harm and disrupt essential services through physical and cyber attacks; pandemic influenza or other health crises; and potential accidents and failures from infrastructure operating beyond its lifespan are threats to the Nation's critical infrastructure system.[627]

Aging Infrastructure

Age is one of the most pressing issues facing America's critical infrastructure, but it is not the only factor that determines the health and safety of critical infrastructure. Age related failure mechanisms include material fatigue, corrosion, and erosion that occur over time making infrastructure susceptible to failure without proper maintenance.[628] One in nine of the Nation's bridges are structurally deficient, while the average age of the country's 607,380 bridges is 42.[629] Additionally, out of 4 million miles of road, 65 percent of America's major roads are rated in less than good condition.[630] The poor condition of America's roads cost $67 billion a year for U.S. motorists.[631]

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[625] Department of Homeland Security, *Aging Infrastructure: Issues, Research, and Technology*, December 2010, p. 1-2; *Homeland Security Presidential Directive 7*, 2003, http://www.dhs.gov/homeland-security-presidential-directive-7.

[626] Federal Emergency Management Agency, *Strategic Foresight Initiative*, January 2012, p. 9.

[627] Department of Homeland Security, National Infrastructure Protection Plan: Partnering for Critical Infrastructure, Security, and Resilience, 2013, p. 8.

[628] Department of Homeland Security, National Risk Estimate: Aging and Failing Critical Infrastructure Systems, December 2014, p. 12.

[629] American Society of Civil Engineers, 2013 Report Card for America's Critical Infrastructure, p. 6.

[630] The White House, An Economic Analysis of Transportation Infrastructure Investment, July 2014, p. 2.

[631] American Society of Civil Engineers, 2013 Report Card for America's Critical Infrastructure, p. 48.

America's aging infrastructure extends beyond roads and bridges to also include water. Water infrastructure in the U.S., including dams, drinking water systems, levees, and wastewater, are overextended and outdated.[632] The growth of the U.S. population over the decades has strained critical water systems.[633] The average age of the 84,000 dams in the country is 52, while the number of high-hazard dams is on the rise.[634] Many of the Nation's estimated 100,000 miles of levees were originally used to protect farmland, but are now increasingly protecting developed communities.[635] Moreover, the country's drinking water infrastructure is nearing the end of its life. There are approximately 240,000 water main breaks in the U.S. every year as repairs take place every day to sustain critical infrastructure.[636] The cost to replace the drinking water aging infrastructure over the next couple of decades could reach nearly $1 trillion.[637]

Banking and Finance/Economic Security

Homeland Security Presidential Directive-7 included the banking and finance sector as an important component of the Nation's critical infrastructure. The Nation's banking and finance sector accounts for more than 8 percent of the U.S. annual gross domestic project and is the backbone for the world economy.[638] America's economic strength is key to the Nation's natural security.[639] The sector is composed of federally insured depository institutions; providers of various investment products; providers of risk transfer products (insurers); and other credit and finance organizations.[640] They are all tied together through a network of electronic systems with innumerable entry points. The sector is threatened by terrorist attacks, large scale power outages, and natural disasters.[641]

The impacts of market crashes, cyber attacks, and natural disasters on the banking and finance sector have ramifications beyond the sector. The current economic crisis has impacted local, state, and Federal budget forecasts. In the decade ahead, the United States and the world face challenges in ensuring continued economic growth and the strength of government finances.[642] The current and near-term budget forecasts for local, state, and Federal budgets are grim and may lead to critical shortfalls in funding to address aging infrastructure and build resilience to and recover from manmade and natural disasters.[643]

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[632] American Society of Civil Engineers, 2013 Report Card for America's Critical Infrastructure, p. 4-5.

[633] American Water Works Association, Buried No Longer: Confronting America's Water Infrastructure Challenge, 2011, p. 3.

[634] American Society of Civil Engineers, "Executive Summary," 2013 Report Card for America's Critical Infrastructure, http://www.infrastructurereportcard.org/a/#p/overview/executive-summary

[635] Ibid.

[636] Ibid.

[637] American Water Works Association, Buried No Longer: Confronting America's Water Infrastructure Challenge, 2011, p. 3.

[638] Department of Homeland Security and Department of the Treasury, Banking and Finance: Critical Infrastructure and Key Resources Sector-Specific Plan as Input to the National Infrastructure Protection Plan, May 2007, p. 1.

[639] The White House, *National Security Strategy*, February 2015, p. i.

[640] Department of Homeland Security and the Department of the Treasury, Banking and Finance: Critical Infrastructure and Key Resources Sector-Specific Plan: An Annex to the National Infrastructure Protection Plan, 2010, p. 1.

[641] Ibid.

[642] Government Accountability Office, *Strategic Plan 2014-2019*, p. 9.

[643] Federal Emergency Management Agency, *Strategic Foresight Initiative; White Paper: Climate Change*, January 2012, p. 4, http://www.fema.gov/media-library/assets/documents/103600.

Energy Sector

The U.S. energy infrastructure is vital to the U.S. economy. America's energy infrastructure is divided into three interrelated segments: electricity, petroleum, and natural gas.[644] Currently, the U.S. is the world's largest natural gas and oil producer, reducing the country's dependence on foreign oil to a 20 year low.[645] The U.S. energy infrastructure is vulnerable to terrorist and cyber attacks, natural disasters, and aging equipment.[646] Power outages have increased from 76 in 2007 to 307 in 2011 as a result of aging equipment.[647]

Since 2008, numerous oil and pipeline failures have occurred.[648] Pipeline failures can potentially impact surrounding populations, property, and the environment.[649] With population growth projected to increase, the U.S. energy infrastructure will encounter problems meeting demand after 2020.[650]

Cyber Security

The range of cyber threat actors, methods of attack, targeted systems, and victims are expanding and growing.[651] While computerized and networked systems provide significant benefits, cyber threats against the country and private institutions can have a serious impact on national security, the economy, and public health and safety.[652] The Nation's economy, safety, and health are linked through a networked infrastructure that is targeted by malicious government, criminal, and individual actors.[653]

The number of reported cyber attacks has continued to grow, resulting in economic loss, privacy breaches, data theft, the compromise of proprietary information or intellectual property, and harm to national security.[654] Cyber threats can be both intentional and unintentional. Types of intentional cyber threats include computer network and disruption activities such as denial of service attacks and destructive attacks that delete information or render systems inoperable. Unintentional cyber threats can result from software upgrades or defective equipment that inadvertently disrupt systems.[655]

[644] Department of Homeland Security, National Infrastructure Protection Plan: Energy Sector, 2011, p. 1.

[645] The White House, *National Security Strategy*, February 2015, p. 5.

[646] American Society of Civil Engineers, 2013 Report Card for America's Critical Infrastructure, p. 60-61; Department of Homeland Security, Energy Sector-Specific Plan: An Annex to the National Infrastructure Protection Plan, 2012, p. 13; The White House, Economic Benefits of Increasing Electric Grid Resilience to Weather Outages, August 2013, p. 3.

[647] American Society of Civil Engineers, 2013 Report Card for America's Critical Infrastructure, p. 61.

[648] Ibid.

[649] Department of Transportation, The State of the National Pipeline Infrastructure, p. 1.

[650] Ibid.

[651] James R. Clapper, Statement for the Record: World Wide Threat Assessment of the U.S. Intelligence Community, Senate Armed Services Committee, February 26, 2015; Government Accountability Office, Cybersecurity: A Better Defined and Implemented National Strategy is Needed to Address Persistent Challenges, March 7, 2013, p. 2.

[652] Government Accountability Office, Cybersecurity: A Better Defined and Implemented National Strategy is Needed to Address Persistent Challenges, March 7, 2013, p. 1.

[653] National Security Strategy, February 2015, p. 12.

[654] Government Accountability Office, Cybersecurity: A Better Defined and Implemented National Strategy is Needed to Address Persistent Challenges, March 7, 2013, p. 1.

[655] Ibid., p. 3.

Demographic Shifts in the U.S. and Potential Future Challenges.

Over the next four decades, the U.S. population will undergo significant demographic changes. By 2025, nearly one in five Americans will be over the age of 65 as that population will jump from 43.1 million in 2012 to 83.7 million in 2050.[656] The growth of the 65 and older population will have significant ramifications for the country economically, socially, politically, and for the emergency management community. The Nation's expenditures on health care will rise considerably. Older Americans are more likely to suffer from chronic diseases as two out of every three older Americans have chronic conditions.[657] Currently, treatment for this population amounts to 66 percent of the country's overall health care budget.[658] By 2030, health care spending in the U.S. will increase by 25 percent, primarily because of the aging population.[659] The cost of Medicare is projected to increase from $555 billion in 2011 to $903 billion in 2020.

In addition to the aging population, internal migratory shifts will also shape the country demographically. Currently, more people in the U.S. are living in metropolitan regions and along coastal areas.[660] Continued urbanization and coastal migration will result in the growth of "megaregions," which include not only cities, but counties that share interlocking economic systems, interrelated population and employment centers, cultures, natural resources and ecosystems, and common transportation systems.[661] Many of the identified megaregions are located along the country's coastal areas.[662] The concentration of the country's population into densely populated areas will have wide ranging ramifications. With changes to the climate, sea level rise could make homes and businesses congregated along coastal areas more prone to flooding.[663] Additionally, for emergency management, the concentration of the population in megaregions could make evacuations more difficult and access to medical resources could be strained.[664] The growth in the U.S. population will increase the stress on aging critical infrastructure and make densely populated areas potentially high terrorist targets.[665]

Beyond internal migratory shifts, international migration to the U.S. is projected to be the primary driver of the country's population growth between 2027 and 2038.[666] This would mark the first time since 1850 that the primary driver of population growth is not the result of domestic births.[667] Higher international migration could result in a fast growing, more diverse, and younger U.S. population.[668]

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[656] Federal Emergency Management Agency, Strategic Foresight Initiative, January 2012, p. 8; Jennifer M. Ortman, Victoria A. Velkoff and Howard Hogan, An Aging Nation: The Older Population in the United States: Population Estimates and Projections, U.S. Census Bureau, May 2014, p. 1.

[657] Centers for Disease Control and Prevention, *The State of Aging and Health in America 2013*, p. ii and p. 5.

[658] Ibid., p ii.

[659] Ibid., p. 5.

[660] Federal Emergency Management Agency, *Strategic Foresight Initiative,* January 2012, p. 8.

[661] Yoav Hagler, "Defining U.S. Megaregions," *America 2050*, November 2009, http://www.america2050.org/upload/2010/09/2050_Defining_US_Megaregions.pdf, p. 1-7.

[662] Ibid., p. 7.

[663] Federal Emergency Management Agency, "U.S. Demographic Shifts: Long-term Trends and Drivers and Their Implications for Emergency Management, *Strategic Foresight Initiative White Papers*, May 2011, p. 5, http://www.fema.gov/media-library/assets/documents/103600.

[664] Ibid., p. 6.

[665] Ibid., p. 5.

[666] U.S. Census Bureau, *International Migration is Projected to Become Primary Driver of U.S. Population Growth for First Time in Nearly Two Centuries*, May 15, 2013, http://www.census.gov/newsroom/press-releases/2013/cb13-89.html (Accessed March 18, 2015).

[667] Ibid.

[668] Ibid.

Food and Water Insecurity

Climate change, global population growth, and economic development have the potential to create water and food insecurity in the coming decades.[669] Food and water insecurity have the possibility of affecting the U.S. domestically and its relationships with numerous countries. Over the course of the next 10 years, many countries important to U.S. national security will experience water problems causing instability in those regions of the world.[670] In California, the ongoing drought caused the town of East Porterville to run out of water in late 2014.[671] Since California is a major producer of agricultural produce, including fruits and vegetables, the severe drought in the state has implications for U.S. produce supplies and prices.[672] Beyond fruit and vegetables, California also leads the Nation in dairy production and produces 21 percent of the Nation's milk.[673] The drought in California could increase the price and decrease the availability of alfalfa, which is the primary feed for dairy cattle.[674]

Global Supply Chain

As globalization continues to shape nations socially, economically, and technologically, the global supply chain is an example of the growing interconnections that stretch across national borders. The efficient and secure movement of goods through the global supply chain is essential for the U.S. economy and security.[675] The global supply chain is composed of a network of "suppliers, manufacturing centers, warehouses, distribution centers, and retail outlets"[676] that involve transportation, postal, air, and shipping assets, which make the U.S. and worldwide trade systems possible.[677] Governments and multinational corporations play key roles in ensuring the functioning of operations across national borders.[678] As a result of its complexity and scale, the global supply chain is vulnerable to a variety of threats and hazards that can cause disruptions. Natural disasters such as earthquakes, tsunamis, and volcanic eruptions, as well as terrorist attacks and labor strikes can heavily impact the global supply chain.[679] The 2011 Japanese earthquake and tsunami provide an example of the global supply chain's vulnerability. After the

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[669] National Intelligence Council, *Global Water Security*, February 2, 2012, p. iii; United Nations, *Water and Food Security*, http://www.un.org/waterforlifedecade/food_security.shtml; The White House, *National Security Strategy*, February 2015, p. 12; World Bank Group, *Water and Food Security: Improving Agricultural Water Productivity*, http://water.worldbank.org/WPP-Food-Security.

[670] National Intelligence Council, *Global Water Security*, February 2, 2012, p. iii.

[671] No author, "East Porterville Residents Without Water as Wells Go Dry During California Drought, *CBS Sacramento*, August 27, 2014, http://sacramento.cbslocal.com/2014/08/27/porterville-residents-without-water-as-wells-go-dry-during-california-drought/

[672] United States Department of Agriculture, "California Drought 2014: Farm and Food Impacts," September 12, 2014, http://ers.usda.gov/topics/in-the-news/california-drought-2014-farm-and-food-impacts.aspx. California is not the only region of the country susceptible to drought. Similar to California, the Midwest provides essential agricultural products for the country. Climate change has the potential to increase the likelihood of droughts in the Midwest alongside wildfires and heatwaves. See Environmental Protection Agency, Climate Impacts in the Midwest, http://www.epa.gov/climatechange/impacts-adaptation/midwest.html.

[673] United States Department of Agriculture, "California Drought 2014: Livestock, Dairy, and Poultry Sectors," September 12, 2014, http://ers.usda.gov/topics/in-the-news/california-drought-2014-farm-and-food-impacts/california-drought-2014-livestock,-dairy,-and-poultry-sectors.aspx.

[674] United States Department of Agriculture, "California Drought 2014: Food Prices and Consumers," October 7, 2014, http://ers.usda.gov/topics/in-the-news/california-drought-2014-farm-and-food-impacts/california-drought-2014-food-prices-and-consumers.aspx.

[675] The White House, National Strategy for Global Supply Chain Security, January 2012, p. 1.

[676] Henry H. Willis and David S. Ortiz, *Evaluating the Security of the Global Containerized Supply Chain*, RAND Corporation, 2007, p. ix.

[677] American National Standards Institute, Department of Homeland Security, *Global Supply Chain Security Standards*, November 2012, p. 1; Department of Homeland Security, *2014 Quadrennial Homeland Security Review*, p. 25.

[678] Federal Emergency Management Agency, *Strategic Foresight Initiative, White Papers: Global Interdependencies*, January 2012, p. 2, http://www.fema.gov/media-library/assets/documents/103600.

[679] Department of Homeland Security, 2014 Quadrennial Homeland Security Review, p. 25The White House, National Strategy for Global Supply Chain Security, January 2012, p. 4-5.

earthquake and tsunami, General Motors, Toyota, and Subaru slowed down or halted production at plants in the United States because needed parts manufactured in Japan were delayed.[680]

Homegrown Violent Extremists

The terrorist threat to the Nation remains significant and continues to evolve, most recently with the rise of the Islamic State in the Levant (ISIL).[681] Homegrown violent extremists are a persistent threat to the country.[682] Homegrown terrorist activity continues to grow as changing national and international security dynamics will affect the Nation's safety, prosperity, and resilience.[683] Individuals (lone offenders) and small groups acting on their own initiative are a tenacious threat and difficult to counter.[684]

The rise of ISIL during the past year and its adept use of media have created unprecedented opportunities for the organization to reach potential recruits or influence people.[685] Social media and the Internet have the potential to play a critical role in the immediate future in radicalizing and mobilizing homegrown extremists towards violence.[686] There is the possibility that a number of individuals traveling to Iraq and Syria to fight with ISIL will return to the country with field training to commit an act of terrorism against the Nation.[687]

Future Risks

Artificial Intelligence

Artificial intelligence describes a branch of computer science that uses algorithms to mimic human intelligence. It "includes performing tasks that normally require human intelligence, such as visual perception, speech recognition, problem solving, and language translation."[688] Artificial intelligence offers many benefits and has evolved greatly within the past decade because of cheap computing, better algorithms, and the ability of computers to process and store increasingly larger and larger amounts of collected data.[689] Everyday application of artificial intelligence includes Netflix recommendations, Facebook's ability to identify users' friends, and

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680 Associated Press, "Japan Disaster, Lack of Parts Forces General Motors to Halt Production," *Huffington Post*, March 17, 2011, http://www.huffingtonpost.com/2011/03/17/japan-general-motors-parts_n_837355.html.

681 Nicholas J. Rasmussen, Current Terrorist Threat to the United States, Testimony before the Senate Select Committee on Intelligence, February 12, 2015. This section is primarily discussing Homegrown Extremists tied to and influenced by radical Islam that advocates attacks on the U.S.

682 Jerome P. Bjelopera, American Jihadist Terrorism: Combating a Complex Threat, Congressional Research Service, January 23, 2013; James R. Clapper, Worldwide Threat Assessment of the U.S. Intelligence Community ,Testimony before the Senate Armed Services Committee, February 11, 2014; Department of Homeland Security, 2014 Quadrennial Homeland Security Review, p. 19; William L. Painter, Issues in Homeland Security Policy for the 113th Congress, Congressional Research Service, September 23, 2013; Federal Emergency Management Agency, Strategic Foresight Initiative, January 2012, p. 9; Government Accountability Office, Strategic Plan 2014-2019, p. 100; Nicholas J. Rasmussen, Current Terrorist Threat to the United States, Testimony before the Senate Select Committee on Intelligence, February 12, 2015.

683 Federal Emergency Management Agency, *Strategic Foresight Initiative*, January 2012, p. 9 and p. 23.

684 Department of Homeland Security, *2014 Quadrennial Homeland Security Review*, p. 18.

685 Nicholas J. Rasmussen, Current Terrorist Threat to the United States, Testimony before the Senate Select Committee on Intelligence, February 12, 2015.

686 Ibid.

687 Ibid.

688 Babak Hoojat, "Myth Busting Artificial Intelligence," *Wired*, February 2015, http://www.wired.com/2015/02/myth-busting-artificial-intelligence/

689 Kevin Kelly, "The Three Breakthroughs that have Finally Unleashed AI on the World," *Wired*, 27 October 2014, http://www.wired.com/2014/10/future-of-artificial-intelligence/

the personal assistant Siri on iPhones.[690] Additionally, artificial intelligence is playing a larger role in cybersecurity by helping companies to identify risks and anticipate problems.[691]

There are potential risks with artificial intelligence. There are concerns that there will be advanced computer systems with the possible ability to match or surpass human intelligence, resulting in unexpected outcomes.[692]

Cognitive Enhancement

Cognitive enhancement involves the "amplification or extension of core capacities of the mind through improvement or augmentation of internal or external information processing systems."[693] Medical and scientific efforts at cognitive enhancement cover a range of drugs and technologies. With some brain disorders and developmental conditions, the use of drugs has become established in clinical practice. Many of these medications, which can also be used to enhance cognitive functions in healthy people above their normal baseline, have been used in the past for military applications and are drugs of abuse in the civilian population.[694] In addition to the use of medical drugs, good nutrition, education, mental training, transcranial magnetic stimulation, increased and better human-computer interaction, and regular exercise have been used to produce long term cognitive improvements.[695] More unconventional and experimental forms of cognitive enhancement include gene therapy, and neural implants.[696]

Cognitive enhancement raises a number of ethical issues and there are a few risks. There are side effects from the use of pharmacological drugs.[697] Ethically, there are concerns about the use of genetic enhancements raising fears about crossing the line into eugenics,[698] and the impacts upon

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690 Babak Hoojat, "The AI Resurgence: Why Now?" *Wired*, March 2015, http://www.wired.com/2015/03/ai-resurgence-now/; Kevin Kelly, "The Three Breakthroughs that have Finally Unleashed AI on the World," *Wired*, 27 October 2014, http://www.wired.com/2014/10/future-of-artificial-intelligence/

691 Rachel King, "The Security Download: Anticipating Cyberattacks with Machine Learning," *Wall Street Journal*, 9 March 2015, http://blogs.wsj.com/cio/2015/03/09/the-security-download-anticipating-cyberattacks-with-machine-learning/.

692 Rory Cellan-Jones, "Stephen Hawking Warns Artificial Intelligence Could End Mankind," *BBC News*, 2 December 2014, http://www.bbc.com/news/technology-30290540; Paul Smith, "Apple Co-founder Steve Wozniak on the Apple Watch, Electric Cars, and the Surpassing of Humanity," *Australian Financial Review*, 23 March 2015, http://www.afr.com/technology/apple-cofounder-steve-wozniak-on-the-apple-watch-electric-cars-and-the-surpassing-of-humanity-20150323-1m3xxk; Baum et al, 2011, "How Long Until Human-Level AI? Results from an Expert Assessment," *Technological Forecasting & Social Change* 78(1) 185-195; Vinge, Vernor, "The Coming Technological Singularity: How to Survive in the Post-Human Era," *Whole Earth Review*, Winter 1993, http://www-rohan.sdsu.edu/faculty/vinge/misc/singularity.html; Eliezer Yudkowsky, "Artificial Intelligence as a Positive and Negative Factor in Global Risk," in *Global Catastrophic Risks*, edited by Nick Bostrom and Milan M. Cirkovic, London, UK: Oxford University Press, 2008, p. 331-333; For contrary views from different perspectives, see Stephen F. DeAngelis, "The Upside of Artificial Intelligence Development," *Wired*, February 2015, http://www.wired.com/2015/02/the-upside-of-artificial-intelligence-development/; Kurzweil, Ray, 2005, *The Singularity is Near: When Humans Transcend Biology*: Viking Press; Lanier, J, "One-Half of a Manifesto: Why Stupid Software Will Save the Future from Neo-Darwinian Machines," *Wired* 8.12 (2000), http://www.wired.com/wired/archive/8.12/lanier_pr.html

693 Nick Bostrom and Anders Sandberg, "Cognitive Enhancement: Methods, Ethics, Regulatory Challenges," *Science and Engineering Ethics* 15 (2009), p. 311.

694 JASON (MITRE Corporation), *Human Performance*, March 2008, https://fas.org/irp/agency/dod/jason/human.pdf; Masud Husain and Mitul A. Mehta, "Cognitive Enhancement by Drugs in Health and Disease," *Trends in Cognitive Sciences*, no. 1, 2011 January 15, p. 28.

695 Nick Bostrom and Anders Sandberg, "Cognitive Enhancement: Methods, Ethics, Regulatory Challenges," *Science and Engineering Ethics* 15 (2009), p. 313-321; Hannah Maslen, Nadira Faulmuller, and Julian Savulescu, "Pharmacological Cognitive Enhancement – How Neuroscientific Research Could Advance Ethical Debate," *Frontiers in Systems Neuroscience* no. 8, 2014, p. 107.

696 Nick Bostrom and Anders Sandberg, "Cognitive Enhancement: Methods, Ethics, Regulatory Challenges," *Science and Engineering Ethics* 15 (2009), p. 312.

697 Masud Husain and Mitul A. Mehta, "Cognitive Enhancement by Drugs in Health and Disease," *Trends in Cognitive Sciences*, no. 1, 2011 January 15.

698 Nick Bostrom and Anders Sandberg, "Cognitive Enhancement: Methods, Ethics, Regulatory Challenges," *Science and Engineering Ethics* 15 (2009), p. 324-328.

society of human enhancement technologies more generically.[699] The improvement of human-computer interaction touches on privacy and data protection.[700]

Nanotechnology

Nanotechnology holds great potential for a variety of fields, but also has potential risks. Nanotechnology involves the "creation of structures, devices, and systems on the atomic scale."[701] In general, nanotechnology is used as a component part in larger manufacturing products, which limits their scope and impact as the manufacturing process and non-nanotechnology components influence the way nanotechnology can be used.[702] The benefits of nanotechnology include a more efficient drug delivery systems, medical imaging for diagnosis, and new cancer therapies.[703] Additionally, nanotechnology is used to improve energy efficiency, de-salinize water, clean up hazardous waste, and detect contaminants.[704] Nanotechnology is now used in over 1,000 consumer products, which marks a 379 percent increase from 2006.[705]

There are different types of possible risks with nanotechnology. Nanotechnology could be used to manufacture weapons on a mass scale.[706] "Uncontrolled aggressive nanotechnology is a scenario in which humanity unleashes weapons that it cannot subsequently bring under control, which go on to have independent negative impacts on the world."[707] In utilizing nanotechnology, there is a fear that robots could self-replicate, thus putting humanity in danger.[708]

It is difficult to provide exact risks from the use of nanotechnology because of the diverse uses and complexity of nanomaterials.[709] There are few studies on the environmental fate of nanomaterials in soil, atmosphere, and water.[710] Nanomaterials could possibly transform in the environment and become toxic to human health.[711]

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[699] National Intelligence Council, *Global Trends 2030: Alternative Worlds*, December 2012, http://www.dni.gov/files/documents/GlobalTrends_2030.pdf.

[700] Nick Bostrom and Anders Sandberg, "Cognitive Enhancement: Methods, Ethics, Regulatory Challenges," *Science and Engineering Ethics* 15 (2009), p. 324-328.

[701] National Aeronautics and Space Administration, "Nanotechnology at AMES,"http://www.nasa.gov/centers/ames/research/technology-onepagers/ames_nanotech.html

[702] Chris Phoenix and Mike Treder, "Nanotechnology as Global Catastrophic Risk," in *Global Catastrophic Risks*, edited by Nick Bostrom and Milan M. Cirkovic, London, UK: Oxford University Press, 2008, p. 482-483.

[703] Daniel J. Fiorino, *Voluntary Initiatives, Regulation, and Nanotechnology Oversight: Charting a Path*, Woodrow Wilson International Center for Scholars, November 2010, p. 12.

[704] Ibid.

[705] Ibid.

[706] Global Challenges Foundation, Global Challenges: 12 Risks that Threaten Human Civilization, February 2015, p. 117.

[707] Ibid.

[708] Bill Joy, "Why the Future Doesn't Need Us," *Wired*, April 2000, http://archive.wired.com/wired/archive/8.04/joy.html

[709] Environmental Protection Agency, *Nanotechnology White Paper*, February 2007, p. 29; Global Challenges Foundation, *Global Challenges: 12 Risks that Threaten Human Civilization*, February 2015, p. 117.

[710] Environmental Protection Agency, *Nanotechnology White Paper*, February 2007, p. 33.

[711] Ibid.

Section 7: SNRA Data Summary

Table 26: SNRA Data Summary

Threat or Hazard	Frequency			Fatalities			Injuries/Illnesses			Direct Economic Loss (2011$ million)			Social Displacement			Psychological Distress			EFF *	Environmental Impact	
	Low	Best	High	Low	Best	High	Low	Best	High	Low	Best	High	Low	Best	High	Low	Best	High		Best	2nd Best
Aircraft as a Weapon	0.036	0.13	0.27	2	290	2,800	3	640	5,100	4.0	2,500	27,000	0	3,000	32,000	18	4,000	39,000	1.2	Low	Moderate
Armed Assault	0.11	0.48	3	0	1.94	334	0	6	810	0.061	0.51	78	0	0	0	0	18	2,800	1.1	De minimus	De minimus
Explosives Terrorism Attack	0.72	7.0	25	0	1	3,650	0	11	4,500	0.043	3.4	20,000	0	5	400	0	21	39,000	1.2		
Biological Food Contamination	0.2	0.64	1.2	0	11	42	200	17,000	45,000				0	400	950	200	17,000	46,000	1	Moderate	Low
Chemical Substance Spill or Release	0.61	1.6	5	1	5	25	0	60	790	0.04	14	330	0	255	5,400	6	230	4,000	1.1	Moderate	High
Dam Failure	0.17	0.54	3	1	17	170	0	50	3,000				1	500	250,000	6	390	130,000	1	Moderate	Moderate
Radiological Substance Release	0.0062	0.0093	0.014	0	230	2,200	0	240	2,300	7,500	8,600	16,000	76,000	150,000	500,000	42,000	82,000	290,000	1.1	Moderate	High
Animal Disease Outbreak	0.04	0.1	0.1	0	0	0	0	0	0	2,300	15,200	69,000	0	1,000			500		1	Low	Moderate
Earthquake	0.11	0.27	2	0	370	8,900	0	8,700	210,000	107	8,700	105,000	160	27,000	2,000,000	90	27,000	1,400,000	1.1	Moderate	High
Flood	0.5	4	10	0	3	25	0	95	4,500	104	740	16,000	150	29,000	200,000	75	15,000	100,000	1	Moderate	Moderate
Human Pandemic Outbreak	0.017	0.033	0.1	77,000	154,000	230,000	61,000,000	77,000,000	110,000,000	71,000	110,000	180,000	0	0	0	61,000,000	78,000,000	110,000,000	1	Low	Moderate
Hurricane	0.33	1.9	7	0	26	1,200	0	650	30,000	100	5,700	92,000	430	520,000	5,000,000	220	260,000	2,500,000	1	Moderate	High
Space Weather	0.0017	0.0067	0.014	90		2,000	400		10,000	5,700		2,000,000	0		40,000,000	850		20,000,000	1	De minimus	Moderate
Wildfire	0.2	0.8	3	0	5	25	0	63	190	100	900	2,800	770	110,000	640,000	390	55,000	320,000	1	Low	High
Drought	0.50	0.63	1.0	0	0	0	0	0	0	2,000	8,680	38,000	0	0	0	0	0	0	1		
Tornado	0.63	2.9	7	0	22	316	0	247	3,125	103	450	4,700							1		
Winter Storm	0.13	0.56	2	0	50	270	0	1,700	14,000	1,000	3,100	9,000							1		
Physical Attack on the Power Grid	0.013	0.25	1	0	0	90	0	2	400	15	46	5,700	0	0	0						
Combustible/Flammable Cargo Accident (Rail)	0.039	0.11	0.22	1	1	1	0	20	52	0.043	0.90	2.9	0	0	0	5	25	59	1		
Transportation Systems Failure	0.17	0.57	2	1	8.6	47	0	8.8	145	0.25	200	6,400	0	0	0	5	150	3,600	1		
Biological Terrorism Attack (non-food)													0	1,800					1.3	Low	Low
Chemical Terrorism Attack (non-food)													0	100,000	700,000				1.3	Moderate	High
CB Food Contamination Terrorism Attack													0						1.3	Low	Moderate
Nuclear Terrorism Attack													330,000	2,000,000	3,000,000				1.3	High	High
Radiological Terrorism Attack													25,000	50,000	100,000				1.3	Low	Moderate

Cell color key	
	New or revised
	Data are classified
	No data

Strategic National Risk Assessment

Supplement:

SNRA 2011 Unclassified Documentation of Findings

Homeland Security

PRE-DECISIONAL DRAFT

NOT FOR PUBLIC DISTRIBUTION OR RELEASE

Errata/Changelist from PPD-8 Review Draft 28 January 2015

The draft SNRA 2011 Unclassified Documentation of Findings was circulated to the PPD-8 Implementation Team and other PPD-8 partners as supporting documentation for the SNRA 2011 public findings, which were the focus of the substantive revision work of the SNRA 2015 project. The period for substantive review of the 2011 findings by PPD-8 partners also served as the period for review of the 2011 Unclassified Documentation of Findings for factual accuracy, as historical documentation of the 2011 assessment, by 2011 project contributors. These factual corrections were incorporated into this final unclassified documentation of the 2011 SNRA. At the end of May 2015, this document comprises part of the full documentation of the 2015 SNRA which informed the 2015 revision of the National Preparedness Goal. A single SNRA technical report integrating the substantive updates and revisions of the 2015 SNRA project with the unchanged 2011 material is in preparation.

Original	Current	Errata/Corrigenda
10, 15	242, 247	Added: Classified findings regarding the adversarial events, and more significantly the comparative findings for the set of SNRA national-level events as a whole, are not provided in the following pages. For these findings, please see the full (classified) SNRA Technical Report. Footnote: All frequency estimates for the adversarial events and fatality, injury/illness, economic, and top level (low/best/high) psychological distress estimates for the chemical/biological/radiological/nuclear (CBRN) events are classified at the SECRET or SECRET//NOFORN level. Top level (low/best/high) estimates for the fatality, injury/illness, economic, and psychological distress metrics for the Aircraft as a Weapon, Armed Assault, and Explosives Terrorism Attack events are unclassified, but are For Official Use Only. All other data, including all social displacement and environmental consequence estimates, are unclassified without caveats.
12	244	Table 1 (Comparative Risk in the SNRA): Changed to logarithmic shading. Linear shaded version moved to new Appendix N.
14, 96, 103	246, 328, 335	For each mention of S&T Human Factors Division (psychological distress, social displacement discussions), footnote: DHS/S&T Resilient Systems Division (RSD) is the current (2015) organizational successor to Human Factors Division.
24, 42	256, 274	Hong Kong flu case fatality rate corrected from 0.5% to 0.05%.
35	267	Environmental Risk, last paragraph: Duplicate mention of space weather removed.
48	280	Footnote 96 [old]/100 [new]: Typo corrected (author's name misspelled).
49, 183	281, 415	Replaced "A terrorist nuclear weapon would be expected to have a yield of less than 1 to several kilotons." with "Generally, when considering nuclear explosion scenarios perpetrated by terrorists, experts assume a low-yield nuclear device detonated at ground level, where low yield in this context ranges from factions of a kiloton (kT) to 10 kT."
49	281	Replaced "A terrorist nuclear attack could be carried out with…" with "A terrorist attack could be carried out with…"
49	281	Changed "The primary obstacle to a terrorist nuclear attack…"to "The primary obstacle to a terrorist IND attack…"
50, 185	282, 417	Deleted "radiological dust" from "heat, debris, radiological dust, and force"
67	299	"…with comparatively little uncertainty around that frequency" removed (last phrase, last bullet, after "1 in 100 years") as potentially misleading.
93	325	Flood, direct economic loss best estimate: Typo of 1,600 corrected to 16,000.
123	355	Added "were" in "these U//FOUO portions were provided…"
125, 127, 131, 134, 137, 143, 145, 148, 150, 152, 159, 162	357, 359, 363, 366, 369, 375, 377, 380, 382, 384, 391, 394	Data Summary, above data table for each event reporting high/best/low frequencies and consequences: In the following table, note that the low and high likelihoods do not correspond to the low and high consequences. In addition, low and high consequences are not necessarily correlated with each other between different consequence categories.
126	358	Additional Relevant Information: Changed "We estimate", to "DHS Office of Health Affairs experts" and "we also use 0.1 in a given year as our best estimate" to "the SNRA project team selected 0.1 in a given year as the best estimate for this event."
135	367	Changed "decrease by 5% - equivalent to $735 billion... it represents a worst case scenario rather than a dominant risk scenario. A 1918-type pandemic is considered highly unlikely" to "decrease by 4.25% - equivalent to $625 billion… it represents a comparatively less likely worst case scenario." Changed CBO citation from unpublished December 2005 paper to published July 2006 paper.
138	369	Table 3 (Social Displacement) caption: Corrected TS Frances date from 2006 to 1998.
176	408	Assumptions, column 2, paragraph "Chemical agents can be disseminated in various modes…" moved to Event Background.
178-179	410-411	Deleted content from and references to U.S. Food and Drug Administration Center for Food Safety and Applied Nutrition (FDA CFSAN) (2003, October 7), Risk assessment for food terrorism and other food safety concerns [incorporated as unclassified replacement for original U//FOUO SNRA content, but reference is not currently available on FDA website – was made public by FDA but withdrawn].
180	412	Table 2 (Damage radius): "High Explosives Only" clarification added to "Explosive Capacity" header.
181	413	Bullet, overpressure damage: "HE" clarification added to blast lung injury sentence.
202	434	New Appendix N: Reproduces linear shaded version of Table 1 (Comparative Risk in the SNRA) (color gradient supports 'X' markings)
204	436	New Appendix O: Reproduces December 2011 public findings report reviewed by the PPD-8 Implementation Team for the 2015 SNRA update.

Unclassified Documentation of Findings

This document is an unclassified adaptation of the classified SNRA Technical Report, the primary written documentation of the 2011 Strategic National Risk Assessment (SNRA). Its purpose is to allow the unclassified content of the United States' first national risk assessment to be communicated and used outside of classified environments.[1]

The quantitative comparison of risk to the Nation from both adversarial threats and non-adversarial (natural and accidental) hazards was a central goal, and accomplishment, of the first SNRA. While the following document retains unclassified discussions of the methods used to obtain the data and findings for the adversarial events, their omission makes this document an incomplete picture of the full SNRA and the national risk picture which it describes. This absence must be kept in mind while reading the following pages.

The SNRA was executed by the DHS Office of Risk Management and Analysis (RMA) in calendar year 2011, in support of Presidential Policy Directive 8 (PPD-8). Its data and findings were reported to FEMA in September 2011 to inform the National Preparedness Goal.[2] The unclassified findings of the SNRA were reported to the public in December 2011.[3]

The following document provides the unclassified data, analysis, and models, and identifies the classified data and models, that were used to derive the publicly disseminated findings of the 2011 SNRA. It additionally describes the analytic judgments used in the selection and analysis of the SNRA data, including assumptions, defaults, and uncertainties; the rationale for these judgments; and the influence of these judgments, and other limitations, upon the findings.

The PPD-8 Program Executive Office (PEO), National Integration Center (NIC), FEMA, assumed project responsibility for the SNRA in March 2014. This adaptation of the SNRA Technical Report was prepared to communicate the data and analysis of the SNRA at an unclassified level so that it can be reviewed, used, and built upon by the whole community of its stakeholders.

[1] The primary sources for this document are the classified SNRA Technical Report and event risk summary sheets, as circulated for interagency review in December 2011 and January 2012. Some minor additions and changes to the documentation made subsequent to the SNRA's transfer to the DHS Office of Policy in March 2012, where consistent with the 2011 findings reported to FEMA and the interagency, are also reflected in this document.

All classified information, material which may be classified by compilation, and Sensitive But Unclassified (SBU) content has been removed. Where possible, this content has been replaced with analogous but fully unclassified content. These substitutions include comparative analyses re-written to refer to non-adversarial events (natural and accidental hazards) only, and extended background discussions of individual adversarial events replaced with text from DHS and U.S. Government products written for public dissemination.

The complete technical documentation of the 2011 SNRA consists of this document; the July 2013 final draft of the classified SNRA Technical Report as delivered to FEMA; the technical documentation of the DHS/NPPD 2010 Risk Analysis Process for Informed Decision-making (RAPID) engine; and the classified technical reports, appendices, and annexes of the DHS/S&T 2011 Integrated CBRN Terrorism Risk Assessment (ITRA) and its component assessments.

[2] U.S. Department of Homeland Security (2011, September). National Preparedness Goal. Federal Emergency Management Agency (FEMA): at http://www.fema.gov/media-library/assets/documents/25959. Presidential Policy Directive 8 is reproduced in Appendix P.

[3] U.S. Department of Homeland Security (2011, December). The Strategic National Risk Assessment in Support of PPD 8: A Comprehensive Risk-Based Approach toward a Secure and Resilient Nation (public summary). At http://www.dhs.gov/xlibrary/assets/rma-strategic-national-risk-assessment-ppd8.pdf.

Strategic National Risk Assessment 2011
Introduction to the Technical Report

The SNRA was executed by the DHS National Protection and Programs Directorate (DHS/NPPD) Office of Risk Management and Analysis (RMA) in calendar year 2011.

The Strategic National Risk Assessment (SNRA) was coordinated by the Federal Emergency Management Agency (FEMA) Program Executive Office (PEO) on behalf of the Secretary of Homeland Security in support of Presidential Policy Directive/PPD-8. Representatives of the Director of National Intelligence and the Attorney General, as well as other members of the Federal interagency, supported this effort.

This report documents the technical approach and findings from the SNRA. The methodology, event-specific data and assumptions used to generate frequency, consequence and risk estimates have not yet undergone formal review. As such, all findings reported here should be considered provisional. The use of Federal interagency data sources or subject matter expertise should not be interpreted as reflecting formal concurrence from participating agencies.

It is important to note that the SNRA is a *strategic national* risk assessment. As such, it does not present a full view of the risk facing local communities. To fully support preparedness planning, it is necessary to both consider national and regional risks, many of which differ from region to region. The SNRA Technical Report is best used as one of many strategic-level inputs to planning and risk management activities.

Inquiries about PPD-8 should be directed to FEMA via email at PPD8-NationalPreparedness @fema.dhs.gov.

Cover image courtesy of the NASA's Visible Earth Project. Data and image by the NASA Goddard Space Flight Center and NOAA National Geophysical Data Center.

Contents

Report

Reference Appendices

EXECUTIVE SUMMARY

This report highlights unclassified findings from the Strategic National Risk Assessment (SNRA) and provides technical documentation of its data sources and methodology.

- The SNRA was executed in support of Presidential Policy Directive/PPD-8, which called for national preparedness to be based on core capabilities that support "strengthening the security and resilience of the United States through systematic preparation for the threats that pose the greatest risk to the security of the Nation, including acts of terrorism, cyber attacks, pandemics, and catastrophic natural disasters."
- Given PPD-8's emphasis on contingency events with defined beginning and endpoints (e.g. hurricanes, terrorist attacks), the SNRA does not explicitly assess persistent, steady-state risks such as border violations, illegal immigration, and drug trafficking, which are also important considerations for DHS and the homeland security enterprise.

Classified findings regarding the adversarial events, and more significantly the comparative findings for the set of SNRA national-level events as a whole, are not provided in the following pages. For these findings, please see the full (classified) SNRA Technical Report.[1]

Analytic Approach

The SNRA methodology is built on the estimation of frequencies and consequences of a set of national-level events with the potential to test the Nation's preparedness and responds specifically to the question: *With what frequency is it estimated that an event will occur and what are the consequences of an event if it does occur?* Annualized loss estimates, constructed by multiplying these estimates of frequency and consequence, are used as a measure of risk.

Key Findings

The assessment finds that a wide range of threats and hazards pose a significant risk to the Nation, affirming the need for an all-threats/hazards, capability-based approach to preparedness planning.

- Many events are estimated to have the potential to happen more than once every 10 years, meaning that it is likely that the Nation's preparedness will be tested in this decade.

Of the natural hazard and accidental events, as shown in Table 1 below, two national-level events in the SNRA stand out for their generally high risk profiles across many consequence categories: *pandemic influenza outbreaks* and *hurricanes*.

- Human pandemic influenza is assessed to dominate the fatality and injury/illness risk of all the non-adversarial events in the SNRA. *The pandemic influenza scenario assessed in the SNRA has more fatality risk and injury/illness risk, at the best estimate, than every other measured natural-hazard or accidental event in the SNRA combined.*

There is a substantial amount of uncertainty concerning the likelihood, and in some cases the consequences, of the threats and hazards examined in the SNRA.

[1] All frequency estimates for the adversarial events and fatality, injury/illness, economic, and top level (low/best/high) psychological distress estimates for the chemical/biological/radiological/nuclear (CBRN) events are classified at the SECRET or SECRET//NOFORN level. Top level (low/best/high) estimates for the fatality, injury/illness, economic, and psychological distress metrics for the Aircraft as a Weapon, Armed Assault, and Explosives Terrorism Attack events are unclassified, but are For Official Use Only. All other data, including all social displacement and environmental consequence estimates, are unclassified without caveats.

Critical areas for future study in the SNRA include the risk associated with cyber events (affecting both data and physical infrastructure) and a subset of natural hazards (including space weather, tsunami, and volcanoes). Data, modeling, and resource limitations prevented the risk of these events from being assessed quantitatively in the SNRA.

Impacts and Future Uses

The SNRA was executed in support of PPD-8 implementation and served as an integral part of the development of the 2011 National Preparedness Goal, assisting in integrating and coordinating identification of the core capabilities and establishing a risk-informed foundation for the National Preparedness System.

The SNRA provides an understanding of the risks that pose the greatest challenge to the Nation's security and resilience. This understanding is crucial for preparedness planning and prioritization. It enables:

- A shared understanding of the potential incidents for which communities should prepare
- A prioritization of the incidents that may pose the greatest negative impact to communities and thus require preparedness
- The evaluation of needed capabilities, and capability levels across all five focus areas: Prevention, Protection, Mitigation, Response, and Recovery.

The results of the SNRA can also assist with a wide range of efforts which are crucial to execute the Preparedness Cycle in support of the National Preparedness System, including planning, organizing and equipping, training, exercises, and evaluation.

Although the development of the SNRA is an important first step, further analysis through the conduct of regional- and community-level risk assessments will help communities better understand their risks and form a foundation for their own security and resilience. In conjunction with Federal, state, and local partners, the SNRA will continue to be expanded and enhanced, and will ultimately serve as a unifying national risk profile to facilitate preparedness efforts.

Table 1: Comparative Risk in the SNRA - Natural Hazard and Accidental Events

National-Level Event	Best Estimate Risk: Fatality	Injury/Illness	Direct Economic	Social Displacement	Psychological Distress	Environmental
Animal Disease			X			
Earthquake			X			
Flood			X	X		X
Human Pandemic Outbreak	X	X	X		X	
Hurricane			X	X	X	X
Wildfire			X	X		
Biological Food Contamination						
Chemical Substance Spill or Release						X
Dam Failure						
Radiological Substance Release						
Insufficient quantitative data to support comparisons to other events						
Space Weather						
Tsunami						
Volcanic Eruption						
Cyber Event affecting Data						
Cyber Event affecting Physical Infrastructure						
Risk estimates are classified						
Aircraft as a Weapon	See classified SNRA results					
Armed Assault						
Biological Terrorism Attack (non-food)						
Chemical/Biological Food Contamination Terrorism Attack						
Chemical Terrorism Attack (non-food)						
Explosives Terrorism Attack						
Nuclear Terrorism Attack						
Radiological Terrorism Attack						

How to read this table:

Best estimate risk is assessed to fall within or bound the top order of magnitude of fatality, injury/illness, direct economic, social displacement, or psychological distress risk or the highest risk bin (Figure 8) of best estimate environmental risk among the natural and accidental hazard events in the SNRA. The relative magnitude (on a logarithmic scale) of the quantitatively based best estimate risks is indicated by background coloring in each cell. [2]

Insufficient quantitative risk data to support comparisons with other events.

In this approach, the relative risk on each consequence axis is considered in isolation, rather than combined. Relative weightings between different consequence measures are subjective value judgments that may vary by decision context and decision maker.

The best estimate of risk for each SNRA event is used to identify highest-magnitude risks. However, there is considerable uncertainty, varying data quality, and substantial overlap in the risk estimates of the SNRA events, making it difficult to generate a rank-ordered list of events based solely on the SNRA risk results.

[2] The distinction between risk levels for cells with or without 'X' marks may be more clear by reference to the version of this table presented in Appendix N, which shades cells by a linear rather than a logarithmic scale.

Table 2: National-Level Events Assessed in the SNRA

Threat/ Hazard Group	Threat/Hazard Type	National-level Event Description
Natural	Animal Disease Outbreak	An unintentional introduction of the foot-and-mouth disease virus into the domestic livestock population in a U.S. state
	Earthquake	An earthquake occurs within the U.S. resulting in direct economic losses greater than $100 Million
	Flood	A flood occurs within the U.S. resulting in direct economic losses greater than $100 Million
	Human Pandemic Outbreak	A severe outbreak of pandemic influenza with a 25% gross clinical attack rate spreads across the U.S. populace
	Hurricane	A tropical storm or hurricane impacts the U.S. resulting in direct economic losses of greater than $100 Million
	Space Weather	The sun emits bursts of electromagnetic radiation and energetic particles causing utility outages and damage to infrastructure
	Tsunami	A tsunami with a wave of approximately 50 feet impacts the Pacific Coast of the U.S.
	Volcanic Eruption	A volcano in the Pacific Northwest erupts impacting the surrounding areas with lava flows and ash and areas east with smoke and ash
	Wildfire	A wildfire occurs within the U.S. resulting in direct economic losses greater than $100 Million
Technological/ Accidental	Biological Food Contamination	Accidental conditions where introduction of a biological agent (e.g., *Salmonella*, *E. coli*, botulinum toxin) into the food supply results in 100 hospitalizations or greater and a multi-state response
	Chemical Substance Spill or Release	Accidental conditions where a release of a large volume of a chemical acutely toxic to human beings (a toxic inhalation hazard, or TIH) from a chemical plant, storage facility, or transportation mode results in either one or more offsite fatalities, or one or more fatalities (either on- or offsite) with offsite evacuations/shelter-in-place
	Dam Failure	Accidental conditions where dam failure and inundation results in one fatality or greater
	Radiological Substance Release	Accidental conditions where reactor core damage causes release of radiation
Adversarial/ Human-Caused	Aircraft as a Weapon	A hostile non-state actor(s) crashes a commercial or general aviation aircraft into a physical target within the U.S.
	Armed Assault	A hostile non-state actor(s) uses assault tactics to conduct strikes on vulnerable target(s) within the U.S. resulting in at least one fatality or injury
	Biological Terrorism Attack (non-food)	A hostile non-state actor(s) acquires, weaponizes, and releases a biological agent against an outdoor, indoor, or water target, directed at a concentration of people within the U.S.
	Chemical/Biological Food Contamination Terrorism Attack	A hostile non-state actor(s) acquires, weaponizes, and disperses a biological or chemical agent into food supplies within the U.S. supply chain
	Chemical Terrorism Attack (non-food)	A hostile non-state actor(s) acquires, weaponizes, and releases a chemical agent against an outdoor, indoor, or water target, directed at a concentration of people using an aerosol, ingestion, or dermal route of exposure
	Cyber Event affecting Data	A cyber event which seriously compromises the integrity or availability of data (the information contained in a computer system) or data processes resulting in economic losses of $1 Billion or greater
	Cyber Event affecting Physical Infrastructure	A cyber event in which cyber means are used as a vector to achieve effects which are "beyond the computer" (i.e., kinetic or other effects) resulting in one fatality or greater or economic losses of $100 Million or greater
	Explosives Terrorism Attack	A hostile non-state actor(s) deploys a man-portable improvised explosive device (IED), Vehicle-borne IED, or Vessel IED in the U.S. against a concentration of people, and/or structures such as critical commercial or government facilities, transportation targets, or critical infrastructure sites, etc., resulting in at least one fatality or injury
	Nuclear Terrorism Attack	A hostile non-state actor(s) acquires an improvised nuclear weapon through manufacture from fissile material, purchase, or theft and detonates it within a major U.S. population center
	Radiological Terrorism Attack	A hostile non-state actor(s) acquires radiological materials and disperses them through explosive or other means (e.g., a radiological dispersal device or RDD) or creates a radiation exposure device (RED)

Table 3: SNRA Data Sources

National-Level Event	Frequency	Fatalities	Injuries/Illnesses	Direct Economic Loss
Animal Disease	USDA Economic Research Service modeling & DHS/OHA and DHS/S&T subject matter expertise			
Hurricane	Historic data compiled from NOAA, the Center for Science and Technology Policy Research at University of Colorado-Boulder & FEMA HAZUS modeling			
Earthquake	Historic data compiled from the Center for Science and Technology Policy Research at University of Colorado-Boulder & FEMA HAZUS modeling			
Flood	Historic data compiled from NOAA National Climactic Data Center (NCDC) and FEMA HAZUS modeling			
Human Pandemic Outbreak	CDC analysis of historic record	CDC modeling		
Space Weather	SNRA Project Team analysis of NOAA data and Oak Ridge National Laboratories assessments			
Tsunami	USGS analysis	USGS & FEMA HAZUS modeling		
Volcanic Eruption	USGS analysis	USGS & FEMA HAZUS modeling		
Wildfire	Historic data compiled from Spatial Hazard Events and Losses Database for the United States (SHELDUS) – University of South Carolina			
Biological Food Contamination	CDC Foodborne Outbreak Online Database (FOOD) and FDA / USDA subject matter expertise			Open source historic examples
Chemical Substance Spill or Release	DOT Pipeline & Hazardous Materials Safety Administration (PHMSA) and EPA Risk Management Program (RMP) incident databases			
Dam Failure	Historic data, U.S. Bureau of Reclamation modeling, & USACE National Inventory of Dams			Open source historic examples
Radiological Substance Release	U.S. Nuclear Regulatory Commission license renewal applications			
CBRN Terrorism Attacks	DHS/S&T 2011 Integrated Terrorism Risk Assessment (ITRA)			
Armed Assault	SNRA IC Elicitation (NCTC, DHS/I&A, FBI)	START Global Terrorism Database		SNRA Project Team modeling using ITRA/RAPID approach
Aircraft-as-a-Weapon	DHS/RMA 2010 Risk Assessment Process for Informed Decision-Making (RAPID)	Open source historic data (Planes hitting buildings or crowds)		SNRA Project Team modeling using ITRA/RAPID approach
Explosives Terrorism Attack	DHS/RMA 2010 RAPID	START Global Terrorism Database		SNRA Project Team modeling using ITRA/RAPID approach
Cyber Events (affecting Infrastructure & Data)	SNRA IC Elicitation (ODNI, CIA, FBI, NSA, NSS, DHS/NPPD/CS&C)	Open source historic examples and NCICC data		

Consequence Type	Data Sources and Subject Matter Expertise
Social Displacement	• University of Maryland, National Consortium for the Study of Terrorism & Responses to Terrorism (START) • Institute for Alternative Futures • University of Pittsburgh Medical Center, Center for Biosecurity
Psychological Distress	• National Center for Disaster Mental Health Research • University of California-Irvine, Department of Psychology and Social Behavior • Carnegie Mellon University, Dept. of Social & Decision Sciences, Dept. of Engineering & Public Policy • University of Maryland, START • DHS/S&T Human Factors Division[3]
Environmental Impacts	• Environmental Protection Agency

[3] DHS/S&T Resilient Systems Division (RSD) is the current (2015) organizational successor to Human Factors Division.

OVERVIEW

The Strategic National Risk Assessment (SNRA) was executed in support of Presidential Policy Directive 8 (PPD-8), which calls for creation of a National Preparedness Goal, a National Preparedness System, and a National Preparedness Report. Specifically, national preparedness is to be based on core capabilities that support "strengthening the security and resilience of the United States through systematic preparation for the threats that pose the greatest risk[4] to the security of the Nation, including acts of terrorism, cyber attacks, pandemics, and catastrophic natural disasters."

As part of the effort to develop the National Preparedness Goal and identify core capabilities, the Secretary of Homeland Security led an effort to conduct a strategic national risk assessment to help identify the types of incidents that pose the greatest threat to the Nation's homeland security. Representatives from the offices of the Director of National Intelligence and the Attorney General, as well as other members of the Federal interagency, supported this effort. The assessment was used:

- To identify high risk factors that supported development of the core capabilities and capability targets in the National Preparedness Goal;
- To support the development of collaborative thinking about strategic needs across prevention, protection, mitigation, response, and recovery requirements; and
- To promote the ability for all levels of Government to share common understanding and awareness of National threats and hazards and resulting risks so that they are ready to act and can do so independently but collaboratively.

The subsequent pages provide an overview of the findings and the analytic approach used to conduct the SNRA. It should be emphasized, however, that although the initial version of the SNRA is a significant step toward the establishment of a new homeland security risk baseline, it contains data limitations and assumptions that will require additional study, review, and revision as the National Preparedness System is developed. These limitations are discussed below, and future iterations of the assessment are expected to reflect an enhanced methodology and improved data sets.

Classified findings regarding the adversarial events, and more significantly the comparative findings for the set of SNRA national-level events as a whole, are not provided in the following pages. For these findings, please see the full (classified) SNRA Technical Report.[5]

[4] The DHS Lexicon defines risk as the potential for an unwanted outcome resulting from an incident, event, or occurrence, as determined by its likelihood and the associated consequences. Available from http://www.dhs.gov/xlibrary/assets/dhs-risk-lexicon-2010.pdf.

[5] All frequency estimates for the adversarial events and fatality, injury/illness, economic, and top level (low/best/high) psychological distress estimates for the chemical/biological/radiological/nuclear (CBRN) events are classified at the SECRET or SECRET//NOFORN level. Top level (low/best/high) estimates for the fatality, injury/illness, economic, and psychological distress metrics for the Aircraft as a Weapon, Armed Assault, and Explosives Terrorism Attack events are unclassified, but are For Official Use Only. All other data, including all social displacement and environmental consequence estimates, are unclassified without caveats.

STRATEGIC NATIONAL RISK ASSESSMENT SCOPE

To inform homeland security preparedness and resilience activities, the SNRA evaluated the risk from known threats and hazards that have the potential to significantly impact the Nation's homeland security. These threats and hazards were grouped into a series of national-level events with the potential to test the Nation's preparedness.

SNRA participants – including Federal agencies, DHS Components, and the intelligence community, among others – developed a list of national-level events (Table 2 above) for assessment in the initial SNRA. The events are grouped into three categories: 1) natural hazards; 2) technological/ accidental hazards; and 3) adversarial, human-caused threats/hazards.

For the purposes of the assessment, DHS analysts identified thresholds of consequence necessary to create a national-level event. These thresholds were informed by subject matter expertise and available data, and are shown in Table 2 of this report.

- For some events, economic consequences were used as thresholds, while for others, fatalities or injuries/illnesses were deemed more appropriate as the threshold to determine a national-level incident.
- In no case, however, were economic and casualty thresholds treated as equivalent to one another (i.e. dollar values were not assigned to fatalities).

Event descriptions in Table 2 that do not explicitly identify a threshold signify that no minimum consequence threshold was employed. This allows the assessment to include events for which the psychological impact of an event could cause it to become a national-level event even though it may result in a low number of casualties or a small economic loss.

Only events having both a distinct beginning and end and an explicit nexus to homeland security missions were included. This approach excluded:

- Persistent, steady-state risks such as border violations, illegal immigration, and drug trafficking which fall within the homeland security mission space, but which do not have a defined beginning and end point;
- Chronic societal concerns, which can represent a large fraction of fatality, economic, and other risks for an average American, such as cancer or car accidents, but which are generally not related to homeland security national preparedness;
- Political, economic, environmental, and societal trends that may contribute to a changing risk environment but are not explicitly homeland security national-level events (e.g. demographic shifts, economic trends). These trends will be important to include in future iterations of a national risk assessment, however.

The SNRA participants identified the 23 events listed in Table 2 as those with the potential to pose the greatest risk to the security of the Nation and formed the analytic basis of the SNRA. Table 2 is not a complete list of risks that exist and will be reconsidered in future iterations of the assessment. Additional threats and hazards, such as droughts, heat waves, winter storms, rain storms, and different types of technological/accidental or human-caused hazards, can also pose a risk to jurisdictions across the country and should be considered, as appropriate, in preparedness planning. Non-influenza diseases with pandemic potential and other animal diseases should also be considered. In addition, assessment participants identified a number of events for possible inclusion in future iterations of the SNRA, including electric grid failure, plant disease outbreak, and transportation system failure.

ANALYTIC APPROACH

> *Risk management is essential for homeland security leaders in prioritizing competing requirements and enabling comprehensive approaches to measure performance and detail progress.*
>
> *DHS Risk Management Fundamentals, 2011*

The SNRA methodology is built on the estimation of frequencies[6] and consequences[7] of national-level events, specifically, *With what frequency is it estimated that an event will occur and what are the consequences of an event if it does occur?* Annualized loss estimates, constructed by multiplying these estimates of frequency and consequence, are a straightforward measure of risk.[8] This annualized loss approach was chosen because it allowed a straightforward construction of risk for all events, even those for which minimal data existed.

Measures of Risk

Homeland security hazards are dissimilar in important ways. Some hazards, such as natural disasters, have a long historical record. Others, including terrorist attacks, have a limited or nonexistent historical record and are initiated by adaptive adversaries who have the ability to respond to our defensive posture. Still other hazards, such as technological accidents, may have been subject to multi-jurisdictional regulations aimed at risk reduction for many years, but are only recently being analyzed in the context of national preparedness. In addition, these disparate types of hazards often have varied and unexpected consequences on society and security when they do occur.

Different consequences can result from homeland security hazards, including health and safety, economic, environmental, and social impacts. Indeed, a recent National Research Council (NRC) Report[9] recommended that DHS risk assessments "should consider a full range of public health, safety, social, psychological, economic, political, and strategic outcomes." An assessment using only some of these consequences (e.g., solely those easy to quantify) would not reflect the full impact on the U.S. and resulting comparisons across hazards would be biased and less informative.

The SNRA examined the risks associated with six categories of harm: loss of life, injuries and illnesses, direct economic costs,[10] social displacement, psychological distress, and environmental impact. Each consequence, when combined with the frequency of the national-level event, produces a different type of risk, such as fatality risk, injury and illness risk, and direct economic risk. This multi-faceted view of potential consequences draws attention to the broad and often interdependent effects of incidents that require whole-of-community preparation and cooperation across the homeland security enterprise. For instance, community resilience relates to both mitigating human and economic consequences and addressing the psychological and social distress caused by the incident within the community. Similarly, other types of resilience involve

[6] Frequency is defined in the DHS Risk Lexicon, 2010 edition, as the "number of occurrences of an event per defined period of time or number of trials."

[7] Consequence is defined in the DHS Risk Lexicon, 2010 edition, as the "effect of an event, incident, or occurrence."

[8] Risk is defined in the DHS Risk Lexicon, 2010 edition, as the "potential for an unwanted outcome resulting from an incident, event, or occurrence, as determined by its likelihood and associated consequences."

[9] National Research Council (2010). *Review of the Department of Homeland Security's approach to risk analysis.* Washington, DC: National Academies Press.

[10] Direct economic losses were defined to include decontamination, disposal, and physical destruction costs, lost spending due to fatalities, medical costs, and business interruptions. Indirect and induced economic impacts, which are often larger than direct losses, are not included in this assessment due to time and resource constraints. Additional information regarding the limitations of the economic analysis in the SNRA is provided on the following pages and Appendix E.

withstanding environmental and infrastructure degradations to ensure essential services continue to be delivered.

The NRC's Review recommended against aggregating these consequences (and risks) into a single metric in a strategic assessment that includes both terrorism and natural disasters, given the current capabilities of risk science. In accordance with the NRC's recommendation, the methodology reports each type of risk separately, as many strategic decisions can be informed without aggregation. Instead, the assessment treated consequence categories differently and allows stakeholders in the National Preparedness System to apply their own expert judgments to the findings and the implications of those findings on core capability targets.

The SNRA relied on the best available quantitative estimates of frequency and consequences from existing Government models and assessments, peer-reviewed literature, and expert judgment. Where sufficient quantitative information was not available or additional research is warranted – such as data related to the frequency of high-consequence space weather incidents – events were assessed semi-quantitatively or qualitatively. The estimates of the frequency and consequences for each of the events was compared where appropriate.

The SNRA used the following approaches to estimate frequency and consequence:

Frequency

In order to apply a consistent methodology across all SNRA event types, frequency was selected as a metric for the likelihood of event occurrence. Frequency was estimated as the potential number of successful attacks (for adversarial/human-caused events) or potential number of occurrences (for natural and technological hazards), per year. Adversarial/human-caused frequencies were estimated primarily using elicitation from subject matter experts.[11] Estimates of natural and technological hazard frequencies were drawn heavily from the historical record.

Frequency ranges included in the SNRA for adversarial/human-caused events are estimates of the frequency of successful attacks. Where subject matter expert judgment was used to determine frequency of successful attacks, adversary intent and capability were considered implicitly by the experts, but were not explicitly quantified or characterized. Attack initiations may occur with higher frequency than the ranges provided.

Fatalities

For events that have occurred in the past, the expected number of fatalities was estimated primarily from the historical record. For events that have never occurred (primarily in terrorism), consequences were estimated using data from previous government risk assessments, which rely on models and simulations.

[11] Subject matter expert (SME) elicitation was a component of modeling frequency in two of the prior assessments leveraged for the SNRA: the 2011 ITRA conducted by DHS/S&T (chemical, biological, radiological, and nuclear terrorism attacks) and the 2010 Risk Assessment Process for Informed Decision-making (RAPID) conducted by DHS/Office of Risk Management & Analysis (aircraft as a weapon, explosives terrorism attack). Separate SME elicitations were conducted for the SNRA with representatives from the Intelligence Community in July 2011 for the armed assault and cyber events. In all cases, the outputs from these models/elicitations were converted to equivalent units of successful events per year for comparison to the frequencies of natural and technological hazards drawn from the historical record.

SME estimation of the frequency of rare, adversarial/human-caused events is challenging, and SME frequency judgments in the SNRA reflect significant uncertainty. As with all data in the SNRA, these SME frequency judgments should be interpreted as order of magnitude estimates for the purposes of comparison.

Injuries and Illnesses

Injuries and illnesses were estimated similarly to fatalities. However, this category mixed permanent debilitating injuries (such as those resulting from chemical accidents) with temporary illnesses (such as those resulting from pandemic influenza). Therefore, the injury and illness consequences should be considered in context with the types of injuries and illnesses likely to result from each hazard.

Direct Economic Loss

Direct economic losses were estimated similarly to fatalities. Direct economic losses were defined to include decontamination, disposal, and physical destruction costs, lost spending due to fatalities, medical costs, and business interruptions. Due to constraints on the time available to execute the SNRA and the community's lack of a broadly agreed upon method for calculating indirect and induced economic impacts, these impacts, which are often larger than direct losses, are not included in this assessment.

- Indirect economic impacts include costs incurred by the suppliers and vendors in the associated expenditure sectors for the industries impacted by the direct costs. Induced costs include those incurred due to reduced spending by households with members employed in any of the directly or indirectly affected industries.
- Induced costs can also include substitution effects or likely transfers of economic activity from one set of sectors to another set, such as avoidance of air or other travel or altered transportation mode preferences to other sectors following an attack on the commercial air transport sector.

Attempts were made to assess direct economic losses as comparably as possible across the range of event types in the SNRA; however, data availability made this challenging.

- For example, direct economic losses from certain natural hazards (including wildfires and floods) primarily reflect property and crop losses only, as business interruption estimates were not available. However, property/crop losses were judged to be the dominant component of the direct economic impacts for these events and therefore to be representative of the direct losses, within the precision of the SNRA.
- Further, some sources of direct economic impact data for the SNRA, such as DHS/S&T's 2011 Integrated CBRN Terrorism Risk Assessment (ITRA), include some types of substitution effects and other offsetting activity in their reported estimates of the net direct economic impacts from chemical, biological, radiological, and nuclear terrorism attacks. Such substitution effects would be expected to reduce the reported estimates for events for which they represented a significant contribution in the calculation of direct economic loss relative to events for which they did not.

The comparability of economic consequence estimates in the SNRA is an important area for future study.

Social Displacement

The number of people forced to leave their home for a period of two days or longer was used as a measure of social displacement. Estimates of displacement were obtained from open source social science literature and emergency management databases for historical events and from relevant models for events with limited historic precedence. The measure of social displacement used in the

SNRA does not capture the significant differences between short-term evacuation and long-term permanent relocation, which is a limitation of the current analysis.

Psychological Distress

Experts in the psychosocial impacts of disasters consulted for the SNRA recommended that *significant and/or prolonged psychological distress* caused by national-level events would be the most meaningful psychological metric for strategic capabilities planning and national preparedness. These experts recommended a methodology to assess significant distress which reflected empirical findings indicating that the psychological consequences of a disaster may follow from the other types of consequences being assessed in the SNRA. Specifically, the experts recommended a consequence index[12] which was a function of the SNRA estimates for deaths, injuries, and displacement related to each national-level event. This approach represents the first attempt to include psychological consequences in a DHS strategic, national-level risk assessment. Additional analysis is required to verify and validate the approach used, and experts consulted about psychological consequences emphasized caution in the application of the SNRA's measure of psychological distress and the need for additional research.[13]

Environmental Impact

For the purposes of the SNRA, environmental risk was defined as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.[14] Environmental effects within urban areas and all human health effects were not included within the scope of this environmental risk assessment, because these impacts were already addressed separately in the other consequence analyses for the SNRA. An *ad hoc* group of experts from the Environmental Protection Agency (EPA) judged the relative environmental impact of each national-level event by selecting one of four categories of severity: *de minimus* (or minimal), low, moderate, and high. In doing so, the experts considered the areal extent of the impact, the potential for adverse consequences, and the severity of adverse consequences.[15]

Documentation

All sources and estimates were documented to promote credibility, defensibility, and transparency within the assessment. Additional information on data sources and methods for frequency and consequences is available in the appendices to this report.

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[12] The consequence index used in the SNRA for psychological distress is analogous to a risk index, an approach which allows multiple factors which affect the level of risk to be incorporated into a single numerical score for the level of risk. For more information, see: International Standards Organization (2009). *Risk management – risk assessment techniques* (ISO 31010).

[13] The Department of Homeland Security and its partner organizations leveraged previously funded social and behavioral science research to better understand how to anticipate, prepare for, counteract, and mitigate the effects of terrorist acts, natural disasters, and technological accidents. Additional research is required to further explore psychosocial factors that enable resilience and affect recovery in individuals, organizations, communities, and at the societal level.

[14] This definition is aligned with the EPA's definition of environmental risk. Source: U.S. Environmental Protection Agency (2012). Terminology Services. Retrieved from http://www.epa.gov/OCEPAterms/eterms.html.

[15] The resulting comments and rankings have not undergone review by the EPA and only represent the opinions of the group.

Interpretation of SNRA Results

The targeted precision of the SNRA is an order-of-magnitude. The results of an order-of-magnitude estimate are intended to be accurate only within a factor of 10, a level of precision which is often sufficient to inform strategic decisions. Scientists and engineers often use order-of-magnitude estimates to quickly develop an understanding of the main factors and relationships in a system before undertaking a more detailed study. This level of precision is particularly appropriate to strategic all-hazard risk assessments, since the frequencies and consequences of the hazards considered differ by many orders-of-magnitude. In many cases, available information regarding a particular hazard was more precise than an order of magnitude, and this higher-fidelity information was retained in the SNRA.

Uncertainty in frequency and consequences was explicitly included in the analysis by representing low and high bounds in addition to the best estimates. Examples of sources of uncertainty include incomplete knowledge of adversary capabilities and intent, uncertainty in the effectiveness of countermeasures, variability in possible event severity and location, or lack of historical precedence.

The SNRA captures uncertainty in various ways, depending on the data source. For frequencies derived from the historical record, upper and lower bounds are estimated using the historic maximum number of occurrences per year and the longest time gap between historic occurrences. For frequencies derived from expert elicitation, the uncertainty is captured using structured techniques to determine the 5^{th} and 95^{th} percentile confidence intervals. For consequences derived from the historical record, upper and lower bounds are estimated from past events. For consequences derived from previous terrorism risk assessments, 5^{th} and 95^{th} percentile confidence intervals were estimated which take into account terrorist capabilities and preferences in weapon and target selection.

Given the uncertainty inherent in assessing risks at a national level and the lack of information about some of the events included, the SNRA was designed to avoid false precision. Instead, the assessment identifies only those differences in risk that are still significant despite the associated uncertainties. If a strategic decision depends on a precise separation of hazards of similar risk, a more detailed assessment would be needed.

Participants designed the SNRA to capture the best information the Nation has about homeland security risks to support the development of the National Preparedness Goal, while recognizing the limitations of conducting such analysis in a shortened time frame.

Limitations in addition to the ones discussed above include:

- The SNRA is a *strategic* risk assessment. As such, it does not present a full view of the risk facing local communities. To fully support preparedness planning, it is necessary to both consider national and regional risks, many of which differ from region to region. Further, it is important to recognize that frequencies represent possible occurrences anywhere in the Nation and do not occur with equivalent frequency in any individual location.
- Only events having both a distinct beginning and end and an explicit nexus to homeland security missions were included. This approach excluded persistent, steady-state risks such as drug trafficking, cancer, or car accidents which can represent a larger fraction of risk for individuals and communities than many events considered in the SNRA.
- The comparisons of relative risk between hazard events in the following pages and charts do not include many risks which meet the above criteria and which could significantly challenge national preparedness. These include hazards not included in the first iteration of

the SNRA, such as ice storms and heat waves, and events included in the SNRA but which could not be treated quantitatively, such as cyber events and space weather.[16] As the SNRA is intended to be used as a comparative treatment of risks within its scope, these absences must be kept in mind while reading or using its charts and findings.

[16] Terrorist attacks treated by the SNRA but leveraging classified or For Official Use Only (FOUO) data are also omitted from quantitative comparisons in this unclassified companion document. The full SNRA documentation should be consulted for these adversarial risks, and their absence from the charts and comparisons of relative risk in the following pages should also be kept in mind.

FINDINGS

The results of the SNRA include a comparison of risks for potential incidents in terms of the likelihood (estimated as a frequency, i.e., number of events per year) and consequences of threats and hazards, as well as an analysis of the uncertainty associated with those incidents.

The assessment finds that a wide range of threats and hazards pose a significant risk to the Nation, affirming the need for an all threats/hazards, capability-based approach to preparedness planning. Many events are estimated to have the potential to happen more than once every 10 years, meaning that it is likely that the Nation's preparedness will be tested in this decade.

Key findings are discussed below. Note that all comparative statements in the following are made within the set of natural and technological hazards treated by this unclassified adaptation of the SNRA Technical Report.

High Risk Events

Of the non-adversarial events, the national-level events that are estimated to have generally high risk across many consequence categories in the SNRA are pandemic influenza outbreaks and hurricanes (see Table 1 above).

To identify these high risk events, the results for each type of risk (estimated as an annualized loss) were considered independently and not aggregated. Events which were estimated to have high risk in each consequence category, taking into account uncertainty and the quality of the underlying data, were identified. The events identified above are those which were identified as high risk across the majority of consequence types.

- Pandemic influenza is estimated to be the highest risk event of all the non-adversarial events in the SNRA for fatality, illness/injury, and psychological distress risk, and is near the top for direct economic risk. At the best estimate, it has more fatality and injury/illness risk than every other natural hazard or accident in the SNRA combined. It is estimated to have no social displacement risk and relatively low environmental risk (Figures 6, 8).
- Hurricanes are the highest direct economic risk, at the best estimate, and present the highest social displacement risks to the Nation of all the non-adversarial events included in the SNRA, coupled with relatively high psychological distress and environmental risks. Though not amongst the largest fatality and injury/illness risks within this set, hurricanes do carry some risk in these dimensions.

When considering the high risk events listed above, it is important to consider that many hazards have the potential to be catastrophic, and many additional natural and accidental hazard national-level events in the SNRA pose significant risk to the Nation.

It is also important to note that this identification process considered each type of risk equally (i.e., fatality and economic risks are equally important to flagging events as "high risk" in this process); however, decision-makers may weigh each type of risk differently, depending on their risk tolerances and the decision context. Further, risk is not the only consideration for capability development and prioritization, and events identified here as high risk are not necessarily those for which the risks are most easily or inexpensively mitigated; additional information about the cost of preparedness capabilities and their effectiveness at reducing risk is necessary for making resource allocation prioritization decisions.

Additional findings specific to each risk type are discussed below. Supplementary information about the data sources and methods used to estimate frequencies and consequences is provided in the appendices to this report.

Human Pandemic Influenza Outbreaks Present Risk to the U.S.

The most salient finding identified within the SNRA is the dominance of the fatality risk and injury/illness risk associated with a human pandemic influenza outbreak, when compared with every other natural hazard and accidental event not only individually, but also in sum. *The pandemic influenza outbreak event considered in the SNRA has more fatality risk and injury/illness risk, at the best estimate, than every other measured natural or unintentional hazard event in the SNRA combined.*

- The SNRA considers a pandemic influenza outbreak with a 25 percent gross clinical attack rate[20] and similar case fatality rate to the 1968-1969 Hong Kong flu pandemic. A pandemic of this type is expected to occur once every 10 to 60 years and cause hundreds of thousands of fatalities. For comparison, deaths in the United States from annual seasonal influenza are on the order of 40,000 each year.

The pandemic influenza scenario and data sources were determined in collaboration with the Centers for Disease Control and Prevention (CDC). The pandemic scenario selected for the SNRA is moderate relative to the characteristics of recent influenza pandemics. For example, the three major influenza pandemics of the 20th century (1918, 1957, and 1968) had gross clinical attack rates (adjusted to current population) of 24% to 34% of the population; therefore, the 25% attack rate assumed for the SNRA scenario is conservative. Further, the 1968-1969 Hong Kong flu pandemic had a relatively low case fatality rate of less than 0.05%, in contrast to the 1918 Spanish influenza which had a much higher case fatality rate of between 2.5% and 10%.[21]

Figure 1 illustrates the relative amount of fatality risk and illness/injury risk, at the best estimate, associated with the SNRA human pandemic influenza outbreak event relative to other natural hazard and accident events in the SNRA. The area of the shapes in the figure represents the relative amount of risk.

[20] The gross clinical attack rate is the fraction of a population that becomes clinically ill from influenza during the pandemic.

[21] For reference sources and additional discussion, refer to the Pandemic Influenza Outbreak section on p.40.

Figure 1: Dominance of Human Pandemic Influenza Outbreak Over All Other Natural and Accidental Hazards – Fatality Risk and Injury/Illness Risk

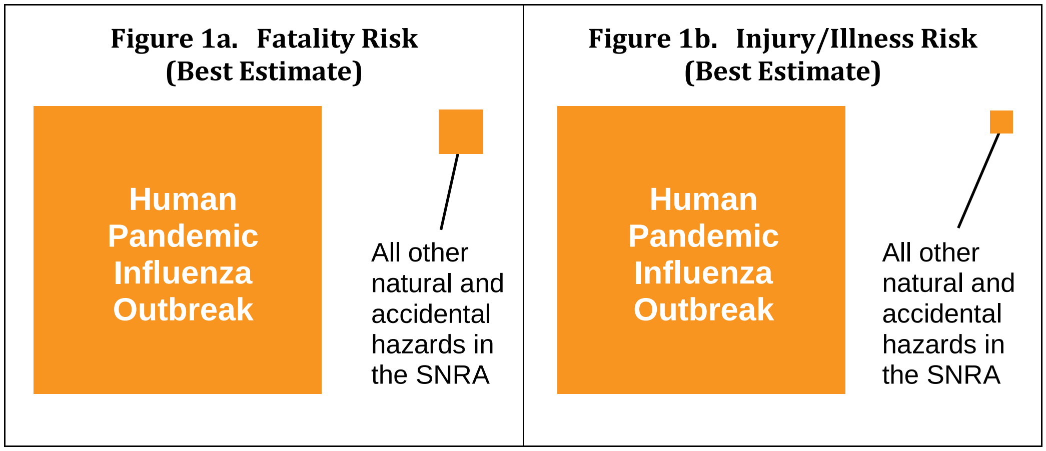
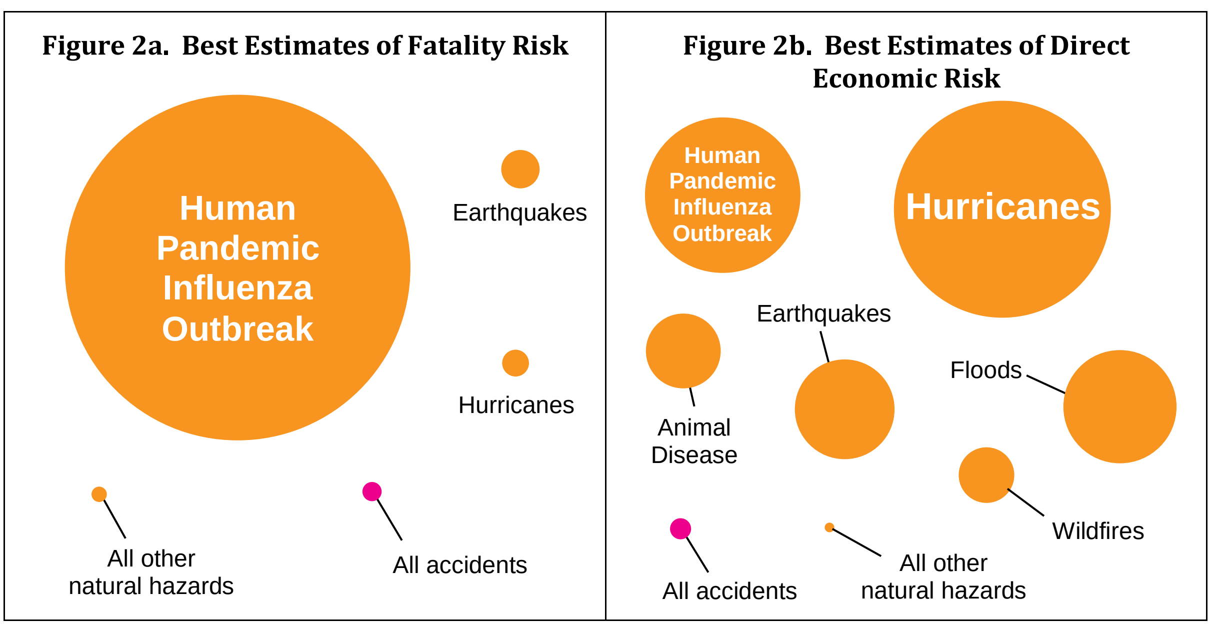


Figure 2 depicts the best estimates of the fatality and direct economic risk for the SNRA's quantitatively assessed natural hazards and accidents, as measured by the product of the best estimates of frequency and fatalities given occurrence (Figure 2a, fatality risk) or the product of the best estimates of frequency and direct economic impacts given occurrence (Figure 2b, direct economic risk). Although it is not the one largest or dominant contributor to direct economic risk among national-level events as it is for human fatality and illness/injury risk, the pandemic influenza outbreak scenario ranks with the most catastrophic natural disaster events assessed in the SNRA.

Figure 2: Best Estimates of Risk in the SNRA Natural-Hazard and Accidental Events



When interpreting Figure 2, it is important to remember that there is significant uncertainty in the frequencies and consequences associated with many events assessed in the SNRA.

Significant Risks May Be Masked By Limited Data

In the course of conducting the SNRA, a number of events were not assessed because of limited quantitative data availability. The SNRA is therefore unable to comment on the relative risk associated with these events, some of which are qualitatively believed to have potential for significant impact. These events include cyber events, space weather, tsunamis, and volcanic eruptions. For each of these identified risks, specific questions have been identified which require further study: these are presented in Table 4.

Table 4: Summary of Outstanding Research Questions

Event	Existing Models and Data	Outstanding Research Questions
Cyber Event affecting Data	Estimated frequency of large-scale events; probable targets	Impacts of large-scale cyber events; Cascading effects in broader network
Cyber Event affecting Physical Infrastructure	Estimated frequency of large-scale events; probable targets	Impacts of large-scale cyber events
Space Weather	Frequency of coronal mass ejections (CMEs) from the Sun	Impacts of a severe space weather event to technology, particularly the sustained impacts to the electric power grid and transformer equipment
Tsunami	Physics-based impact models for specific locations and wave height	Probabilistic modeling of the frequency and severity of tsunami impacts on a national scale
Volcanic Eruption	Physics-based impact models for specific locations and severity of eruption	Probabilistic modeling of the frequency and severity of volcanic impacts on a national scale

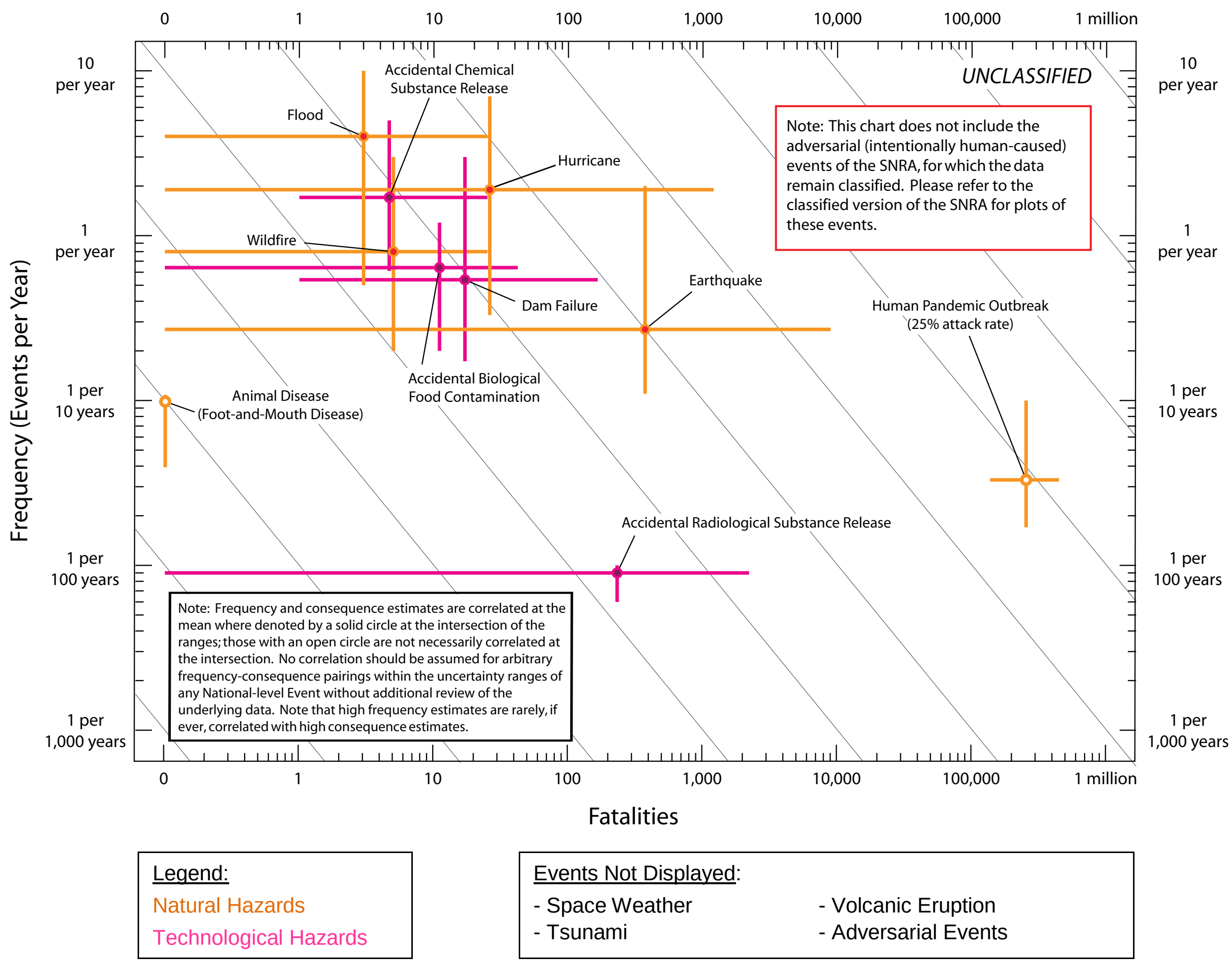
Of the events listed in Table 4, cyber events are the most challenging to consider in the current SNRA framework which focuses on high-impact events with defined beginning and endpoints. It is clear that while a cyber event could result in high-impact and widespread consequences with cascading effects, cyber risks are most prominently persistent threats which require significant focus on an ongoing basis. Cyberspace has become inseparable from our daily lives. And while this increased connectivity has led to remarkable transformations and global advances across society, the corollary of this openness and connectivity is that it has also increased the complexity of the risks we face as a nation. Future efforts to expand the SNRA to include cyber events will pay particular attention to the overall national impact of both high-frequency, low-consequence cyber events and lower-frequency, higher-consequence events.

Fatality Risk

Fatality risk was estimated for each national-level event by multiplying the best estimate of the frequency by the best estimate of the resulting fatalities given occurrence. Figure 3 presents a visual depiction of fatality risk across the SNRA-assessed accidental and natural hazard events.

Note that all comparative statements are made within the set of natural and technological hazards treated by this unclassified adaptation of the SNRA Technical Report.

Figure 3: Fatality Risk



As discussed above, the pandemic influenza outbreak event considered in the SNRA has greater fatality risk, at the best estimate, than every other measured natural or technological hazard in the SNRA combined.

- The SNRA considers a pandemic influenza outbreak with a 25 percent gross clinical attack rate[22] and similar case fatality rate to the 1968-1969 Hong Kong flu pandemic. A pandemic of this type is expected to occur once every 10 to 60 years and cause hundreds of thousands of fatalities. For comparison, deaths in the United States from annual seasonal flu are on the order of 40,000 each year.

Compared with hazards such as hurricanes or floods, pandemic influenza is a higher consequence, lower likelihood event. In other words, pandemic influenza is driven to be a high fatality risk by its significant expected consequences given occurrence, rather than its frequency.

At the best estimate, earthquakes and hurricanes are estimated to pose less fatality risk than a pandemic influenza outbreak by a factor of a hundred or more, but may nonetheless pose relatively high risk when uncertainty is taken into account.

[22] The gross clinical attack rate is the fraction of a population that becomes clinically ill from influenza during the pandemic.

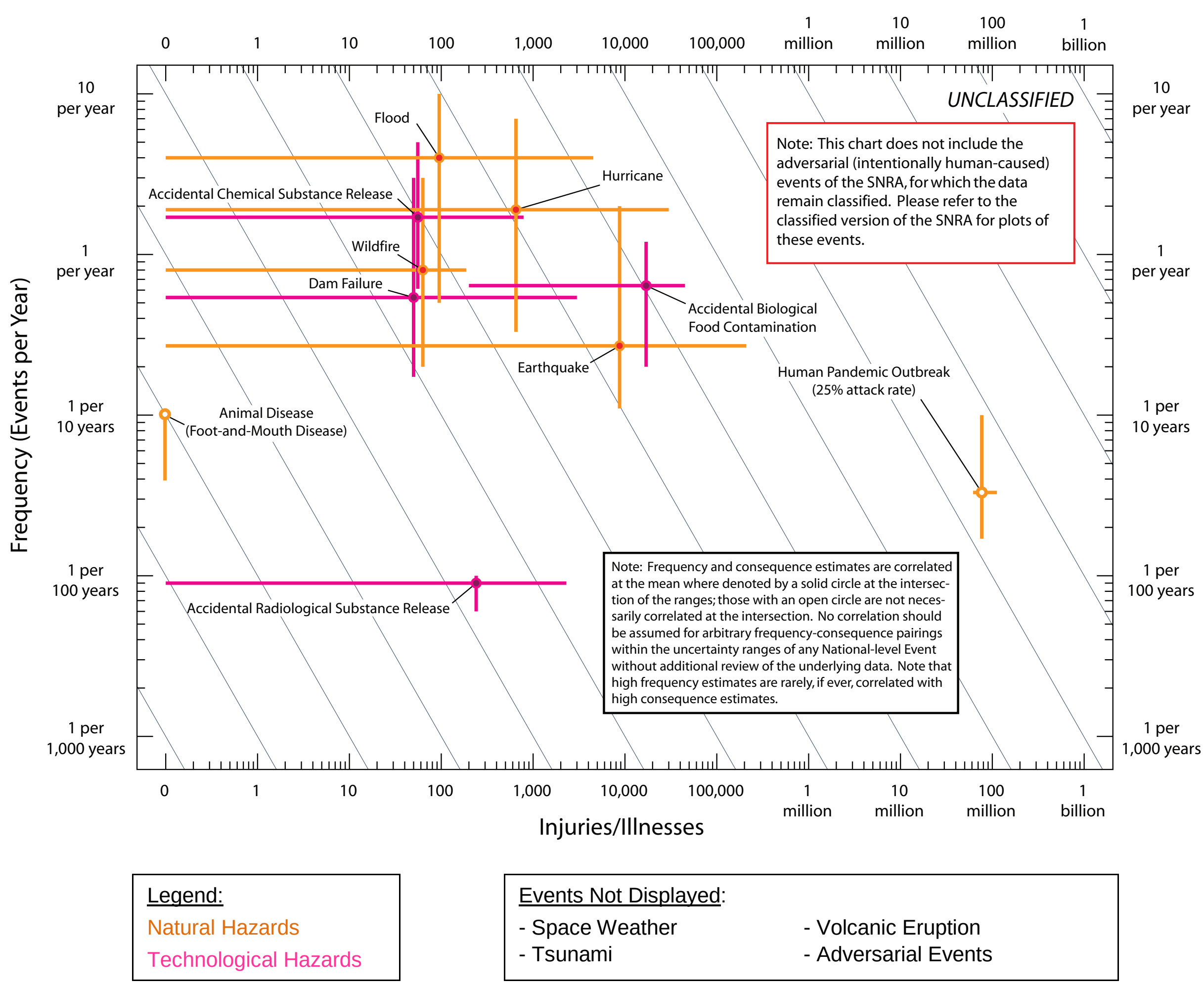
By comparison with pandemic influenza and every other natural and technological hazard quantitatively assessed by the SNRA, foot-and-mouth disease has considerably less fatality risk than other types of events in the SNRA. Although an outbreak of foot-and-mouth disease in the United States has the potential to have considerable impact on livestock and the agricultural economy, it poses little health risk to humans.

Insufficient data about the fatality risk associated with cyber events, space weather, tsunamis, and volcanoes was collected during the SNRA to support quantitative comparisons to other national-level events. For this reason, these events are not displayed in Figure 3.

Injury/Illness Risk

Injury/illness risk was estimated for each national-level event by multiplying the best estimate of the frequency by the best estimate of the resulting injuries/illnesses given occurrence. Figure 4 presents a visual depiction of injury/illness risk across SNRA-assessed events.

Figure 4: Injury/Illness Risk



Note that all comparative statements are made within the set of natural and technological hazards treated by this unclassified adaptation of the SNRA Technical Report.

A pandemic influenza outbreak with a 25 percent gross clinical attack rate and similar case fatality rate to the 1968-1969 Hong Kong flu pandemic has vastly more injury and illness risk, at the best estimate, than every other measured natural or technological hazard in the SNRA combined (see Figure 4). However, pandemic influenza illnesses are different than most of the other injuries and illnesses in the SNRA, in that most victims who become ill but do not die are likely to recover fully and have no lasting physical impact on their lives.

After pandemic influenza, there are several events that cluster together with a factor of 100 to 1,000 times smaller injury/illness risk than pandemic, but which also are estimated to pose significant illness/injury risk relative to other non-adversarial events in the SNRA, at the best estimate. These events include accidental biological food contamination, earthquakes, and hurricanes. In contrast to pandemic influenza, those injured or struck ill by many of the events listed here may face chronic health problems for years after the initial event.

Floods are estimated to pose less illness/injury risk, at the best estimate, than the events listed above, but may pose relatively high risk when uncertainty is taken into account.

Foot-and-mouth disease poses little to no health risk to humans.

Insufficient data about the injury/illness risk associated with cyber events, space weather, tsunamis, and volcanoes was collected during the SNRA to support quantitative comparisons to other national-level events. For this reason, these events are not displayed in Figure 4.

Direct Economic Risk

Direct economic risk was estimated for each national-level event by multiplying the best estimate of the frequency times the best estimate of the resulting direct economic losses given occurrence.

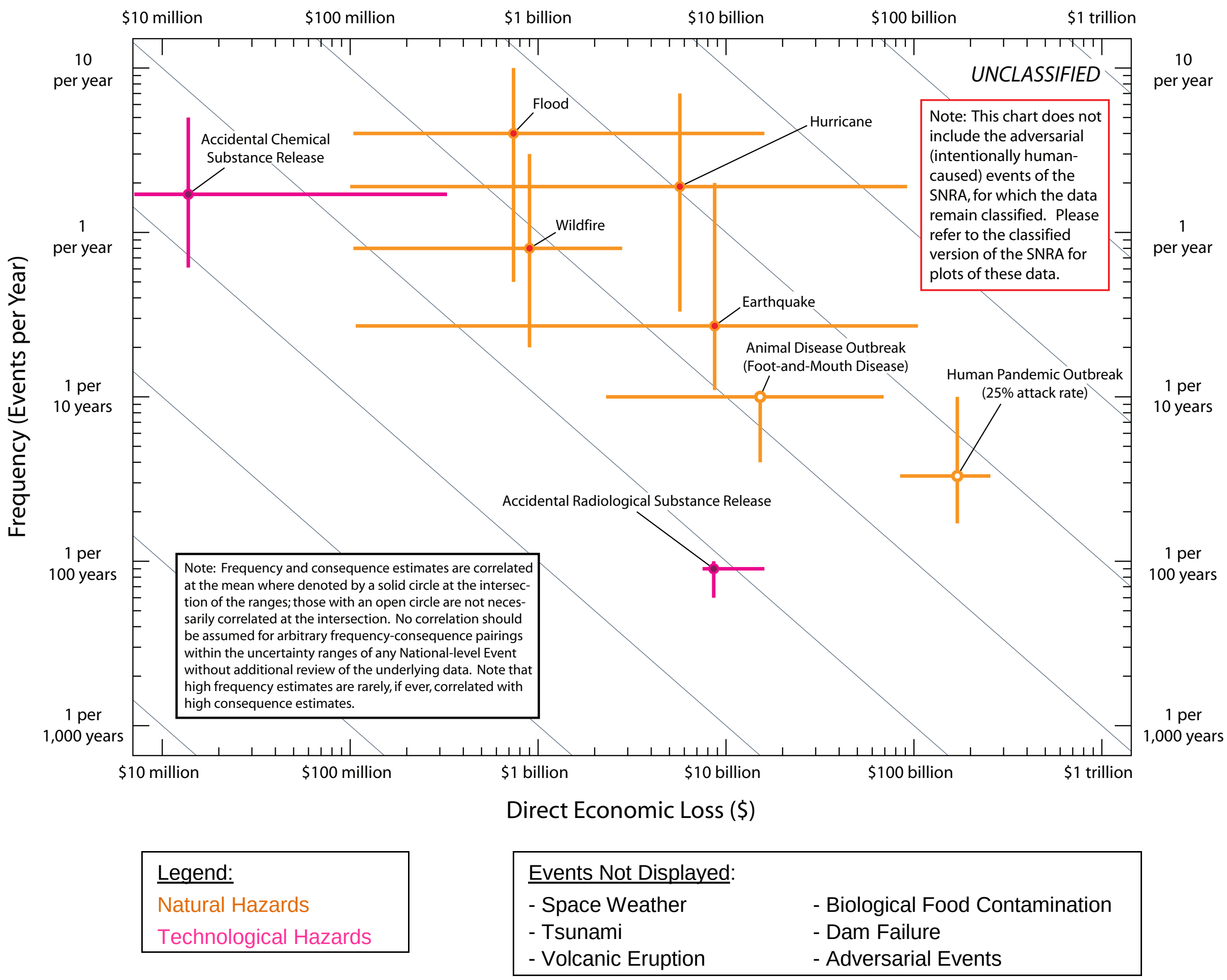
Note that all comparative statements are made within the set of natural and technological hazards treated by this extract of the SNRA.

No single national-level event dominates direct economic risk among the natural and technological hazards of the SNRA to the extent that pandemic influenza outbreaks dominate the fatality and injury/illness risk. Hurricanes pose the largest direct economic risk of natural and technological hazards in the SNRA at the best estimate, given the precision of the SNRA, although there is considerable uncertainty (see Figure 1). Other SNRA events that pose the same order of magnitude of direct economic risk as hurricanes, at the best estimate, are pandemic influenza outbreaks, foot-and-mouth disease, earthquakes, and floods.

- For many high-consequence disasters such as hurricanes and floods, mitigation strategies resulting from advanced warning, such as advance evacuations from areas expected to be impacted, have reduced human health risks over time. However, the physical destruction from natural disasters, combined with their frequency, results in significant direct economic risk.
- Pandemic direct economic costs are dominated by factors directly related to the high numbers of fatalities and illnesses resulting from a pandemic. Primarily, these are the value of lost productivity due to the hundreds of thousands of fatalities, and from the millions unable to work while ill, or caring for someone who is ill.
- The direct economic risk associated with a foot-and-mouth disease (FMD) outbreak in the United States is driven by the immediate reduction in international trade which would occur given an outbreak as well as disease control and eradication efforts. Given the value placed on FMD-free status, a confirmed case of FMD in the U.S. would result in an immediate

restriction of exports. The current control strategy in U.S. Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) regulations to regain FMD-free status is to cull all infected and susceptible animals.[23,24] The APHIS Administrator has discretion to examine other options based on the size of the outbreak.

Figure 5: Direct Economic Risk



Events which are assessed to pose relatively low direct economic risk in the SNRA in comparison with the other non-adversarial hazards include accidental radiological substance release (a lower frequency, higher consequence event) and accidental chemical substance release (a higher frequency, lower consequence event).

The direct economic consequences associated with accidental radiological substance release (a nuclear power plant accident) are highly dependent upon the assumed decontamination standard.

It is important to note that none of the above risk estimates include indirect or induced economic costs, which have the potential to be as large or greater than the direct economic consequences.

[23] U.S. Code of Federal Regulations (2011). Title 9, Section 53.4. *Destruction of animals*. Washington, DC: U.S Government Printing Office. Retrieved from http://www.gpo.gov/fdsys/pkg/CFR-2011-title9-vol1/pdf/CFR2011-title9-vol1-sec53-4.pdf.

[24] U.S. Government Accountability Office (2002, July). *Foot and mouth disease: To protect U.S. livestock, USDA must remain vigilant and resolve outstanding issues* (GAO-02-808). Retrieved from http://www.gao.gov/new.items/d02808.pdf.

Social Displacement Risk

Social displacement risk was estimated in a semi-quantitative manner using a risk matrix displayed in Figure 6 below. These risks are assessed and communicated in this manner due to the inherent challenges in obtaining best estimates of social displacement that were correlated to the best estimates for the frequency of each event. Higher-fidelity social displacement data is required to defensibly multiply the best estimates of event frequency and displacement to approximate an expected loss.

Figure 6: Social Displacement Risk

Frequency (Best Estimate, events per year)	None	Between 1 and 10,000	Between 10,000 and 1 million	Greater than 1 million
Greater than 1 per year		Accidental Chemical Substance Release	Flood Hurricane	Higher Risk
Between 1 per year and 1 per 10 years		Accidental Biological Food Contamination Dam Failure	Wildfire Earthquake	
Less than 1 per 10 years	Pandemic Influenza Lower Risk	Animal Disease Outbreak	Accidental Radiological Substance Release	

	None	Between 1 and 10,000	Between 10,000 and 1 million	Greater than 1 million
Consequences only (events for which frequencies are classified)	Chemical/Biological Food Contamination Terrorism Attack* Cyber Event affecting Data	Armed Assault Biological Terrorism Attack (non-food) Cyber Event affecting Physical Infrastructure Explosives Terrorism Attack	Aircraft as a Weapon Chemical Terrorism Attack (non-food) Radiological Terrorism Attack	Nuclear Terrorism Attack

Social Displacement

How to read this chart: This is a plot of social displacement risk, as drawn from the best estimates of frequency and social displacement. Higher risk national-level events tend toward the upper right of the chart, lower risk ones towards the lower left. One national-level event can be said to be higher risk than another when it is both higher frequency AND higher consequence. The color coding of the national-level events corresponds to the hazard type: **technological/accidental hazards** and **natural disasters**. As the likelihoods and hence the social displacement risk of adversarial events are classified, the unclassified social displacement consequences of **adversarial events** are displayed without likelihood information. For social displacement consequences (without the likelihood component of risk) for all events including adversarial events, see Appendix F.

* While a best estimate for social displacement could not be determined, subject matter experts consulted for the SNRA judged that displacement was likely to be minimal.

Note that all comparative statements are made within the set of natural and technological hazards treated by this unclassified adaptation of the SNRA Technical Report.

- Low, best, and high estimates of social displacement conditional upon event occurrence are unclassified for all events in the SNRA, and may be found in the event risk summary sheets and Appendix F. As social displacement *risk* represents the product of these consequence measures with estimated frequencies of event occurrence which are classified for all adversarial SNRA events, only natural and technological hazards are discussed below. Comparative analysis among all SNRA events based on social displacement consequences alone, independently of frequency of occurrence, is presented in Appendix F.

Two events were judged to have relatively high social displacement risk among the natural and technological hazards: hurricanes and floods.

- Hurricanes and floods are relatively high frequency and result in moderate to high social displacement. These natural hazard events possess significant displacement risk in part because of advance warning of the event and evacuations to safer locations.

Pandemic influenza outbreaks were estimated to pose minimal social displacement risk, because displacement due to hospitalizations was not included in the social displacement consequence assessment.

None of the technological hazards was estimated to pose a high social displacement risk compared with the natural hazards.

Note that there is a significant difference between short-term evacuations up to a week and longer term permanent relocation – a distinction that is not made in the SNRA. As such, caution is advised when interpreting the social displacement risks in Figure 6.

Insufficient data about the social displacement risk associated with space weather, tsunamis, and volcanoes was collected during the SNRA to support quantitative comparisons to other national-level events. For this reason, these events are not displayed in Figure 6.

Psychological Distress Risk

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as inputs.[25] More details regarding the SNRA psychological distress consequence analysis and the limitations of this analysis are available in Appendix G.

Note that all comparative statements are made within the set of natural and technological hazards treated by this unclassified adaptation of the SNRA Technical Report.

Psychological distress risk was estimated in a semi-quantitative manner using a risk matrix similar to the one used for social displacement risk above, and is displayed in Figure 7 below. To our knowledge, the SNRA was the first systematic effort to compare psychological impacts and risks from national-level events; as such, additional research into the psychological consequences of disasters is required to improve the understanding of these consequences at a strategic, national level to permit better estimates of expected loss.

[25] The index approach currently does not include a component for translating economic losses into psychological distress. If estimates of homes destroyed and jobs lost (rather than overall direct economic consequences) are obtained as consequence estimates for various national-level events, it would be possible to capture financial loss as part of the equation for psychological distress in future iterations of the SNRA.

Two events were estimated to have relatively high psychological distress risk compared with other non-terrorism related hazards: pandemic influenza outbreaks and hurricanes. These findings are driven by the underlying method used to estimate significant distress in the SNRA, which heavily weighted contributions from events' fatalities and injuries/illnesses, as well as social displacement to a lesser extent. As discussed above, pandemic influenza dominates the fatality and injury/illness risk, while hurricanes pose a significant social displacement risk. Because the equation used to represent significant distress considers each of these consequence types, events that are high risk in these three categories will correspondingly pose relatively high psychological distress risk.

Other events that are not estimated to pose the highest psychological distress risks among the non-adversarial hazards, but which are still noteworthy, include floods and wildfires.

Insufficient data about the psychological distress risk associated with cyber events, space weather, tsunami, and volcanoes were collected during the SNRA to support quantitative comparisons to other national-level events. For this reason, these events are not displayed in Figure 7.

Figure 7: Psychological Distress Risk

Frequency (Best Estimate, events per year) \ Psychological Distress	Less than 500	Between 500 and 5,000	Between 5,000 and 50,000	Between 50,000 and 500,000	Between 500,000 and 5 million	Greater than 5 million
Greater than 1 per year	Accidental Chemical Substance Release		Flood	Hurricane		Higher Risk
Between 1 per year and 1 per 10 years	Dam Failure		Accidental Biological Food Contamination Earthquake	Wildfire		
Less than 1 per 10 years	Lower Risk			Accidental Radiological Substance Release		Pandemic Influenza

How to read this chart: This is a plot of psychological distress risk, as drawn from the best estimates of frequency and psychological distress. Higher risk national-level events tend toward the upper right of the chart, lower risk ones towards the lower left. One national-level event can be said to be higher risk than another when it is both higher frequency AND higher consequence. The color coding of the national-level events corresponds to the hazard type: **technological/accidental hazards** and **natural disasters**. Psychological distress likelihood and consequences for adversarial events are classified or restricted at the U//FOUO level, and are not displayed on this chart.

Environmental Risk

Since environmental impacts are measured on a four-level ordinal scale (minimal, low, moderate, high), estimating environmental risk is not as straightforward as for other types of risk. Analysts' judgments were used to choose events with high combinations of environmental impact and frequency. The lack of quantitative environmental risk estimates necessitates a subjective judgment of high risk events; this is an area of the SNRA recognized for future improvement.

Note that all comparative statements are made within the set of natural and technological hazards treated by this unclassified adaptation of the SNRA Technical Report.

Figure 8: Environmental Risk

Frequency (Best Estimate, events per year)				
Greater than 1 per year			Flood Hurricane Accidental Chemical Substance Release	Higher Risk
Between 1 per year and 1 per 10 years		Wildfire	Accidental Biological Food Contamination Dam Failure Earthquake	
Less than 1 per 10 years	Lower Risk	Animal Disease Outbreak Pandemic Influenza	Accidental Radiological Substance Release	
	De Minimus	Low	Moderate	High

Consequences only (events for which frequencies are classified)	Armed Assault Cyber Event affecting Data Cyber Event affecting Physical Infrastructure Radiological Terrorism Attack	Aircraft as a Weapon Biological Terrorism Attack (non-food) Chemical/Biological Food Contamination Terrorism Attack Explosives Terrorism Attack	Chemical Terrorism Attack (non-food)	Nuclear Terrorism Attack
	De Minimus	Low	Moderate	High

Environmental Consequences

How to read this chart: This is a plot of environmental risk, as drawn from the best estimates of frequency and environmental impact. Higher risk national-level events tend toward the upper right of the chart, lower risk ones towards the lower left. One national-level event can be said to be higher risk than another when it is both higher frequency AND higher consequence. The color coding of the national-level events corresponds to the hazard type: **technological/accidental hazards** and **natural disasters**. As the likelihoods and hence the environmental risk of adversarial events are classified, the unclassified environmental impacts of **adversarial events** are displayed without likelihood information.

- Estimates of environmental conditional upon event occurrence are unclassified for all events in the SNRA, and may be found in the event risk summary sheets and Appendix H. As environmental *risk* represents the product of these consequence measures with estimated frequencies of event occurrence which are classified for all adversarial SNRA events, only natural and technological hazards are discussed below. Comparative analysis among all SNRA events based on environmental consequences alone, independently of frequency of occurrence, is presented in Appendix H.

Three national-level events among the natural and technological hazards are estimated to have relatively high environmental risk: floods, hurricanes, and accidental chemical substance releases (toxic inhalation hazards). These events were judged to be of high environmental risk because they were judged to result in the most significant environmental impacts (moderate, at the best estimate) of the events with the highest frequency estimates in the SNRA (greater than one event per year, at the best estimate).

No natural or technological hazards were assessed to have a high environmental impact and hence high environmental risk at the best estimate, although some were assessed to have the potential to have high adverse impacts on the environment at the second best estimate (see Appendix H for table).

Although it did not have a quantitative likelihood estimate allowing it to be included in this matrix, space weather was judged to have *de minimis* (minimal) environmental risk because of its assessed *de minimis* adverse environmental impact, at the best estimate. If a space weather event affecting physical infrastructure were to result in extended power outages, the potential for environmental impacts would increase to low/moderate as chemical and treatment plants failed.

Insufficient data about the environmental risk associated with tsunamis and volcanoes was collected during the SNRA to support comparisons to other national-level events. For this reason, these events are not displayed in Figure 8.

Risks Requiring Additional Study

While the analysis of all events in the SNRA would benefit from additional research and deliberate, long-term study, four event types considered in the SNRA – cyber events, space weather, tsunamis, and volcanoes – were judged to have insufficient data, or data of such uncertainty, that quantitative estimates of frequency, consequences, or annualized loss were not included in most of the visualizations presented in this Findings section.

Highly Uncertain Risks

Cyber events and space weather events were determined to be highly uncertain risks in the SNRA, as the risk from these events is difficult to quantify.

Regarding cyber events, the SNRA includes elicited quantitative frequency information for two types of adversarial cyber events: Cyber Event affecting Physical Infrastructure and Cyber Event affecting Data. For each of these events, the specific consequence thresholds outlined in Table 2 were provided to subject matter experts from whom cyber event frequencies were elicited.[26] Since cyber security is a relatively new field with few prior studies, a more complete range of consequences could not be generated and included in this iteration of the SNRA given time limitations.

In addition to data and modeling limitations, future attempts to study cyber events will need to address unique challenges that continue to challenge the cyber community. First, the cyber environment is constantly evolving, with both new attack types being developed and new vulnerabilities being created. Cyber systems are frequently probed and tested, but system operators are not fully aware of what these attacks are seeking to exploit, making consequence estimation problematic. Additionally, cyber attacks are frequently directed at private sector targets, whose owners may be reticent to share data regarding potential consequences of a major cyber event. Cascading effects across assets and sectors are also poorly understood for attacks that would impact the operation of the internet backbone itself. Finally, the current scoping of cyber event consequences in the SNRA does not include the loss of intellectual property, since it is very complex to link ultimate market impact with a cyber event that is separate in space and time.

Despite these challenges, cyber risk is an issue of concern within the homeland security enterprise and warrants further analysis. Programs within DHS and the interagency are working to better understand strategic-level cyber risk and may be positioned to provide additional data in the future.

Regarding space weather, most experts agree that a large and prolonged disruption of the electric grid would produce significant displacement of the impacted population, and significant economic impacts. However, there is significant disagreement among experts regarding whether or not

[26] These frequencies may be found in the classified (full) SNRA Technical Report.

coronal mass ejections from the sun – "geomagnetic storms" – could cause the systemic scale outage required to produce those consequences. While studies by Kappenman[27,28,29] connect these storms (particularly the March, 1989 storm) to failures in electric grid transformers, there is some skepticism from the U.S. Department of Energy's Office of Electricity Delivery and Energy Reliability that the transformer failures referenced in the studies can be credibly attributed specifically to the storms. Although very severe solar storms are known to have occurred in the past, the vulnerability of the modern U.S. national grid to permanent, widespread damage from such events postulated by catastrophic scenarios is due to particular technological and organizational characteristics of the grid which are comparatively recent, and hence these scenarios have not been effectively tested. In the absence of definitive evidence of long-term transformer problems directly caused by a solar storm event, no clear consensus on the likelihood or likely extent of such damage presently exists in the scientific and technical communities concerned with space weather risk.[30]

Historically, it is known that space weather events present a risk to electric grid infrastructure, but there is significant uncertainty in the expected consequences from these events as well as the expected frequencies with which consequential events are expected to occur. For these reasons, we note that considerable research must be done to further characterize these events before quantified expected losses can be included in assessments such as the SNRA.

Tsunamis and Volcanoes

Significant work has been done by the United States Geological Survey and other Federal interagency partners to understand the risks that tsunamis and volcanoes pose at the local and regional level. However, such work typically focuses on specific volcanoes or coastal regions, and additional work is needed to scale local and regional scales up to the national level. For example, the estimated frequencies with which individual volcanoes have historically erupted could be aggregated to arrive at a national frequency for volcanic eruption, but such analysis was not possible within the time frame of the SNRA. For this reason, a specific volcano (Mount Rainer) and a specific tsunami (inundation of the Oregon coast due to an earthquake in the Cascadia Subduction Zone) were studied. Frequency and consequence data for this specific volcano and tsunami is provided in the appendices to this report, but the risk from these events is only a subset of the risk from all types of national-level volcano and tsunami events, and thus is not comparable to the other analysis in the SNRA.

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[27] Kappenman, J. G. (1996). Geomagnetic storms and their impact on power systems. *IEEE Power Engineering Review*, 16(5), 5-8.

[28] Kappenman, J. G. (2010). Geomagnetic storms and their impacts on the U.S. power grid. Metatech, report Meta-R-319, for the U.S. EMP Commission; at http://www.fas.org/irp/eprint/geomag.pdf.

[29] Chapter 7 of National Research Council (2008). *Severe space weather events – understanding societal and economic impacts: A workshop report*. Washington, DC: National Academies Press. Available from http://www.nap.edu/catalog.php?record_id=12507.

[30] Kappenman (1996), (2010), *op. cit.*; National Research Council (2008). *Severe space weather events – understanding societal and economic impacts: A workshop report*. Washington, DC: National Academies Press. Available from http://www.nap.edu/catalog.php?record_id=12507; Holdren, John P, Beddington, John, 2011. Celestial storm warnings. *New York Times* 2011/03/10, Opinion; at http://www.nytimes.com/2011/03/11/opinion/11iht-edholdren11.html?_r=1; JASONS, MITRE Corporation (2011), for DHS Science & Technology Directorate*. Impacts of severe space weather on the electric gri*d. MITRE report JSR-11-320, November 2011; at http://www.fas.org/irp/agency/dod/jason/spaceweather.pdf; North American Electric Reliability Corporation (NERC) (2012). *Effects of geomagnetic disturbances on the bulk power system*; at http://www.nerc.com/files/2012GMD.pdf; Oak Ridge National Laboratory (1991). *Electric utility industry experience with geomagnetic disturbances*. ORNL-6665.; at http://www.ornl.gov/~webworks/cpr/v823/rpt/51089.pdf; CENTRA Consulting (2011), for DHS Office of Risk Management & Analysis. *Geomagnetic Storms*. Issue paper for Future Global Shocks report, Organization of Economic Cooperation & Development (OECD) paper IFP/WKP/FGS(2011)4; at http://www.oecd.org/dataoecd/57/25/46891645.pdf.

RISK INFORMATION BY HAZARD AREA

Note that all comparative statements are made within the set of natural and technological hazards treated by this unclassified adaptation of the SNRA Technical Report.

Natural Hazards Discussion

Hurricanes

> *Natural hazards, including hurricanes, earthquakes, tornados, wildfires, and floods, present a significant and varied risk across the country.*
>
> *National Preparedness Goal, September 2011*

Hurricanes are estimated to present the largest direct economic and social displacement risks to the Nation of all the natural and technological hazards included in the SNRA, coupled with relatively high psychological distress and environmental risks. Though not among the largest, hurricanes do carry some fatality and injury/illness risk.

- For the purpose of the SNRA, a national-level hurricane is defined as a hurricane producing direct economic loss in excess of $100 million dollars.

Over 50 percent of U.S. citizens live in coastal communities, a 45 percent increase from 1970, and this number is expected to grow another 10 percent by 2020.[31] As more people move to coastal communities that experience hurricanes, population and economic growth in these areas increases societal vulnerability to extreme weather. A recent study on hurricane damage suggests that "potential damage from storms is growing at a rate that may place severe burdens on society. Avoiding huge losses will require either a change in the rate of population growth in coastal areas, major improvements in construction standards, or other mitigation actions."[32]

Economic losses from hurricane impacts vary depending on characteristics of the area being impacted (e.g., density, building features, wind building codes, land use, and evacuation plans/execution), as well as the size and strength of the storm itself. For example, Hurricane Andrew (1992) was a fast-moving, compact but strong Category 5 storm that heavily impacted a small area in South Florida, while Hurricane Katrina (2005) was a lesser Category 3 storm that impacted a very large area. Hurricane Irene (2011), by contrast, was an even weaker storm but also impacted a very large area. All three storms created considerable losses though the specific nature of their impacts were different. Preparedness efforts for hurricanes will need to account for both potential storm strength and breadth of impact area.

Floods

Floods are one of the most common hazards in the United States. Their effects can be local, impacting a neighborhood or community, or large, affecting entire river basins and multiple

[31] National Oceanic and Atmospheric Administration (2012). State of the coast. Retrieved from http://stateofthecoast.noaa.gov/population/welcome.html.

[32] Pielke, R. J., Landsea, C., Collins, D., Saunders, M., and Musulin, R. (2008). Normalized hurricane damage in the United States: 1900-2005. *Natural Hazard Review*, 9(1), 29-42.

states.[33] For the purpose of the SNRA, a national-level flood is defined as a flood producing direct economic loss in excess of $100 million dollars using data from 1993 to 2005. All hurricanes were removed from flood events to avoid over-reporting flooding already captured in the hurricane data.

Similar to hurricanes, fatality risk from floods is relatively small due to advanced warning and effective evacuation. Economic consequences from floods are significant, however. The historical average and maximum direct economic damage from a national-level flood in the SNRA analysis were $740 million and $16 billion respectively (see Table 1 in Appendix E). It is also important to note that the SNRA used historical data to estimate flood risk. A number of trends could increase flood risk in the future, including greater economic development and population growth in high-risk areas, lack of adequate flood insurance coverage, and climate change.

Wildfires

Wildfires, as evidenced by the historical record, do not have the same potential for causing catastrophic loss of life as other natural-hazard events: the last time a wildfire killed hundreds of people in the United States was 1918.[34] Rather, most of their potential harm comes from the economic damage they can cause, largely by direct destruction of property, and their capacity to significantly challenge local and federal response efforts.[35] For this reason, an economic threshold of $100 million in direct losses is used to define a national-level wildfire in the SNRA. It is not uncommon for a wildfire to spread to and threaten a large geographic area, requiring a month or more of federally-supported firefighting efforts to successfully contain and extinguish the threat.[36]

The historical period of 1990-2009, selected by the SNRA team because of the completeness and uniformity of available historical data,[37] shows a sharp increase in the frequency and severity of super-catastrophic wildfires affecting human populations in the United States compared with prior years.[38] Two possible drivers of this trend are the unintended consequences of long-term changes in forest management practices intended to reduce the threat of wildfires, but which many scholars argue have had the opposite effect,[39] and the spread of wildfire-favoring intensive grass species in the Western United States in recent decades.[40] Two other drivers which have been identified as responsible for this upward trend in frequency and impact on human populations are population

[33] Federal Emergency Management Agency (2011, November 9). Flood. Retrieved from http://www.fema.gov/hazard/flood/ .

[34] National Interagency Fire Center (n.d.). Historically significant wildland fires. Retrieved from http://www.nifc.gov/fireInfo/fireInfo_stats_histSigFires.html.

[35] National Interagency Fire Center (n.d.). Total Wildland Fires and Acres (1960-2009). Retrieved from http://www.nifc.gov/fireInfo/fireInfo_stats_totalFires.html; U.S. Fire Administration (2002). Fires in the wildland/urban interface. *Topical Fire Research Series*, 2(16). Retrieved from http://www.usfa.dhs.gov/downloads/pdf/tfrs/v2i16.pdf; U.S. Fire Administration (2001). Wildland fires: A historical perspective. *Topical Fire Research Series*, 1(3). Retrieved from http://www.usfa.fema.gov/downloads/pdf/statistics/v1i3-508.pdf; Western Forestry Leadership Coalition (2010). The true cost of wildfire in the western U.S. Retrieved from http://www.wflccenter.org/news_pdf/324_pdf.pdf.

[36] See note 35.

[37] Hazards & Vulnerability Research Institute (2011). The Spatial Hazard Events and Losses Database for the United States (SHELDUS), version 8.0 [online database]. Columbia, SC: University of South Carolina. Available from http://www.sheldus.org.

[38] See notes 41 - 43.

[39] U.S. Fire Administration (2002). Fires in the wildland/urban interface. *Topical Fire Research Series*, 2(16). Retrieved from http://www.usfa.dhs.gov/downloads/pdf/tfrs/v2i16.pdf; Westerling, A. L., Hidalgo, H. G., Cayan, D. R., & Swetnam, T. W. (2006). Warming and earlier spring increase western U.S. forest wildfire activity. *Science,* 313(5789), 940-943. Retrieved from http://www.sciencemag.org/content/313/5789/940.full.pdf.

[40] Balch et al (2013). Introduced annual grass increases regional fire activity across the arid western USA (1980-2009). *Global Change Biology*, 19(1), 173-183.

growth in vulnerable areas[41] and the early effects of climate change,[42] drivers shared with the potential increase in risk of floods and hurricanes. As these common drivers are expected to continue to increase, there is a substantial likelihood that the overall risk to populated regions in the U.S. from wildfires will continue to increase in coming years.[43]

Earthquakes

According to the United States Geological Survey (USGS), there are two primary areas with the highest probability of seismic impacts that could significantly impact the U.S.: California and the New Madrid Seismic Zone (NMSZ) in the central United States.[44] Because scientists cannot yet make precise predictions of their date, time, and place, earthquake forecasts are presented in the form of probabilities. According to the Southern California Earthquake Center, the chance of having one or more magnitude 6.7 or larger earthquakes in California over the next 30 years is 99.7 percent. For powerful quakes of magnitude 7.5 or greater, there is a 37 percent chance that one or more will occur in the next 30 years in southern California.[45] For the NMSZ, scientists estimate that the probability of a magnitude 6.0 or larger earthquake occurring in within any 50 year period is 25-40 percent.[46] While California and the NMSZ have the highest probability of significant impacts, earthquakes have the potential to occur throughout the United States, and for this reason a threshold of $100 million in direct economic losses was used to characterize the frequency and consequences of earthquakes in the SNRA, regardless of geographic location.

The range of potential loss and damage can be extremely high. Structural damage in the form of cracked or unstable foundations, damage to support beams, broken connections in walls or floors, and collapsed tiers can severely hamper rescue efforts. Further, damage to transportation networks like bridges and roads would slow down rescue work, construction repair teams, and disaster relief efforts. The blockages of waterways would also reduce the viability of major shipping channels. Specific to the NMSZ, interruption of oil, natural gas, electricity and water delivery is likely for the region affected as well as more distant places like New England. All of these large systems could further be affected by factors such as population density, building codes, and time of the event.

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41 U.S. Fire Administration (2002). Fires in the wildland/urban interface. *Topical Fire Research Series*, 2(16). Retrieved from http://www.usfa.dhs.gov/downloads/pdf/tfrs/v2i16.pdf.

42 Committee on America's Climate Choices, National Research Council (2011). *America's Climate* Choices. Washington, DC: National Academies Press. Available from http://dels.nas.edu/Report/Americas-Climate-Choices/12781; U.S. Global Change Research Program (2009). *Global Climate Change Impacts in the United States*, p 82. Cambridge: Cambridge University Press. Available from http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf; U.S. Climate Change Science Program and the Subcommittee on Global Change Research (2008). *The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States* (Synthesis and Assessment Product 4.3). Washington, DC: U.S. Department of Agriculture. Available from http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf; Westerling, A. L., Hidalgo, H. G., Cayan, D. R., & Swetnam, T. W. (2006). Warming and earlier spring increase western U.S. forest wildfire activity. *Science,* 313(5789), 940-943. Retrieved from http://www.sciencemag.org/content/313/5789/940.full.pdf.

43 Federal Emergency Management Agency (2011). Strategic Foresight Initiative project papers, including *Summary of Findings, U.S. Demography Shifts*, and *Climate Change*. At http://www.fema.gov/about/programs/oppa/strategic_foresight_initiative.shtm#3 .

44 United States Geological Survey (2008). *United States national seismic hazard maps*. Available from http://earthquake.usgs.gov/hazards/products/conterminous/2008/.

45 Southern California Earthquake Center (2012). Uniform California Earthquake Rupture Forecast (UCERF). Retrieved from http://www.scec.org/ucerf/.

46 Central United States Earthquake Consortium (n. d.). New Madrid Seismic Zone. Retrieved from http://www.cusec.org/earthquake-information/new-madrid-seismic-zone.html.

Unlike some natural disasters, there is no warning before an earthquake. This lack of a warning system makes mitigation strategies like evacuation unlikely. Therefore, options like building codes and retrofitting older structures are necessary to minimize consequences.

Tsunamis

All oceanic regions of the world can experience tsunamis, but there are more frequent large, destructive tsunamis in the Pacific Ocean because of the many large earthquakes along the highly seismically active Pacific Rim. The SNRA included an analysis of the risk from a large tsunami originating from the Cascadia Subduction Zone with a wave of approximately 50 feet impacting the Oregon coast of the United States. The range of potential loss could be broad depending upon factors such as the population density of low-lying coastal areas, presence of agricultural assets such as crops and livestock, and location of nearby drinking water supplies. Like hurricanes and floods, fatalities from tsunamis are assumed to be minimal except in areas that do not receive warning in time, in communities not trained in evacuation, in flat areas where no evacuation routes exist, and for persons who do not obey orders to evacuate. The direct economic costs of the tsunami analyzed in the SNRA were dominated by building losses. The consequences caused by a tsunami can be mitigated through preparedness strategies like warning and monitoring systems such as those used by the National Weather Service Pacific Tsunami Warning Center, identifying evacuation routes and training communities in how to use them, and communicating the importance of evacuation to individuals living or working in vulnerable areas.

Volcanic Eruptions

The SNRA also included an analysis of a volcanic eruption scenario associated with Mount Rainier, Washington that impacts the surrounding areas with lava flows and ash, and areas east with smoke and ash. The average time interval between eruptions of Mount Rainier is estimated at 100 to 1,000 years,[47] with the most recent Mount Rainier volcanic event estimated to be between 1820 and 1870. According to the USGS, there is no immediate indication of renewed activity at Mount Rainier; however, hazard mitigation actions should be explored given the large population in the surrounding area. Possible negative consequences of volcanic ash include, but are not limited to: disruption of ground and air transportation, damage to electronics and machinery, crop damage, interruption of telecommunications, water contamination, respiratory effects, eye and skin irritation, indirect effects like reduction of visibility on roadways, and increased demand on power leading to electricity loss.[48] The consequences of a volcanic eruption will depend on the severity of the eruption, the sophistication of the monitoring and warning systems, and the level of preparedness of the surrounding population areas.

Space Weather

The SNRA considered national risk from a G-5 level (extreme) space weather event as defined by NOAA's Geomagnetic Storm Space Weather Scale. Space weather occurs when the sun emits bursts of electromagnetic radiation and energetic particles. Technologies that can be directly affected by extreme space weather are the electric power, spacecraft, aviation, and GPS-based positioning industries. Within the last 30 years, space weather events have disrupted all of these technologies. Severe storms could result in additional consequences for numerous systems that rely on the

[47] Hoblitt, R. P., Walder, J. S., Driedger, C. L., Scott, K. M., Pringle, P. T., & Wallace, J. W. *Volcano Hazards from Mount Rainier, Washington*, (U.S. Geological Survey Open-File Report 98-428). Available from http://vulcan.wr.usgs.gov/Volcanoes/Rainer/Hazards/OFR98-428/framework.html.

[48] International Volcanic Health Hazard Network (n. d.). The health hazards of volcanic ash: A guide for the public. Retrieved from http://www.ivhhn.org/images/pamphlets/Health_Guidelines_English_WEB.pdf.

electrical grid. As stated in a 2008 NRC workshop report on severe space weather events, "Impacts would be felt on interdependent infrastructures, with, for example, potable water distribution affected within several hours; perishable foods and medications lost in about 12-24 hours; and immediate or eventual loss of heating/air conditioning, sewage disposal, phone service, transportation, fuel resupply, and so on."[49] The potential effects of a more severe event have been studied but are still subject to considerable uncertainty (see discussion in "Highly Uncertain Risks" in the "Findings" section above). Direct environmental and health effects are expected to be minimal as damage occurs mainly through the medium of disruption of technology.

Human and Animal Disease Discussion

Pandemic Influenza Outbreak

> *A virulent strain of pandemic influenza could kill hundreds of thousands of Americans, affect millions more, and result in economic loss. Additional human and animal infectious diseases may present significant risks.*
>
> *National Preparedness Goal, September 2011*

A pandemic influenza outbreak with similar characteristics to the 1968-1969 Hong Kong pandemic flu is estimated to present the largest risk to the Nation of the natural and technological hazard events included in the SNRA for fatality, illness/injury, and psychological distress risk, and has relatively high direct economic risk. At the best estimate, it has more fatality and injury/illness risk than every other natural or accidental hazard in the SNRA combined (see Figures 1 and 2). However, pandemic influenza illnesses are different than most of the other injuries and illnesses in the SNRA, in that most victims who become ill but do not die are likely to recover fully and have no lasting economic impact on their lives. Pandemic influenza poses no social displacement risk[50] and relatively low environmental risk.

Despite advances in medical care over the last 50 years, pandemic influenza events, such as the Hong Kong flu of 1968-1969, are nevertheless assessed to have the potential to produce large numbers of fatalities and illnesses (and therefore economic impacts) in the United States. Influenza pandemics are caused by a family of influenza viruses that are usually transmitted from person to person through aerosolized virus-containing droplets generated by coughing or sneezing, or through interaction with contaminated surfaces.[51,52] Influenza viruses infect humans by binding to, and invading, epithelial cells in the nose, throat, and mouth – this attachment and invasion is facilitated by a particular virus protein on its surface, called Hemagglutinin, or "HA". Once the viruses hijack cells' internal machinery to make copies of themselves, those new virus copies escape the human cell to continue the infection via another virus surface protein called Neuraminidase, or "NA". These two virus proteins, along with others, determine a particular strain's ability to invade and escape cells, and form the basis for the "H" and "N" influenza strain designations. For example,

[49] Committee on the Societal and Economic Impacts of Space Weather Events, National Research Council (2008). *Severe space weather events – understanding societal and economic impacts: A workshop report*, p. 77. Washington, DC: National Academies Press. Available from http://www.nap.edu/catalog.php?record_id=12507.

[50] Hospitalizations due to pandemic influenza were not considered displacement for the purposes of the SNRA. The direct economic loss estimates account for the cost of medical care.

[51] Kramer, A., Schewebke, I., & Kampf, G. (2006). How long do nosocomial pathogens persist on inanimate surfaces? A systematic review. *BMC Infectious Diseases*, 6, 130.

[52] Jones, R. M. & Adida, E. (2011). Influenza infection risk and predominant exposure route: Uncertainty analysis. *Risk Analysis,* 31(10), 1622-1631.

the "swine flu" pandemic of 2009 had HA and NA proteins both of type one, and was designated H1N1. In contrast, the 1968-1969 Hong Kong flu was an H3N2 influenza strain since its HA protein was type three, and its NA protein was type two.

At a high level, there are two important rates associated with an influenza pandemic that determine its impact. The first is the overall gross clinical "attack" rate, which is defined as the fraction of the population that becomes clinically ill from influenza during the pandemic. While it varies by age, typically the overall attack rate for seasonal influenza each year is between 5% and 20% of the population of the United States.[53,54,55,56] In contrast, the three influenza pandemics of the 20th century (1918, 1957, and 1968) had gross clinical attack rates (adjusted to current population) of 24% to 34% of the population,[57,58,59,60,61] a significant increase over the yearly seasonal rates. Given this range of observed clinical attack rates for recent influenza pandemics (24% to 34%), the 25% attack rate assumed for the SNRA scenario is conservative.

The second important rate affecting the impact of an influenza pandemic is the case fatality rate, or CFR, defined as the proportion of people with influenza illness who die. Assessed to be a "Category 2" pandemic on the Centers for Disease Control and Prevention's (CDC's) Pandemic Severity Index[62] based on its CFR, the Hong Kong Flu caused an estimated 34,000 deaths in the United States (one million worldwide).[63] The 1968-1969 Hong Kong Flu had a relatively low CFR of less than 0.05% in contrast to the 1918 Spanish Flu which had a much higher CFR of between 2.5% and 10%.[64,65]

Beyond the attack rate and the CFR, there are a number of drivers that explain why pandemic influenza is a significant risk, the first being influenza virus biology and ecology. Since an influenza strain's ability to invade, reproduce in, and escape human cells depends in part on the particular H and N surface proteins as well as other proteins, variations in them can determine how quickly an

[53] Bridges, C. B., Thompson, W. W., Meltzer, M. I., Reeve, G. R., Talamonti, W. J., Cox, N. J., et al. (2000). Effectiveness and cost-benefit of influenza vaccination of healthy working adults: a randomized control trial. *Journal of the American Medical Association,* 824(13), 1655-63.

[54] Edwards, K. M., Dupont, W. D., Westrich, M. K., Plummer, W. D., Palmer, P. S., & Wright, P. F. (1994). A randomized control trial of cold-adapted and inactivated vaccines for the prevention of influenza A disease. *Journal of Infectious Disease,* 169, 68-76.

[55] Keitel, W. A., Cate, T. R., Couch, R. B., Huggins, L. L., & Hess, K. R. (1997). Efficacy of repeated annual immunization with inactivated influenza virus vaccines over a five year period. *Vaccine*, 15(10), 1114-1122.

[56] Neuzil, K., Zhu, Y., Griffin, M., Edwards, K. M., Thompson, J., Tollefson, S., et al. (2002). Burden of interpandemic influenza in children younger than 5 years: a 25-year prospective study. *Journal of Infectious Disease,* 185, 147-152.

[57] Brundage, J. F. (2006). Cases and deaths during pandemic influenza in the United States. *American Journal of Preventative Medicine,* 31(3), 252-256.

[58] Davis, L. E., Caldwell, G. C., Lynch, R. E., & Bailey, R. E. (1970). Hong Kong influenza: The epidemiologic features of a high school family study analyzed and compared with a similar study during the 1957 Asian influenza epidemic. *American Journal of Epidemiology,* 92, 240-257.

[59] Elveback, L. R., Fox, J. P., & Ackerman, E. (1976). An influenza simulation model for immunization studies. *American Journal of Epidemiology*, 103, 152-165.

[60] Longini, I. M., Ackerman, E., & Elveback, L. R. (1978). An optimization model for influenza A epidemics. *Mathematical Biosciences,* 38, 141-157.

[61] Sharrar, R. G. (1969). National influenza experience in the USA, 1968-1969. *Bulletin of the World Health Organization*, 41, 361-366.

[62] U.S. Department of Homeland Security and U.S. Department of Health and Human Services (2008). *Guidance on allocating and targeting pandemic influenza vaccine.* Retrieved from http://www.flu.gov/individualfamily/vaccination/allocationguidance.pdf.

[63] Patel, R., Longini, I. M., & Halloran, M. E. (2005). Finding optimal vaccination strategies for pandemic influenza using genetic algorithms. *Journal of Theoretical Biology*, 234, 201-212.

[64] Ibid.

[65] Taubenberger, J. K. & Morens, D. M. (2006). 1918 influenza: The mother of all pandemics. *Emerging Infectious Diseases,* 12(1), 15-22.

influenza outbreak spreads, and is a factor along with others in the case fatality rate and other aspects of the pandemic.[66,67] In addition to contributing to transmissibility, the large amount of variability and frequency of mutations in the influenza H/N proteins accounts for much of the lack of immunity within the general population. This lack of immunity is by far the largest driver of the high illness/fatality statistics from a scientific standpoint.

An additional driver for pandemic influenza's risk is the fact that vaccine production for an emerging pandemic influenza strain currently takes a significant amount of time (planning estimates are on the order of several months,[68] with the actual experience of H1N1 in 2009 being about a year to produce sufficient vaccine to protect the entire nation[69]). This fact means that other control measures such as isolation of symptomatic individuals and identifying and quarantining their contacts are important components of a pandemic response prior to vaccine availability.[70] However, recent research and epidemiological modeling indicates that the biggest determinant of the success of these control measures (even more than the virus's inherent transmissibility) is the degree to which the particular pandemic strain can be transmitted by individuals who have the virus but are not yet symptomatic.[71] If individuals can unknowingly spread the virus, while they themselves do not have symptoms, then the effectiveness of these control measures will be reduced. Consequently, direct estimation of the degree of asymptomatic and presymptomatic transmissibility is important during pandemic influenza outbreaks to guide response. New epidemiological analysis of the 2009 H1N1 influenza pandemic and other recent research appears to indicate that presymptomatic transmission can in fact occur, as early as a day before the onset of symptoms;[72,73,74] however, other previous research has been inconclusive regarding this important aspect of the virus's transmissibility.[75]

Since it is not feasible to prevent the emergence of new strains of influenza that could give rise to a potentially high-consequence pandemic, mitigation options generally fall into three categories, the "pillars" of the 2005 National Strategy for Pandemic Influenza:[76] preparedness, surveillance and detection, and response and containment. The strategy notes that a foundation of influenza

[66] Connor, R. J., Kawaoka, Y., Webster, R. G., & Paulson, J. C. (2004). Receptor specificity in human, avian, and equine H2 and H3 influenza virus isolates. *Virology*, 205, 17-23.

[67] Van Doremalen N., Shelton H., Roberts K. L., Jones, I. M., Pickles, R. J., et al. (2011). A single amino acid in the HA f pH1N1 2009 influenza virus affects cell tropism in human airway epithelium, but not transmission in ferrets. *PLoSOne,* 6(10), e25755.

[68] World Health Organization (2009, August 9). Pandemic influenza vaccine manufacturing process and timeline: Pandemic (H1N1) 2009 briefing note 7. Retrieved from http://www.who.int/csr/disease/swineflu/notes/h1n1_vaccine_20090806/en/index.html.

[69] President's Council of Advisors on Science and Technology (2010, August). *Report to the President on reengineering the influenza vaccine production enterprise to meet challenges of pandemic influenza*. Retrieved from: http://www.whitehouse.gov/sites/default/files/microsites/ostp/PCAST-Influenza-Vaccinology-Report.pdf.

[70] Homeland Security Council (2005). *National strategy for pandemic influenza*. Retrieved from http://www.flu.gov/planning-preparedness/federal/pandemic-influenza.pdf.

[71] Fraser, C., Riley, S., Anderson, R. M., & Ferguson, N. M. (2004). Factors that make an infectious disease outbreak controllable. *Proceedings of the National Academies of Science,* 101(16), 6146-6151.

[72] Gu, Y., Komiya, N., Kamiya, H., Yasui, Y., Taniguchi, K., & Otabe, N. (2011). Pandemic (H1N1) 2009 transmission during presymptomatic phase, Japan. *Emerging Infectious Diseases,* 17(9), 1737-1739.

[73] Dawood, F. S., Jain, S., Finelli, L., Shaw, M. W., Lindstrom, S., Garten, R. J., et al. (2009). Emergence of a novel swine-origin influenza A (H1N1) virus in humans. *New England Journal of Medicine*, 360, 2605-2615.

[74] Carrat, F., Vergu, E., Ferguson, N. M., Lemaitre, M., Cauchemez, S., Leach, S., et al. (2008). Time lines of infection and disease in human influenza: A review of volunteer challenge studies. *American Journal of Epidemiology*, 167, 775-785.

[75] Patrozou, E. & Mermel, L. A. (2009). Does influenza transmission occur from asymptomatic infection or prior to symptom onset? *Public Health Reports*, 124(2), 193-196.

[76] Homeland Security Council (2005). *National strategy for pandemic influenza*. Retrieved from http://www.flu.gov/planning-preparedness/federal/pandemic-influenza.pdf.

preparedness is vaccination, similar to seasonal influenza. However, given the time required for vaccine development, and the limited advanced warning for a pandemic strain's emergence, vaccination alone is not sufficient to limit the impact of a pandemic. However, coupled with new approaches for decreasing the time for vaccine development,[77] early detection and surveillance can limit the spread of the pandemic and increase the time available for vaccine production and distribution. Finally, containment and effective public health response can limit fatalities and economic impacts through sufficient public health surge capacity for severe influenza cases, and through other containment measures to limit or slow the spread of disease.

While influenza was the only type of pandemic outbreak considered in the SNRA, a number of biological agents are currently known to have the potential for epidemic or pandemic outbreaks that produce significant human health and economic impacts. Zoonotic agents (agents that usually infect animals, but that can infect humans as well) and new emerging infectious disease agents that are unanticipated may present significant risks as well. Recent examples of emerging diseases are the emergence of Ebola virus in 1976 in which the index case was thought to have become infected from bats in the Zaire cotton factory in which he worked,[78] and the SARS coronovirus originating in Asia which nearly became a pandemic in 2002 and 2003.[79]

Animal Disease Outbreak

The SNRA included an unintentional introduction of the foot-and-mouth disease (FMD) virus into a single dairy cattle herd in California. FMD is one of the most devastating diseases affecting cloven-hoof animals such as cattle, swine, sheep and deer. The virus is highly contagious and robust, with seven types and more than 80 sub-types, and vaccination for one type does not confer immunity to the others. While there are no significant human health implications of FMD, an outbreak of the disease can have important economic consequences. In 2001, the United Kingdom suffered one of the largest FMD epidemics in a developed country in several decades. Approximately seven million animals were culled, and the outbreak devastated the nation's farming industry. It is estimated that the outbreak cost the UK an estimated $11.9-$18.4 billion, including $4.8 billion in losses to agriculture, the food industry and the public sector, $4.2-$4.9 billion in lost tourism and $2.9-$3.4 billion in indirect losses.[80] As noted in the Findings section, a confirmed case of FMD in the U.S. would result in an immediate restriction of exports. The current control strategy in U.S. Department of Agriculture (USDA) Animal and Plant Inspection Service (APHIS) regulations to regain FMD-free status is to cull all infected and susceptible animals.[81,82]

[77] President's Council of Advisors on Science and Technology (2010, August). *Report to the President on reengineering the influenza vaccine production enterprise to meet challenges of pandemic influenza*. Retrieved from: http://www.whitehouse.gov/sites/default/files/microsites/ostp/PCAST-Influenza-Vaccinology-Report.pdf.

[78] Pourrut, X., Kumulungui, B., Wittman, T., Moussavou, G., Delicat, A., Yaba, P., et al. (2005, June). The natural history of Ebola virus in Africa. *Microbe and Infection / Institut Pasteur*, 7(7-8), 1005-1014.

[79] Chan-Yeung, M. & Xu, R. H. (2003, November). SARS: epidemiology. *Respirology*, 8(Suppl.), S9-S14.

[80] Carpenter, T.E. O'Brien, J.M. Hagerman, A.D. McCarl, B.A. (2011). Epidemic and economic impacts of delayed detection of foot-and-mouth disease: A case study of an outbreak in California. *Journal of Veterinary Diagnostic Investigation*, 23, 26-33.

[81] U.S. Code of Federal Regulations (2011). Title 9, Section 53.4. *Destruction of animals.* Washington, DC: U.S. Government Printing Office. Retrieved from http://www.gpo.gov/fdsys/pkg/CFR-2011-title9-vol1/pdf/CFR-2011-title9-vol1-sec53-4.pdf.

[82] U.S. Government Accountability Office (2002, July). *Foot and mouth disease: To protect U.S. livestock, USDA must remain vigilant and resolve outstanding issues* (GAO-02-808). Retrieved from http://www.gao.gov/new.items/d02808.pdf.

Technological and Accidental Hazards Discussion

Accidental Biological Food Contamination

> *Technological and accidental hazards, such as dam failures or chemical spills or releases, have the potential to cause extensive fatalities and severe economic impacts, and the likelihood of occurrence may increase due to aging infrastructure.*
>
> *National Preparedness Goal, September 2011*

The SNRA included an analysis of an accidental introduction of a biological agent (e.g., *Salmonella*, *E. coli*, botulinium toxin) into the food supply (e.g., milk, meat, vegetables, processed food) that results in harm to the public. The analysis utilized data from the Center for Disease Control and Prevention's (CDC's) Foodborne Outbreak Online Database[83] to identify accidental food contamination events. Most foodborne outbreaks are investigated by the state, local, territorial, and tribal health departments where the outbreak occurs. Outbreak information is then reported to the CDC by the public health agency that conducted the investigation. The SNRA analysis used CDC correction factors to account for known underreporting and underdiagnosis of food contamination.[84]

Public health consequences of biological food contamination can be mitigated by identifying and recalling the contaminated food product. Recalls and lost sales, in addition to the immediate costs associated with medical care, drive the direct economic consequences of a biological food contamination event.[85] Further economic damage may be incurred by industry due to uncertainty in determining the correct product as the source of the outbreak. For example, in 2008, a *Salmonella* outbreak was erroneously blamed on tomatoes early in the investigation before jalapeño and serrano peppers were identified as the cause. As a result of the initial misidentification, the tomato industry was severely impacted even though all tomatoes tested negative for *Salmonella*. Economic estimates of losses to the tomato industry exceeded $100 million in Florida and almost $14 million in Georgia.[86,87]

Dam Failure

In a recent report on the progress of the National Dam Safety Program, FEMA noted that, "while the data reveal encouraging trends in many areas, the larger picture of dam safety remains problematic at best."[88] Many Americans are living below structurally deficient high-hazard potential dams whose failure would cause loss of human life. They are, for the most part, unaware of the risk, and unaware of the existence or lack of existence of plans to evacuate them to safety in the event of a failure.[89] The Interagency Committee on Dam Safety classifies dams whose failure would cause loss

[83] Centers for Disease Control and Prevention (2012). Foodborne Outbreak Online Database (FOOD). Retrieved from http://wwwn.cdc.gov/foodborneoutbreaks/.

[84] Scallan, E., Hoekstra, R. M., Angulo, F. J., Tauxe, R. V., Widdowson, M. A., Roy, S. L., et al. (2011). Foodborne illness acquired in the United States – major pathogens. *Emerging Infectious Diseases*, 17(1), 7-15.

[85] U.S. Food and Drug Administration (2007, July 18). *An overview of the CARVER Plus Shock Method for food sector vulnerability assessments.* Retrieved from http://www.fsis.usda.gov/PDF/Carver.pdf.

[86] Produce Safety Project (2008, November 17). *Breakdown: Lessons to be learned from the 2008* Salmonella *Saint Paul outbreak*. Georgetown University. Available from http://www.producesafetyproject.org/reports?id=0001.

[87] Center for Agribusiness and Economic Development (2008, July). *Economic impact of Georgia tomato production value losses due to the U.S. Salmonella outbreak* (Center Report CR-08-17). University of Georgia. Retrieved from http://www.caed.uga.edu/publications/2008/pdf/CF-08-17.pdf.

[88] Federal Emergency Management Agency (2009, February). *Dam safety in the United States: A progress report on the National Dam Safety Program* (FEMA Publication No. P-759), p. 5.

[89] Ibid.

of human life as "high-hazard potential", and dams whose failure would result in no probable loss of life but could cause economic loss, environmental damage, or other impacts as "significant-hazard potential". The number of high-hazard potential dams in the U.S. is currently about 13,000, with more than 3,300 high and significant dams located within one mile of a downstream population center and more than 2,400 located within two miles.[90]

A significant factor influencing loss of life to dam failure is the suddenness of the dam collapse and the magnitude of the emergency planning and preparedness required for such an incident. Deaths on a massive scale may result if an evacuation cannot be quickly implemented to move people above inundation levels. The loss of life from dam collapse can be reduced if decision making for protective actions is informed by risk management, alert and notification systems are robust and timely, the public is educated and prepared to mobilize, evacuation is preplanned, and citizens are not unable to evacuate due to traffic congestion.

Data provided to the U.S. Army Corps of Engineers Dam Safety Program Management Tools (DSPMT) indicate that progress is being made in increasing the percentage of state-regulated high-hazard potential dams (an increase from 32 percent in 1999 to 51 percent in 2006) and that states are continuing to increase their inspections of dams. State dam safety programs are continuing to improve through assistance from the National Dam Safety Program and the Interagency Committee on Dam Safety, and such progress is crucial as the Federal Government owns or regulates only about 5 percent of dams in the United States.[91]

Accidental Radiological Substance Release

Though anticipated to be unlikely (see Table B1, Appendix B), an accidental radiological release from a nuclear power plant accident or public exposure to lost or stolen radioactive sources could produce significant public health and economic consequences. Given the severe consequences of a large, radiological release from a power plant, the SNRA analysis focused on nuclear power plant accidents. A national-level power plant accident is defined as any accident that damages the reactor core. The risk to the public and environment is highly dependent on radiation containment and the location of the reactor.[92]

Should the unlikely event of an accident occur, the consequences caused by a nuclear release would be mitigated through several preparedness strategies. Monitoring systems would help individuals in the designated evacuation zone evacuate to the recommended safe distance. Regular testing of monitoring and warning systems ensures that they are functioning properly when an event occurs. In addition, medical countermeasures in the form of potassium iodide tables are currently distributed to all individuals working or residing within 10 miles of nuclear power plants.[93] Taken shortly after a radioactive release, potassium iodide has some protective effect against thyroid cancer resulting from exposure to any radioactive iodine released in the accident. Finally,

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[90] Association of State Dam Safety Officials (2012). Dam Safety 101. Available from http://www.damsafety.org.

[91] See note 88.

[92] While the SNRA analysis did not explicitly consider the risk of cascading events such as the Fukushima disaster in Japan (i.e., an earthquake, tsunami, and nuclear release happening concurrently), the frequency of core damage failure caused by external events (fire, seismic events, floods, high winds) is included in some of the publicly-available nuclear power plant license renewal applications used as data sources in the SNRA. The license renewal applications are available from the public website of the U.S. Nuclear Regulatory Commission at http://www.nrc.gov/reactors/operating/licensing/renewal/applications.html.

[93] Marburger, J. H. (2008, January 22). *Decision on delegation of section 127(f) of the Public Health Security and Bioterrorism Preparedness and Response Act of 2002*. [Decision memorandum]. Washington, DC: Office of Science and Technology Policy, Executive Office of the President. Retrieved from http://www.whitehouse.gov/sites/default/files/microsites/ostp/ki-memo-2008.pdf.

evacuation and safe routes are identified and communicated in nuclear power plant communities, and exercises are regularly conducted to test and refine planning for many communities.

Accidental Chemical Substance Spill or Release

The potentially catastrophic consequences of a worst-case scenario accidental spill or release of a highly toxic chemical substance have been frequently studied: models of a release of a highly toxic gas such as chlorine in a densely populated area have projected thousands, even hundreds of thousands of casualties.[94] There have been historical examples of high-consequence releases of chemical substances, including the 1984 Union Carbide accident in India which killed thousands of people in the nearby city of Bhopal, and the massive casualty figures from uses of chlorine and other toxic gases as a deliberate weapon of war.[95] However, these consequence models do not attempt to estimate the likelihood of an accident causing fatalities on such a scale to occur in the United States. Because no national-scale quantitative risk assessments of fixed chemical plants and storage facilities were available, the SNRA analysis utilized 1994-2010 historical accident data reflecting higher-probability but lower-consequence accidents in the U.S. to derive the findings for chemical accidents at fixed facilities.[96] Although chemical accidents in the transportation sector have been extensively and quantitatively modeled on a national scale,[97] it appears that no quantitative national risk assessment for catastrophic accidents in the fixed sector has been completed for the U.S.[98]

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[94] U.S. Department of Homeland Security (2005). *National Planning Scenario #8: Chlorine*; Risk Management Solutions (2004). *Catastrophe, injury, and insurance: the impact of catastrophes on workers compensation, life, and health insurance*, pp. 54-59. Retrieved from http://www.rms.com/Publications/Catastrophe_Injury_Insurance.pdf; Branscomb, L. M., Fagan, M., Auerswald, P., Ellis, R. N., & Barcham, R. (2010, February*). Rail transportation of toxic inhalation hazards: policy responses to the safety and security externality* (Discussion Paper 2010-01). Belfer Center for Science and International Affairs, Harvard Kennedy School. Available from http://belfercenter.ksg.harvard.edu/files/Rail-Transportation-of-Toxic-Inhalation-Hazards-Final.pdf. A significant counterexample is Chang, Y. S., Samsa, M. E., Folga, S. M., & Hartmann, H. M. (2007, November). *Probabilistic consequence model of accidental or intentional chemical releases* (ANL/DIS-08/3). Decision and Information Sciences Division, Argonne National Laboratory. Retrieved from http://www.dis.anl.gov/pubs/61981.pdf.

[95] Branscomb et al, note 94 above; Pastel, Ross, What we have learned about mass chemical disasters. *Psychiatric Annals,* (11), 754-765. Retrieved from http://www.psychiatricannalsonline.com/showPdf.asp?rID=24853. A significant historical counterexample is the 1979 Mississauga accident.

[96] From the EPA's Risk Management Program (RMP) accident data for chemical accidents at fixed facilities, and the U.S. Department of Transportation's Pipeline and Hazardous Materials Safety Administration (PHMSA) accident data for chemical accidents during transportation by road, rail, air, water, or pipeline, in both cases limited to casualties and economic damages directly caused by a toxic inhalation hazard gas (and excluding flammable and explosive materials such as gasoline, propane, and ammonium nitrate). RMP data is publicly available at http://www.rtknet.org. PHMSA data is publicly available at https://hazmatonline.phmsa.dot.gov/IncidentReportsSearch.

[97] See for instance Raj, P. K. (1988, November). *A risk assessment study on the transportation of hazardous materials over the U.S. railroads* (DOT/FRA/ORD-88/14). Washington, DC: Federal Railroad Administration, U.S. Department of Transportation. Retrieved from http://www.fra.dot.gov/downloads/research/ord8814.pdf; Raj, P. K., and Turner, C. K. (1993, May 15). *Hazardous material transportation in tank cars: Analysis of risks – Part I* (DOT/FRA/ORD-92/34). Washington, DC: Federal Railroad Administration, U.S. Department of Transportation. Retrieved from http://www.fra.dot.gov/downloads/Research/ord9234.pdf; Brown, D. F., Dunn, W. E., & Policastro, A. J. (2000, December). *A national risk assessment for selected hazardous materials in transportation* (ANL/DIS-01-1). Decision and Information Sciences Division, Argonne National Laboratory. Retrieved from http://www.ipd.anl.gov/anlpubs/2001/01/38251.pdf; Vanderbilt Center for Transportation Research (2012). Intermodal GIS network risk assessment. Vanderbilt University. Retrieved from http://www.vanderbilt.edu/vector/?page_id=340.

[98] Fullwood, R. R. (2000). Probabilistic Safety Assessment in the Chemical and Nuclear Industries. Woburn, MA: Elsevier; Mannan, S. (Ed.). (2005). Lees' Loss Prevention in the Process Industries (3rd ed.). Burlington, MA: Elsevier.

Adversarial Events

Overview[99]

The SNRA leveraged the 2011 DHS Integrated Terrorism Risk Assessment (ITRA) for likelihood and fatality, illness/injury, and economic loss estimates for the five CBRN national-level events. As the ITRA is designed to generate customized reports to inform multiple decision contexts, including differing thresholds and splits or aggregations by specific agents or targets, the DHS Directorate of Science & Technology (S&T) provided data corresponding to the scope of the five CBRN events as defined in the SNRA. Chemical and biological attacks on the food supply chain were split out from the ITRA chemical and biological attack events and combined into a single SNRA event.

All likelihood and consequence estimates derived from the ITRA, the psychological distress estimates derived from the ITRA fatality and injury/illness data, and comparative risk judgments are classified at the SECRET//NOFORN level and may be found in the full SNRA Technical Report. The methodology and analysis of the ITRA are described in detail in the technical reports of the ITRA and its three component assessments, the Biological Terrorism Risk Assessment (BTRA), the Chemical Terrorism Risk Assessment (CTRA), and the Radiological/Nuclear Terrorism Risk Assessment (RNTRA). The TRAs leverage a probabilistic risk assessment (PRA) methodology of substantial complexity and maturity which is difficult to treat fairly in a compact manner, and thus the methodological discussion for these events is limited to the key parameters needed for a reviewer with the appropriate clearances to replicate the SNRA's quantitative estimates from the ITRA computational engine. Detailed discussion of the PRA methodology and its adaptation for DHS's terrorist risk assessments may be found in the unclassified literature.[100]

For the three conventional attack method national-level events (Armed Assault, Aircraft as a Weapon, and Explosives Terrorism Attack) the SNRA leveraged open-source literature and prior work by the DHS Office of Risk Management & Analysis for the fatality, injury and illness, and economic loss estimates. While these consequence estimates and the psychological consequence estimates derived from them are U//FOUO, the majority of the methodology and sources used to derive them are unclassified (non-FOUO) and may be found in the corresponding risk summary sheets. Event frequencies were elicited from subject-matter experts provided by multiple agencies in the Intelligence Community, and are also classified at the SECRET or SECRET//NOFORN level.

Classified frequency estimates for the two cyber events were also obtained by expert elicitation from the Intelligence Community and DHS and U.S. Government agencies responsible for cyber security. The SNRA project was not able to obtain consensus consequence estimates corresponding to the elicited frequencies, however. For this reason, while the classified frequency estimates themselves may be found in the full SNRA Technical Report, the remainder of the SNRA's cyber event analysis and discussion is unclassified and included here in full.

The SNRA's social displacement and environmental consequence estimates are unclassified and non-FOUO for all events and are included here in full. However, since the SNRA defines the *risk* corresponding to a measure of consequence to be the product of these consequences with event frequencies, all of which are classified for adversarial events, risk judgments and visualizations comparing the adversarial events among themselves or with other events are classified at the SECRET or SECRET//NOFORN level and may be found in the full SNRA Technical Report.

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99 Additional discussion of the classified data sources of the SNRA is provided in Appendix M.

100 See Ezell et al (2010, April), Probabilistic risk analysis and terrorism risk, *Risk Analysis* 30(4) 575-589.; and pp 101-104, Gerstein, Daniel M. (2009), *Bioterror in the 21st Century: Emerging Threats in a New Global Environment*, Naval Institute Press, Annapolis MD. While somewhat dated, the most comprehensive and critical review remains National Research Council (2008), *Department of Homeland Security Bioterrorism Risk Assessment: a call for change*, National Academies Press, Washington DC.

Nuclear Terrorism Attack

The SNRA leveraged the 2011 DHS Integrated Terrorism Risk Assessment (ITRA) to estimate the risk from nuclear terrorism attacks. Specifically, the SNRA included analysis of a nuclear attack in which a hostile non-state actor(s) acquires an improvised nuclear weapon through manufacture from fissile material, purchase, or theft, and detonates it. Nine U.S. cities were considered in calculating the frequency and consequences of the attack. The cities were chosen to sample a variety of locations and population densities and included New York, Washington, Houston, and Miami. Impacts of the attack were evaluated for four yields across the nine cities and were evaluated 12 times throughout the year to sample atmospheric conditions at detonation.[101]

A successful nuclear attack would cause substantial fatalities, injuries, and infrastructure damage from the heat and blast of the explosion, and significant radiological consequences from both the initial nuclear radiation and the radioactive fallout that settles after the initial event. A nuclear detonation in a modern urban area would impact the medical system more than any disaster previously experienced by the Nation.[102] An electromagnetic pulse from the explosion could also disrupt telecommunications and power distribution. Significant economic, social, psychological, and environmental impacts would be expected.[103]

Nuclear explosions are classified by yield, or the amount of energy they produce, relative to how many tons of TNT would be needed to produce an equivalent explosive yield. Strategic nuclear weapon systems held by state actors deliver weapons with yields in the multi-hundred kilotons to megaton (1,000 kiloton) range. Generally, when considering nuclear explosion scenarios perpetrated by terrorists, experts assume a low-yield nuclear device detonated at ground level, where low yield in this context ranges from factions of a kiloton (kT) to 10 kT.[104] A terrorist attack could be carried out with an improvised nuclear device (IND), which is a crude nuclear device built from the components of a stolen weapon or from scratch using nuclear material (plutonium or highly enriched uranium).

The primary obstacle to a terrorist IND attack is limited access to weapon-grade nuclear materials: highly enriched uranium, plutonium, and stockpiled weapons are carefully inventoried and guarded. Nuclear attack is also impeded because:

1. Building nuclear weapons is difficult – general principles are available in open literature, but constructing a workable device requires advanced technical knowledge in areas such as nuclear physics and materials science.
2. Crude nuclear weapons are typically very heavy, ranging from a few hundred pounds to several tons, and are difficult to transport, especially by air. Specially designed small nuclear weapons, including the so-called "suitcase nuclear weapons" are much lighter, but they are difficult to acquire and to construct.[105]

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[101] U.S. Department of Homeland Security (2011, October 24). *2011 Radiological/Nuclear Terrorism Risk Assessment (RNTRA)*, Vol. 1. (Reference is SECRET//NOFORN: Extracted information is UNCLASSIFIED.)

[102] National Security Staff Interagency Policy Coordination Subcommittee for Preparedness and Response to Radiological and Nuclear Threats (2010, June). *Planning Guidance for Response to a Nuclear Detonation* (2nd ed), p. 81.

[103] National Academies, U.S. Department of Homeland Security (2005). Nuclear attack. Fact sheet for the public (series, Communicating in a Crisis). Retrieved from http://www.dhs.gov/xlibrary/assets/prep_nuclear_fact_sheet.pdf via http://www.ready.gov (checked April 2015).

[104] It should be noted that if a state-built weapon were available to terrorists, the presumption of low yield may no longer hold. NSS (2010) *op cit.*, p. 15.

[105] National Academies & DHS (2004). Nuclear attack public fact sheet, *op. cit.*

Radiological Terrorism Attack

The SNRA leveraged the 2011 DHS Integrated Terrorism Risk Assessment (ITRA) to estimate the risk from radiological terrorism attacks. The analysis only included data for successful attacks (e.g. detonation of the device or successful spread into the food or water system). Failed attacks, whether from interdiction during the fabrication and assembly of the dispersal device, interdiction during travel to United States, or failure of the dispersal device, were not included in this analysis.

Radiological devices used for terrorism may include radiological dispersal devices (RDD) and radiological exposure devices (RED). The principal type of RDD is a "dirty bomb" that combines a conventional explosive with radioactive material. A second type involves radioactive material dispersed in air or water by other mechanical means, such as a water spray truck, a crop duster, or manually spread. An RED may comprise a powerful radioactive source hidden in a public place, such as a trash receptacle in a busy train or subway station, to expose passers-by to a potentially significant dose of radiation.[106]

It is very difficult to design an RDD that would deliver radiation doses high enough to cause immediate health effects or fatalities in a large number of people. Most injuries from a dirty bomb would probably occur from the heat, debris, and force of the conventional explosion used to disperse the radioactive material, affecting individuals close to the site of the explosion. At the low radiation levels expected from an RDD, the immediate health effects from radiation exposure would likely be minimal.[107] Subsequent decontamination of the affected area could involve considerable time and expense. A dirty bomb could have significant psychological and economic effects.[108]

Most radiological devices would have very localized effects, ranging from less than a city block to several square miles. Factors determining the area of contamination would include the amount and type of radioactive material, the means of dispersal, the physical and chemical form of the radioactive material (for example, material dispersed in the form of fine particles may be carried by the wind over a relatively large area), local topography and location of buildings, and local weather conditions.[109]

Preparedness and effectiveness of response teams will play a significant role in mitigating the consequences caused by an RDD attack. Early identification of a radiological attack is important in determining whether or not to evacuate the area or shelter in place and the size of the area requiring cordoning.

Biological Terrorism Attack (non-food)

The SNRA leveraged the 2011 DHS Integrated Terrorism Risk Assessment (ITRA) in order to estimate risk from non-food biological terrorism attacks.

The SNRA considered the risk from a non-food biological attack in which a hostile non-state actor(s) acquires, weaponizes, and releases a biological agent against an outdoor, indoor, or water target with a concentration of people within the United States. Frequency estimates for this event only include data for successful attacks (e.g., detonation of a device or release of an agent). Examples of failed attacks not included in the SNRA include interdiction during the fabrication and

[106] U.S. Environmental Protection Agency (2006, October). OSC Radiological Response Guidelines. Office of Solid Waste and Emergency Response, Office of Air and Radiation, U.S. EPA; at http://www.uscg.mil/hq/nsfweb/foscr/ASTFOSCRSeminar/References/EnvResponsePapersFactSheets/OSCRadResponseGuidelines.pdf (retrieved April 2013).

[107] National Academies and U.S. Department of Homeland Security (2004). Radiological attack: dirty bombs and other devices. Retrieved from http://www.dhs.gov/radiological-attack-fact-sheet via http://www.ready.gov.

[108] EPA (2006) OSC Radiological Response Guidelines, *op. cit.*

[109] Ibid.

assembly of the dissemination device, interdiction during travel to the United States, or failure of the dissemination device.

Biological agents can be isolated from sources in nature, acquired from laboratories or a state bioweapons stockpile, or synthesized or genetically manipulated in a laboratory. Potential dissemination mechanisms of a biological agent by terrorists include aerosol dissemination from sprayers or other devices outdoors or through the ventilation system of a building, subway, or airplane, human carriers, insects or other animal vectors, or physical distribution through the U.S. Mail or other means. Biological agents include transmissible agents that spread from person to person (e.g. smallpox, Ebola) or agents that may cause adverse effects in exposed individuals but which do not make these individuals contagious (e.g. anthrax, botulinium toxin).[110]

Unlike a nuclear or chemical attack, a biological attack may go undetected for hours, days, or potentially weeks (depending on the agent) until humans, animals, or plants show symptoms of disease. If there are no immediate signs of the attack as with the anthrax letters, a biological attack will probably first be detected by local health care workers observing a pattern of unusual illness, or by early warning systems that detect airborne pathogens. There may be uncertainties about crucial facts such as the exact location or extent of the initial release, the type of biological agent used, and likelihood of additional releases. The exact infectious dose (the number of organisms needed to make one sick, referred to as dose response) and the long-term health consequences for those who survive exposure are key scientific knowledge gaps for many biological agents: while approximate ranges and prognoses for humans have been extrapolated from animal studies, they comprise additional uncertainties which may complicate the public health response to a biological attack.[111]

Chemical Terrorism Attack (non-food)

The SNRA leveraged the 2011 DHS Integrated Terrorism Risk Assessment (ITRA) in order to estimate risk from non-food chemical terrorism attacks.

The SNRA considered the risk from a non-food chemical attack in which a hostile non-state actor(s) releases a chemical agent against an outdoor, indoor, or water target with a concentration of people within the United States. Frequency estimates for this event only include data for successful attacks (e.g. detonation of a device or release of an agent). Examples of failed attacks not included in the SNRA include interdiction during the fabrication and assembly of the dissemination device, interdiction during travel to the United States, or failure of the dissemination device.

Chemical agents can be acquired from a variety of different sources (e.g., chlorine, mustard gas, sarin) and disseminated in various modes. Potential delivery mechanisms of a chemical agent by terrorists include building ventilation systems, misting or aerosolizing devices, passive release (container of chemical left open), explosives, improvised devices combining readily available chemicals to produce a dangerous chemical, or sabotage of industrial facilities or vehicles containing chemicals.[112]

According to the 2010 Chemical Terrorism Risk Assessment (CTRA), exposure to a chemical threat can result in health effects within a matter of minutes. This stands in contrast to many biological scenarios, and significantly impacts the risk reduction potential that exists in the chemical scenarios where casualties can occur rapidly after exposure. For chemicals with a delayed

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[110] National Academies and U.S. Department of Homeland Security (2004). Biological attack: human pathogens, biotoxins, and agricultural threats. Retrieved from http://www.dhs.gov/biological-attack-fact-sheet via http://www.ready.gov.

[111] Ibid.

[112] National Academies and U.S. Department of Homeland Security (2004). Chemical attack: warfare agents, industrial chemicals, and toxins. Retrieved from http://www.dhs.gov/chemical-attack-fact-sheet via http://www.ready.gov.

symptom onset, the 2010 CTRA identified related critical issues, including the timeliness of event detection and the logistics associated with successfully delivering medical countermeasures to exposed victims. These scenarios continue to be good candidates for risk management effort because improvements in event detection time or in medical countermeasure delivery were assessed to have the potential to significantly reduce chemical terrorism risk.[113]

Chemical/Biological Food Contamination Terrorism Attack

The SNRA also examined a national-level event involving successful chemical/biological attacks targeting food within the U.S. supply chain. The DHS Science and Technology Directorate (S&T) extracted data from the 2011 DHS Integrated Terrorism Risk Assessment (ITRA)[114] for chemical and biological attacks on food and beverage targets for analysis as a national-level event in the SNRA distinct from attacks on non-food targets.[115]

Chemical and biological weapons differ in potential toxicity, specificity, speed of action, duration of effect, controllability, and residual effects.[116] Children, the elderly, pregnant women, and immune-compromised individuals are particularly susceptible to the adverse effects of a chemical/biological food contamination.[117]

A terrorist attack on the Nation's food supply chain using chemical or biological agents may initially be indistinguishable from an unintentional food contamination. Depending on the type of agent used in the attack, it could take several days for individuals to show symptoms and possibly weeks before public health, food, and medical authorities suspect terrorism as the source.[118] In 1984 members of the Rajneeshees, a religious community in an accelerating political dispute with the Oregon county where they had established their commune, deliberately contaminated salad bars at eight county restaurants with *Salmonella* bacteria, infecting or sickening 751 people and hospitalizing 45.[119] However, deliberate contamination was not identified until a year later, when

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[113] U.S. Department of Homeland Security (2010, May). *Chemical Terrorism Risk Assessment (CTRA): Full report.* (Reference is SECRET: Extracted information is UNCLASSIFIED.)

[114] DHS Directorate of Science & Technology (2011), Integrated CBRN Terrorism Risk Assessment (reference is SECRET//NOFORN).

[115] The scope of the SNRA chemical/biological food contamination event (e.g. the portions of the ITRA event tree for which the event's data were calculated) included water products (i.e. bottled water) distributed through the food consumer supply chain, but all other attacks against water targets (e.g. piped water) were included with the chemical and biological non-food attacks.

Attacks on agriculture were excluded from all events. While intentional attacks on agriculture were prioritized for inclusion in the SNRA as a national-level event corresponding to the unintentional Animal Disease event, methodological issues involving data comparability prevented the use of ITRA data on agricultural targets in the first iteration of the SNRA.

[116] United Nations (1970). Chemical and Bacteriological (Biological) Weapons and the Effects of Their Possible Use, p. 12. Report of the Secretary-General, UN Publication no. E.69.I.24. Reprinted by Ballantine Books, 1970.

[117] FEMA (2008), *op. cit.*

[118] Federal Emergency Management Agency (August 2008), Food and Agricultural Incident Annex, p. 2, at http://www.fema.gov/pdf/emergency/nrf/nrf_FoodAgricultureIncidentAnnex.pdf (retrieved January 2015).

[119] This was to test a plan to poison the county water supply on Election Day, to suppress voter turnout and enable the group to take over the county board by electing their own candidates. Török et al (1997, August 6). A large community outbreak of Salmonellosis caused by intentional contamination of restaurant salad bars. *Journal of the American Medical Association (JAMA)* 278(5) 389-395; at http://www.cdc.gov/phlp/docs/forensic_epidemiology/Additional%20Materials/Articles/Torok%20et%20al.pdf (retrieved May 2014). Although unsuccessful in identifying deliberate action as the cause of the poisoning, CDC and FBI investigations following the incident may have deterred the group from carrying out their planned Election Day attack in November. Sobel et al (2002, March 9). Threat of a biological attack on the US food supply: the CDC perspective. *Lancet* 359(9309) 874-880.

the commune collapsed and criminal investigations into its other activities uncovered its clandestine biological laboratories.[120,121]

Population exposure can be limited with fast and accurate identification of the agent and vehicle (water, milk, lettuce, etc.) utilized to target the food supply system. A prepared public communications plan will assist in further limiting the spread while also mitigating the economic losses associated with falsely identifying the food contaminant.

Aircraft as a Weapon

Terrorists have long viewed aviation as a target for attack and exploitation. Successful attacks in the air domain can inflict mass casualties and grave economic damage, and attract significant public attention. Historically, large passenger aircraft have been at the greatest risk to terrorism, whether bombings, taking of hostages, traditional hijacking, and attack using human-portable surface-to-air missiles. Aircraft have also been used as weapons against targets on the ground, most notably but not limited to the attacks of September 11, 2001.[122]

For this incident, the SNRA only considered the risk of aircraft being used as a kinetic mode of attack (e.g. a 9/11 style attack) rather than the risk of an improvised explosive device (IED) being detonated on an aircraft. The latter risk is considered under the explosives incident category in the SNRA.

Explosives Terrorism Attack

Terrorism attacks using explosives are a familiar threat to the American public, having occurred at the World Trade Center in 1993, Oklahoma City in 1995, and the Summer Olympics in 1996, amongst other occasions. Explosive devices can come in many forms, ranging from a small pipe bomb to a sophisticated device capable of causing massive damage and loss of life. Explosives can be carried or delivered in a vehicle; carried, placed, or thrown by a person; delivered in a package; or concealed on the roadside.[123] The reliability and availability of needed components and materials make it likely that explosives will remain a major part of terrorists' inventory in the future. Additionally, recent innovations in explosive use by groups such as al Qaeda in the Arabian Peninsula (AQAP) suggest that terrorist explosive attacks will remain a complex defensive challenge to the Nation in coming years.[124]

The SNRA analyzed the risk of a hostile non-state actor(s) successfully deploying a man-portable explosive device such as an improvised explosive device (IED), vehicle-borne IED (VBIED), or vessel IED in the U.S. against a concentration of people and/or structures like critical commercial or government facilities, transportation targets, or other critical infrastructure sites. Bombings of

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120 Török et al, *op cit.*

121 Carus, W. Seth (2001, February). Bioterrorism and biocrimes: the illicit use of biological agents since 1900. Pages 50-58. National Defense University; at http://www.ndu.edu/centercounter/full_doc.pdf (retrieved March 2013). Agents experimented with included *Salmonella typhimurium*, the variant which was used in the salad bar attacks, *Salmonella typhi* which causes hepatitis and typhoid fever, *Giardia*, HIV, and multiple chemical and pharmaceutical poisons. *Giardia lamblia* was to be introduced into the county water supply via dead rats and beavers, which carry the parasite (p. 54).

122 U.S. Department of Homeland Security (2007, March 26). *National Strategy for Aviation Security.* At http://www.dhs.gov/publication/national-strategy-aviation-security.

123 National Academies and U.S. Department of Homeland Security (2004). IED attack: improvised explosive devices. Retrieved from http://www.dhs.gov/ied-attack-fact-sheet.

124 Clapper, James R. (2011, February 16). Statement for the Record on the Worldwide Threat Assessment of the U.S. Intelligence Community for the Senate Select Committee on Intelligence [written testimony]. Retrieved from http://www.intelligence.senate.gov/110216/dni.pdf.

aircraft (as opposed to use of an airplane as a weapon which was treated separately) were also included within the scope of the Explosives Terrorism Attack event.

Armed Assault

For the SNRA, the health and safety consequences of a hostile, non-state actor(s) using assault tactics to conduct strikes on vulnerable target(s) was estimated using historical data from the Global Terrorism Database (GTD).[125] To capture the range of terrorist attacks with small arms including large-scale assault/siege-type attacks like the 2008 complex attack in Mumbai, India, historical incidents of successful armed assault and explosives attacks, involving the use of firearms but excluding biological and chemical weapons were included in the data set used to determine fatality and injury estimates. Direct economic damage estimates for incidents of corresponding scope to this historical incident set were calculated using the DHS RAPID 2010 risk modeling engine.[126]

However, the SNRA incorporates new data about the frequency of successful armed assault attacks in the United States which was elicited from Intelligence Community subject matter experts. An overview of the elicitation process is given in Appendix B: additional details and results may be found in Appendix B of the classified SNRA Technical Report.

[125] The Global Terrorism Database (GTD) is an open-source database including information on terrorism events around the world (including domestic, transnational, and international incidents) from 1970 to 2010. For each GTD incident, information is available on the date and location of the incident, the weapons used and nature of the target, the number of casualties, and – when identifiable – the group or individual responsible. National Consortium for the Study of Terrorism and Responses to Terrorism (START) (2011, July). Global Terrorism Database [Data file]. Available from http://www.start.umd.edu/gtd.

[126] The Risk Assessment Process for Informed Decision Making (RAPID) 2010 is a strategic level, DHS-wide process to assess risk and inform strategic planning priorities developed by the DHS Office of Risk Management & Analysis (National Protection & Programs Directorate). The RAPID engine is a suite of computational tools for calculating human and economic measures of risk and the relative effectiveness of different DHS programs in risk reduction. Like the SNRA it is a quantitative tool for calculating and comparing risks in the homeland security mission space with each other, but unlike the SNRA it is designed for additionally calculating the comparative effectiveness of different governmental programs in buying down risk.

Cyber Event Discussion

The SNRA included two types of cyber events: cyber events affecting data and cyber events affecting physical infrastructure. Cyber events which are intentionally caused by any type of human actor, including hackers, activists, states, terrorists, malicious insiders, or criminals, were considered. Unintentional human-caused events (such as unintentional breaches or accidents) or non-human caused events (such as those caused by natural disasters or equipment malfunctions) were not considered.

All types of cyber weapons, including but not limited to malicious software, botnets, distributed denial-of-service attacks, etc., were considered. Note that for the purposes of the SNRA – which is intended to inform civilian capability development – direct attacks on defense systems were not considered. Additionally, state and non-state espionage was not considered.

Cyber Event affecting Data

> *Cyber attacks can have their own catastrophic consequences and can also initiate other hazards, such as power grid failures or financial system failures, which amplify the potential impact of cyber incidents.*
>
> *National Preparedness Goal, September 2011*

The SNRA evaluated cyber events that focus on compromising data or data processes as the primary result. Although events in this category almost always have indirect effects that "occur beyond the computer", events for which impacts to physical infrastructure is a primary objective of the attack were excluded and considered separately. For the purposes of the SNRA, a national-level cyber event affecting data was defined as an event which resulted in at least $1 billion in economic losses. Such events could take many forms and be perpetuated in order to achieve many goals. Some examples include the altering of records in a healthcare or financial system or an event that causes the internet or communications networks to cease.

Frequency information about the type of data/data processes targeted in cyber events is difficult to locate in open source material, but as one example, a 2010 Verizon report analyzed 141 data breach cases from 2009.[127] To obtain the SNRA frequency for this type of event, the frequency of successful cyber events affecting data resulting in $1 billion in economic losses or greater was elicited from Intelligence Community (IC) subject matter experts. The frequency elicitation is described in greater detail in Appendix B.

Consequences for cyber events are difficult to quantify because of the cascading impacts which can originate from a cyber event. The consequences included in the above referenced Verizon report estimate the total number of data records compromised to exceed 143 million.[128] For those data breaches included in the Verizon report, most of the losses came from only a few of the 141 breaches, which was consistent with breaches which had occurred in previous years.[129]

More anecdotally, the Wall Street "Flash Crash" of 2010 also highlights potential consequences of a cyber event. As a result of complex automated trades, this incident created enough market volatility to hemorrhage approximately $1 trillion in only minutes, with some stocks dropping more than 90 percent in value. While the volatility was unintentional and the stocks recovered, the crash

[127] Verizon RISK Team (2010). *2010 Data breach investigations report*, p. 7. Retrieved from http://www.verizonbusiness.com/resources/reports/rp_2010-data-breach-report_en_xg.pdf.

[128] Ibid.: p. 7.

[129] Ibid.: p. 40.

illustrates the potential consequences of sophisticated cyber attacks against a financial system that relies increasingly on automated high-frequency trading.[130]

Cyber Event affecting Physical Infrastructure

The SNRA assessed the risk of cyber events affecting physical infrastructure or assets that have the potential to produce national-level events outside the physical world. For the purposes of the SNRA, a national-level cyber event affecting physical infrastructure was defined as an event which resulted in at least one fatality or $100 million in economic losses. These types of events could involve a variety of targets, such as the electric grid, a dam, or a water system. While the events in this category may involve the manipulation of data as a means to an end, an event whose *direct* result is only compromised data (such as intellectual property theft or altered healthcare records) was not considered.

The threat of cyber events affecting physical infrastructure has seen increased prominence recently, as the extent of the Stuxnet infections have come to light. A 2010 CSIS-McAfee survey of 200 critical infrastructure executives from the energy, oil/gas, and water sectors in 14 countries found that around 40 percent of respondents had discovered Stuxnet on their computers.[131] While three-quarters of respondents who found Stuxnet were confident it had been removed from their systems, the potential for widespread sabotage through the introduction of malware into SCADA systems was clearly demonstrated.[132]

To obtain the SNRA frequency for this type of event, the frequency of successful cyber events affecting physical infrastructure resulting in $100 million in economic losses or greater was elicited from Intelligence Community (IC) subject matter experts. This frequency elicitation is described in greater detail in Appendix B.

Consequences for these types of cyber events are sector-dependent and difficult to quantify. Approximately 85 percent of critical infrastructure is believed to be owned and operated by the private sector, and system vulnerability and resilience is highly sector-dependent and localized.[133]

Final Notes

The SNRA findings detailed above provide a broad analysis of the risks from the varied threats and hazards faced by the Nation. As noted above, the assessment finds that a wide range of threats and hazards pose a significant threat to the Nation, affirming the need for an all-threats/hazards, capability-based approach to preparedness planning. Many opportunities exist to implement broad preparedness strategies that cut across many different threats and hazards. It is also important to keep in mind that within an all-hazards preparedness context, particular events which present risk to the Nation – such as nuclear attacks or chemical releases – require additional specialized response activities.

[130] Quoted in full from Pett, D. (2010, May 8). High-frequency swaps, dark pools under scrutiny. *National Post's Financial Post & FP Investing;* and from Scannell, K. & Lauricella, T. (2010, October 2). Flash crash is pinned on one trade. *The Wall Street Journal*; as originally cited in Lord, K.M. & Sharp, T. (2011, June). *America's cyber future: Security and prosperity in the information age,* Vol. 1. Washington, DC: Center for a New American Security, p. 25.

[131] McAfee and the Center for Strategic and International Studies (2011, April). *In the dark: Crucial industries confront cyberattacks*, p. 8. Retrieved from http://www.mcafee.com/us/resources/reports/rp-critical-infrastructure-protection.pdf.

[132] Ibid.

[133] U.S. Department of Homeland Security, Office of Infrastructure Protection (2011, September 12). Critical infrastructure sector partnerships. Retrieved from http://www.dhs.gov/files/partnerships/editorial_0206.shtm.

IMPACTS AND FUTURE USES

The SNRA was executed in support of PPD-8 implementation and served as an integral part of the development of the National Preparedness Goal, assisting in integrating and coordinating identification of the core capabilities and establishing a risk-informed foundation for the National Preparedness System.

In addition, conducting a Strategic National Risk Assessment supported the National Preparedness System by providing a consolidated list of "national level events" for consideration and augmentation for Threat and Hazard Identification and Risk Assessment (THIRA) processes at multiple jurisdiction levels. Some events, such as explosives or earthquakes, generally cause more localized consequences, while other events, such as human pandemics, may cause consequences that are dispersed throughout the Nation, thus creating different types of impacts for preparedness planners to consider.

The SNRA provides an understanding of the risks that pose the greatest challenge to the Nation's security and resilience. This understanding is crucial for preparedness planning and prioritization. It enables:

- A shared understanding of the potential incidents for which communities should prepare
- A prioritization of the incidents that may pose the greatest negative impact to communities and thus require preparedness
- The evaluation of needed capabilities, and capability levels across all five focus areas: Prevention, Protection, Mitigation, Response, and Recovery

More specifically, the SNRA has already served as an integral part of the development of the National Preparedness Goal, assisting in integrating and coordinating identification of core capabilities. The core capabilities identified in the Goal were mapped to the events assessed in the SNRA to identify any additional core capabilities that may be needed and/or any capabilities that did not address high priority risks.

In addition to supporting the development of the National Preparedness Goal, the SNRA has the potential to assist with a wide range of efforts which are crucial to executing the Preparedness Cycle.

Figure 9: The Preparedness Cycle

These include:

- *Planning* – The SNRA findings can help a planning team decide which hazards deserve special attention, what actions must be planned for and what capabilities (and eventually resources) are likely to be needed. Since the SNRA is a strategic and national assessment, it was designed first and foremost to support planning at the national level. It can do so by being an input to help identify national planning factors that support the ability to deliver a target level of capabilities. According to the National Preparedness System, planning factors are based on assessments of risk and the desired outcome(s) to be achieved. For example, if a desired outcome is to prevent an imminent terrorist attack, then a set of planning factors that help to define the adversary or modes of attack will aid in identifying the level of capability required to prevent the attack. These planning factors help inform decisions about the capability level required and the resources needed to achieve it.

  Ultimately, however, it is important for communities to develop their own planning factors, tailored to their specific circumstances. Therefore, it is necessary to not only consider national risks as done through the SNRA but also risks at a regional level, many of which differ from region to region. This will allow for the development of regional planning factors that will support community planning consistent with the National Planning System.

- *Organizing and Equipping* – The SNRA, along with other risk assessments, should be a key component of an analytically-driven approach to allocate resources at the national level. By better understanding the risks facing the Nation, the Federal government and its partners can identify realistic capability requirements and organize and equip to deliver these capabilities. This can be done via the development of new policy or regulatory approaches, an increase in organizational capacity, and the prioritization of new research and development efforts, as well as other mechanisms for building capability.

- *Training and Exercises* – The SNRA can help focus limited training and exercising resources and ensure they are targeted to incidents of the highest risk. The SNRA can also be used as an input to help identify core capabilities that should be tested in training and exercises in order to reduce risks from identified threats and hazards. This is true for many types of exercises – whether an exercise-based planning session, a drill, or a functional or full-scale exercise.

- *Evaluate/Improve* – A principal aim of the National Preparedness System is to support the ability to measure how prepared we are at the national and community level. Assessments aid in that endeavor. As capabilities are assessed, they may be included in future iterations of the SNRA to better understand the impact of enhanced preparedness on the national risk picture and support dynamic and flexible planning to emerging risks.

In summary, the SNRA informs prioritization and tradeoff decisions by enabling the analysis of which capabilities are likely to have an impact at reducing identified high-risk events. Using the SNRA, the homeland security enterprise can better understand which scenarios are more likely to impact them, what the consequences would be, what risks merit special attention, what actions must be planned for, and what resources are likely to be needed. This allows for making risk-informed tradeoffs within and across core capabilities.

The SNRA is, of course, not the only input to such tradeoff decisions. Organizations will appropriately continue to consider other factors – including costs and expected performance of capabilities, stakeholder input, policy and statutory considerations, and other types of risk analysis. Still, the SNRA provides a common national risk picture to serve as an additional input into preparedness prioritization, which is crucial to achieve the vision of the National Preparedness

System. Future versions of the assessment will refine and improve our understanding of the national risk picture.

Although the development of the SNRA is an important first step, further analysis through the conduct of regional- and community-level risk assessments will help communities better understand their risks and form a foundation for their own security and resilience. In conjunction with Federal, state, and local partners, the SNRA will continue to be expanded and enhanced, and will ultimately serve as a unifying national risk profile to facilitate preparedness efforts.

Appendices

APPENDIX A: DATA VISUALIZATION IN THE SNRA

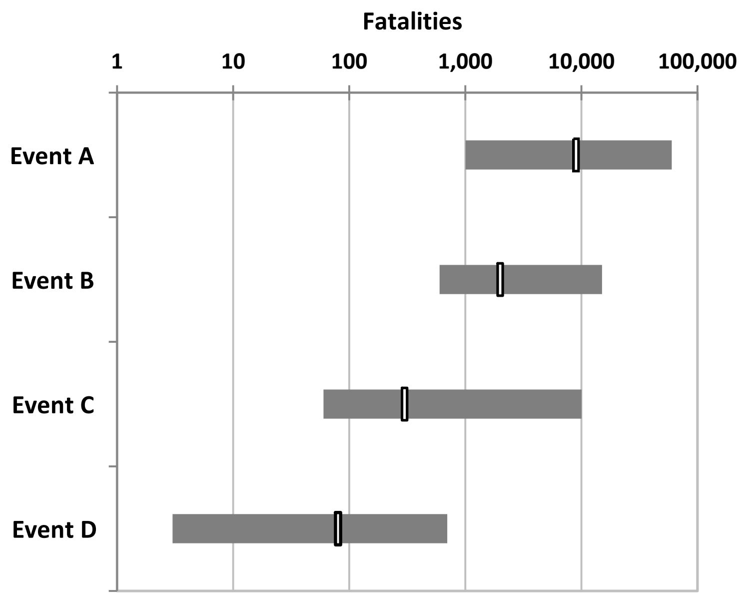
The main body and appendices of the SNRA Technical Report include two types of quantitative charts: bar plots and scatter plots. Bar plots are used when analyzing a single type of information (such as frequency or consequence, but not both at the same time), and scatter plots are used to analyze two types of information simultaneously (such as frequency and fatalities).

Bar Plots

On a bar plot, each bar represents a single national-level event. Bars that are located toward the top of the chart are larger in the plotted quantity than points at the bottom. Each bar is a visual representation of the uncertainty in the value of the plotted quantity for a specific national-level event. As illustrated in Figure A1, three points characterize each bar: (1) the best estimate of the plotted quantity, represented by a vertical stripe; (2) the high estimate of the plotted quantity, represented by the right end of the bar; and (3) the low estimate of the plotted quantity, represented by the left end of the bar. When two bars overlap (meaning that one can draw a vertical line that intersects both bars), then there is some uncertainty as to which of the two quantities is larger. The larger the degree of overlap, the more uncertain it is which quantity is larger.

Each bar plot included in this report is constructed using a logarithmic horizontal axis. This means that each vertical background line denotes a change in the plotted quantity (whether frequency or consequence) by a factor of ten. As a result, the difference between the left and the right of the SNRA bar plots can be quite large, even factors of thousands or millions. Logarithmic axes allow quantities that differ by very large ratios to be plotted on the same chart, and straightforwardly compared.

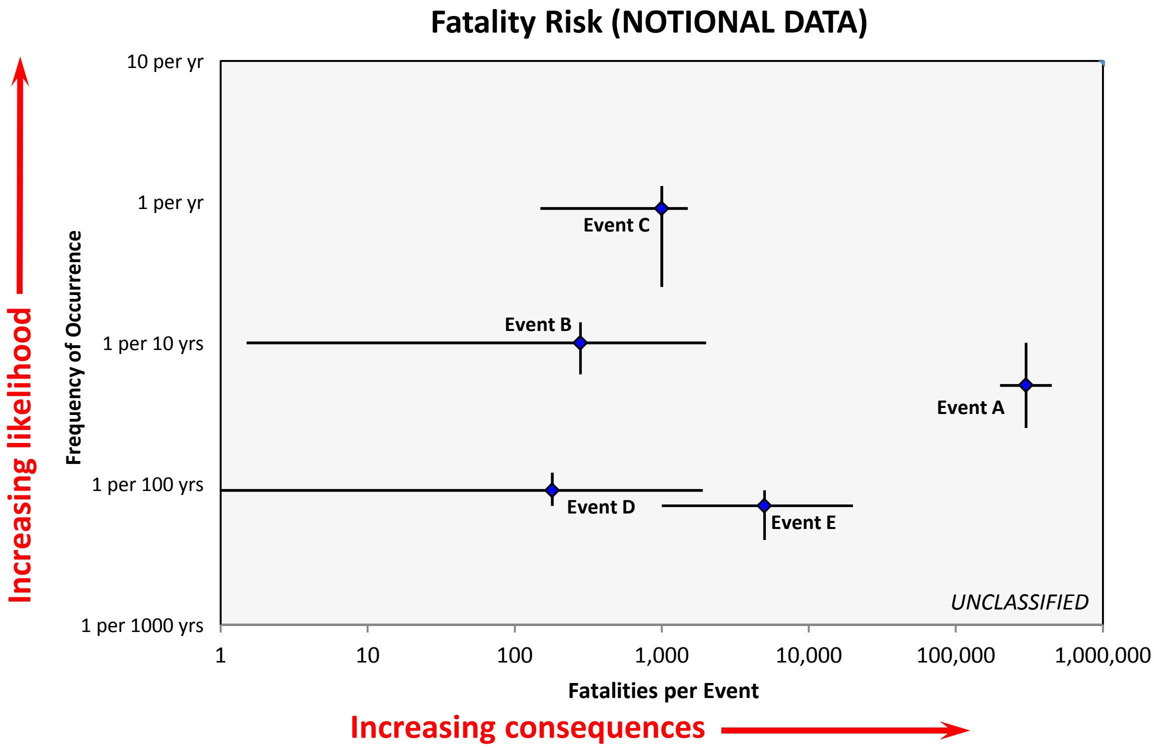
Figure A1: Example Bar Plot



Scatter Plots

On a scatter plot, each point, with crosshairs, represents a single national-level event. Since frequency (events per year) is the vertical axis, events that are higher frequency tend toward the top of the plot. Similarly, events with higher consequence tend toward the right of the plot. This is illustrated in Figure A2.

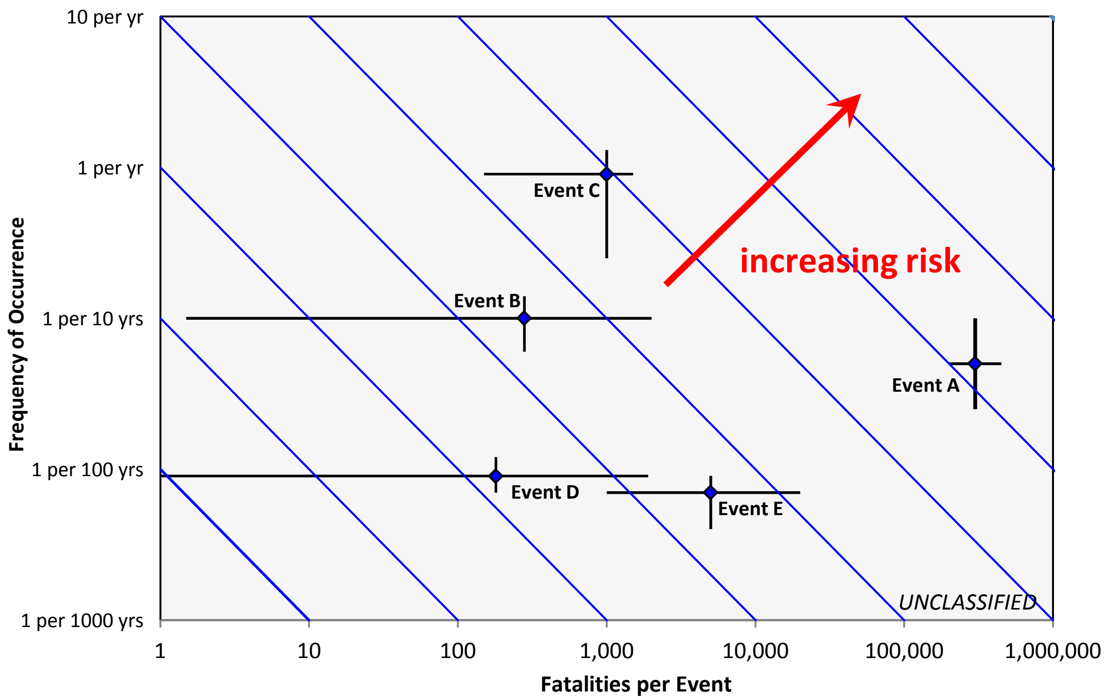
Figure A2: Example Scatter Plot



The vertical line of the crosshair denotes the uncertainty in frequency and the horizontal line denotes the uncertainty in consequence. The interpretation of the crosshairs depends on how the data was gathered for that particular national-level event and is guided by the text that accompanies each scatter plot: "Frequency and consequence estimates are correlated at the mean where denoted by a solid circle at the intersection of the ranges; those with an open circle are not necessarily correlated at the intersection. No correlation should be assumed for arbitrary frequency-consequence pairings within the uncertainty of any national-level event without additional review of the underlying data. Note that high frequency estimates are rarely, if ever, correlated with high consequence estimates."

Like the bar plots, scatter plots are constructed using logarithmic axes. However, in contrast to the bar plots, the scatter plots are logarithmic in both the vertical and horizontal axes. Scatter plots have an additional useful interpretation when they are constructed with logarithmic frequency and consequence axes: the highest risk national level events congregate in the upper right hand corner and the lowest risk events in the lower left. The diagonal background lines, drawn in the upper left to lower right direction, represent lines of constant risk, as illustrated in figure A3. This means that two national level events that fall on the same line have a similar level of risk.[1] The diagonal lines are drawn to differentiate between factors of ten in risk. This means that if there are two national level events that fall on adjacent diagonal lines, the one on the higher diagonal line has ten times as much risk as the one on the lower diagonal line. The lines act multiplicatively, meaning that if one event falls exactly on a diagonal line and a second event falls two lines below it, the first event has one hundred times more risk than the second.

Figure A3: Interpreting Risk Results in Scatter Plots



The uncertainty in the frequencies and consequences complicates this discussion. Even if a crosshair is centered on a line, it does not imply that the national level event has exactly that amount of risk. If the frequency and consequence data is correlated for that particular national level event, the best estimate of risk is likely near the intersection point. If the data are uncorrelated, the estimated risk is likely to appear somewhere in the crosshairs, but it is unclear exactly where.

[1] This interpretation depends on a particular definition of risk, and does not account for differing risk preferences.

APPENDIX B: FREQUENCY ASSESSMENT

Note that all comparative statements are made within the set of natural and technological hazards treated by this unclassified adaptation of the SNRA Technical Report.

Overview

In order to apply a consistent methodology across all SNRA event types, frequency was selected as a metric for the likelihood of event occurrence. Frequency was estimated as the potential number of successful attacks (for adversarial/human-caused events) or potential number of occurrences (for natural and technological hazards), per year. Adversarial/human-caused frequencies were estimated primarily using elicitation from subject matter experts.[1] Estimates of natural and technological hazard frequencies were drawn heavily from the historical record.

When interpreting the frequency results presented below, it is important to consider that the frequency data in the SNRA is directly related to the threshold included in each national-level event definition. For example, the results for floods indicate that *floods causing greater than $100 million in direct economic losses* are estimated to occur with a frequency between once every two years and ten times per year, with a best estimate of four times per year. For reference, the full national-level event definitions, including thresholds, can be found in Table 2 of the main report.

Frequency ranges included in the SNRA for adversarial/human-caused events are estimates of the frequency of successful attacks. Where subject matter expert judgment was used to determine frequency of successful attacks, adversary intent and capability were considered implicitly by the experts, but were not explicitly quantified or characterized. Attack initiations may occur with higher frequency than the ranges provided.

A designated Intelligence Community (IC) agency reviewed and commented on the relative frequency of the adversarial/human-caused events for which data was derived from previous governmental risk assessments, including DHS/S&T's Integrated Terrorism Risk Assessment (ITRA) and DHS/NPPD/RMA's Risk Assessment Process for Informed Decision-making (RAPID). To accomplish this, the agency reviewed frequency data, including the 5th, mean, and 95th percentiles of the frequency distributions. The review was performed in the summer of 2011.

The IC agency did not comment on the absolute values of the frequencies.

Through this process, the IC agency did not comment on the relative ordering of the frequencies for the two cyber events or armed assault, since those frequencies had not yet been elicited from the Intelligence Community SMEs within the SNRA project's structured elicitation process.

[1] Subject matter expert (SME) elicitation was a component of modeling frequency in two of the prior assessments leveraged for the SNRA: the 2011 ITRA conducted by DHS/S&T (chemical, biological, radiological, and nuclear terrorism attacks) and the 2010 Risk Assessment Process for Informed Decision-making (RAPID) conducted by DHS/Office of Risk Management and Analysis (RMA) (aircraft as a weapon, explosives terrorism attack). Separate SME elicitations were conducted for the SNRA with representatives from the Intelligence Community in July 2011 for the armed assault and cyber attack events. In all cases, the outputs from these models/elicitations were converted to equivalent units of successful events per year for comparison to the frequencies of natural and technological hazards drawn from the historical record.

SME estimation of the frequency of rare, adversarial/human-caused events is challenging, and SME frequency judgments in the SNRA reflect significant uncertainty. As with all data in the SNRA, these SME frequency judgments should be interpreted as order of magnitude estimates for the purposes of comparison.

Elicited Frequency Data

Within the adversarial/human-caused set of events, there were two event types, armed assault and cyber (affecting data and affecting physical infrastructure) for which appropriate frequency data sources could not be located. For these events, an elicitation protocol was developed and separate elicitations were conducted of IC experts.

For the cyber elicitation, representatives from DHS/NPPD/CS&C, ODNI, CIA, FBI, NSS, and NSA participated in a two part elicitation. All participants attended a half day working session to discuss the scope of the cyber events, identify event thresholds, and begin to provide frequency data. A subset of the participating agencies (ODNI, CIA, FBI, NSS) then completed the frequency elicitation tool and submitted it as input for consideration and review by the larger group.

- Elicitations for the cyber event affecting data incorporated three specific target types (financial institution system, public health/emergency system, internet) and asked that the elicitees provide individual frequency judgments for each of these target types.
- Elicitations for the cyber event affecting physical infrastructure incorporated five specified target types (dam failure, chemical release, electric grid failure, radiological release from a nuclear reactor, transportation system failure) and asked that the elicitees provide individual frequency judgments.
- As noted in the body of this report, no consensus consequence estimates corresponding to these elicited frequency judgments were obtained for the cyber events.

For the armed assault elicitation, representatives from DHS/I&A, FBI, and NSS participated in a group elicitation. All participants attended a half day working session to discuss the scope of the armed assault event, identify event thresholds, and provide frequency data. All data was collected during this group session, with the exception of one domestic terrorism expert who was individually elicited to ensure that domestic terrorism perspectives were included. No specific target types were articulated by the group.

For all elicitations, elicitees were asked to assign a frequency range to the events leveraging structured bins. Elicitees identified whether the frequency of these events were more or less frequent than once per year. If more frequent, elicitees then assigned the events to one of four buckets, each of varying order of magnitude (1-10 events per year, 11-100 events per year, 101-400 events per year, or greater than 400 events per year). If less frequent than once per year, elicitees assigned the events to one of four probability ranges (1% or less probable per year, 10% probable per year, 25% probable per year, or 50% probable per year). Elicitee input was aggregated into a range, which is represented within the SNRA frequency data.

Major Findings

- Many events are estimated to have the potential to happen more than once every 10 years, meaning that it is likely that the Nation’s preparedness will be tested in this decade.
- By their best estimates, the most frequent natural and technological hazard events in the SNRA are floods, hurricanes, and accidental chemical substance releases (toxic inhalation hazards), which are expected to occur a few times per year. However, other events have the potential to occur at least this frequently, when uncertainty is considered.
- Of the non-adversarial events with frequency data of sufficient quality upon which to base comparisons, the least frequent event, a radiological substance release, is expected to have only a 1% chance of happening each year (or a frequency of approximately 1 in 100 years.

Additional Information

Frequency information of sufficient quality upon which to base comparisons could not be found for every national-level event.

- The space weather event analyzed for the SNRA is assessed to have a frequency of approximately 1 in 100 years, but no information was obtained about the uncertainty associated with the frequency of space weather during the time frame of this assessment.
- The specific cases of tsunami (Oregon coast) and volcanic eruption (Mount Rainier) assessed in the SNRA have expected frequencies of 1 in 200 years and 1 in 500 years, respectively, at the best estimate. These frequencies do not necessarily represent the rate of occurrence of tsunamis and volcanic eruption across the entire Nation, so this data is not appropriate for comparison to other national-level events.

Figure B1: Frequency by National-level Event

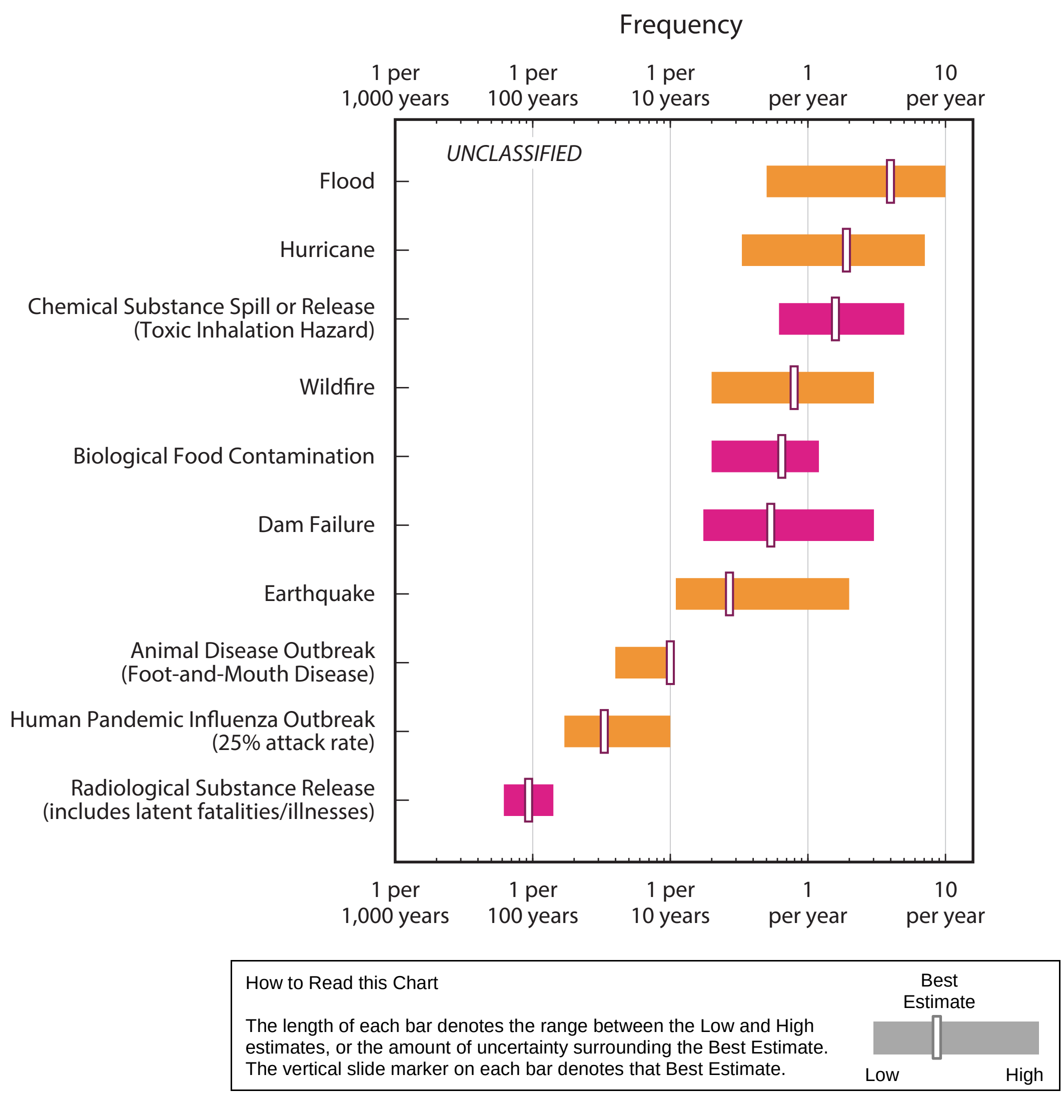


Table B1: SNRA Frequency Data and Sources

Threat/ Hazard Group	Threat/Hazard Type	Frequency Estimate (number of events per year)		Source Information
Adversarial/ Human-Caused	Aircraft as a Weapon	Low		Data reflects the 5th percentile, mean, and 95th percentile of DHS RAPID 2010 estimates of the frequency of successful aircraft as a weapon terrorism attacks.[1]
		Best		
		High		
	Armed Assault	Low		Frequency data was elicited from the Intelligence Community (IC) by the SNRA project team in July 2011.[2]
		Best		
		High		
	Biological Terrorism Attack (non-food)	Low		Data reflects the 5th percentile, mean, and 95th percentile frequency of events matching the SNRA definition of biological terrorism attacks (non-food) in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Frequency estimates in the SNRA only include data for successful attacks, e.g., release of an agent.[3]
		Best		
		High		
	Chemical Terrorism Attack (non-food)	Low		Data reflects the 5th percentile, mean, and 95th percentile frequency of events matching the SNRA definition of chemical terrorism attacks (non-food) in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Frequency estimates in the SNRA only include data for successful attacks, e.g., release of an agent.
		Best		
		High		
	Chemical/Biological Food Contamination Terrorism Attack	Low		Data reflects the 5th percentile, mean, and 95th percentile frequency of events matching the SNRA definition of chemical/biological food contamination terrorism attacks in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Frequency estimates in the SNRA only include data for successful attacks, e.g., release of an agent.
		Best		
		High		
	Cyber Event affecting Data	Low		Frequency data was elicited from the Intelligence Community (IC) by the SNRA project team in July 2011.[4] Only attacks resulting in $1 Billion in losses or greater were considered.
		Best		
		High		
	Cyber Event affecting Physical Infrastructure	Low		Frequency data was elicited from the Intelligence Community (IC) by the SNRA project team in July 2011.[5] Only attacks resulting in 1 fatality or greater or $100 Million in losses or greater were considered.
		Best		
		High		
	Explosives Terrorism Attack	Low		Data reflects the 5th percentile, mean, and 95th percentile of DHS RAPID 2010 estimates of the frequency of successful man-portable improvised explosive device (IED), vessel borne IED, and vehicle borne IED terrorism attacks.[6]
		Best		
		High		
	Nuclear Terrorism Attack	Low		Data reflects the 5th percentile, mean, and 95th percentile frequency of events matching the SNRA definition of nuclear terrorism attacks in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology
		Best		
		High		

Threat/ Hazard Group	Threat/Hazard Type	Frequency Estimate (number of events per year)		Source Information
				Directorate. Frequency estimates in the SNRA only include data for successful attacks, e.g., detonation of a device.
	Radiological Terrorism Attack	Low		Data reflects the 5th percentile, mean, and 95th percentile frequency of events matching the SNRA definition of radiological terrorism attacks in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Frequency estimates in the SNRA only include data for successful attacks, e.g., detonation of a device or radiation exposure.
		Best		
		High		
Technological/ Accidental	Biological Food Contamination	Low	0.20	Historic events in the CDC's Foodborne Outbreak Online Database (FOOD) which were multistate outbreaks requiring greater than 100 hospitalizations formed the data set. Frequency estimates correspond to the inverse of the number of years between outbreaks (low), the mean frequency of the outbreaks (best), and the greatest number of outbreaks within one year (high). Years included in FOOD include 1998-2008.[7]
		Best	0.64	
		High	1.2	
	Chemical Substance Spill or Release	Low	0.61	Estimates correspond to the inverse of the number of years between accident events (low), the mean frequency of the accident events (best), and the greatest number of accidents within one year (high) within the U.S. historic data set used for the SNRA analysis.[8]
		Best	1.6	
		High	5	
	Dam Failure	Low	0.17	Estimates correspond to the inverse of the number of years between dam failures causing 1 fatality or greater (low), the mean frequency of dam failures causing 1 fatality or greater (best), and the greatest number of dam failures causing 1 fatality or greater within one year (high) from the U.S. historic events during the time period from 1960-2009.[9]
		Best	0.54	
		High	3	
	Radiological Substance Release	Low	0.0062	Estimates are drawn from core damage failure frequencies in the license renewal applications available on the public website of the U.S. Nuclear Regulatory Commission.[10]
		Best	0.0093	
		High	0.014	
Natural	Animal Disease Outbreak	Low	0.04	Estimates provided by DHS Office of Health Affairs subject matter experts. These estimates only reflect the likelihood of an outbreak of Foot-and-Mouth Disease (FMD).
		Best	0.1	
		High	0.1	
	Earthquake	Low	0.11	Estimates correspond to the inverse of the number of years between earthquakes causing greater than \$100 M in damages (low), the mean frequency of earthquakes causing greater than \$100M in damages (best), and the greatest number of earthquakes causing greater than \$100 M in damages within one year (high) from the U.S. historic events between 1906-2005.[11]
		Best	0.27	
		High	2	
	Flood	Low	0.5	Estimates correspond to the inverse of the number of years between floods causing greater than \$100
		Best	4	

Threat/ Hazard Group	Threat/Hazard Type	Frequency Estimate (number of events per year)		Source Information
		High	10	M in damages (low), the mean frequency of floods causing greater than $100M in damages (best), and the greatest number of floods causing greater than $100 M in damages within one year (high) from the U.S. historic events between January 1, 1993 to December 31, 2005.[12]
	Human Pandemic Outbreak	Low	0.017	Estimates provided by CDC subject matter experts, informed by the historic frequency of influenza pandemics since 1729.[13]
		Best	0.033	
		High	0.10	
	Hurricane	Low	0.33	Estimates correspond to the inverse of the number of years between hurricanes causing greater than $100 M in damages (low), the mean frequency of hurricanes causing greater than $100M in damages (best), and the greatest number of hurricanes causing greater than $100 M in damages within one year (high) from the U.S. historic events between 1970-2010.[14]
		Best	1.9	
		High	7	
	Space Weather	Low	N/A	The space weather scenario analyzed for the SNRA is judged to be a 1 in 100 year event.[15]
		Best	0.01	
		High	N/A	
	Tsunami	Low	0.0024	Estimates informed by the likelihood of a major earthquake along the Cascadia Subduction Zone, causing a tsunami to hit the Oregon coast.[16]
		Best	0.005	
		High	0.0074	
	Volcanic Eruption	Low	0.001	Estimates informed by the average time intervals between eruptions of Mount Rainier.[17]
		Best	0.002	
		High	0.01	
	Wildfire	Low	0.2	Estimates correspond to the inverse of the number of years between wildfires causing greater than $100 M in damages (low), the mean frequency of wildfires causing greater than $100M in damages (best), and the greatest number of wildfires causing greater than $100 M in damages within one year (high) from the U.S. historic events between 1990-2009.[18]
		Best	0.8	
		High	3	

[1] DHS' RAPID assessment (the Risk Assessment Process for Improved Decision-making), estimates "residual threat" or the frequency of a successful attack. This estimate is a weighted average that incorporates adversary preferences among different attack scenarios as well as the ability of DHS and non-DHS programs to detect and interdict these attacks.

[2] IC participants in the Armed Assault frequency elicitation included subject matter experts from NSS, DHS/I&A, and FBI. The frequency estimates reflect the opinion of the group and have not been formally vetted by any of the agencies which participated.

[3] Examples of failed attacks not considered in the SNRA frequency estimates include interdiction during the fabrication and assembly of the dissemination device, interdiction during travel to the United States, or failure of the dissemination device.

[4] IC participants in the Cyber Event affecting Data frequency elicitation included subject matter experts from ODNI, CIA, FBI, NSA, NSS, and DHS/CS&C. The frequency estimates reflect the opinion of the group and have not been formally vetted by any of the agencies which participated.

[5] IC participants in the Cyber Event affecting Physical Infrastructure frequency elicitation included subject matter experts from ODNI, CIA, FBI, NSA, NSS, and DHS/CS&C. The frequency estimates reflect the opinion of the group and have not been formally vetted by any of the agencies which participated.

[6] See note (1) above.

[7] Centers for Disease Control and Prevention (CDC) Foodborne Outbreak Online Database (FOOD) is available online at http://www.cdc.gov/foodborneoutbreaks.

[8] The set of historic chemical substance release events used for analysis in the SNRA were those which met the following criteria: 1) at least one "public" fatality, defined as one fatality other or in addition to an employee fatality, caused by the hazardous material; or 2) at least one fatality of any kind caused by the hazardous material, plus a reported evacuation or shelter-in-place order. This set came from the set of all reported toxic inhalation hazard (TIH) incidents reported 1994-2010 to either the EPA's Risk Management Program (RMP) accident database for fixed industrial producers and consumers of the listed toxic chemicals above given threshold limits, or to the Department of Transportation's Pipeline and Hazardous Substances Administration (PHMSA)'s database of road, rail, water, and air transportation accidents.

[9] Historic data for U.S. dam failures were provided by the U.S. Bureau of Reclamation via the DHS Office of Infrastructure Protection Dams Sector Branch. Dam failures which were caused by cascading events (e.g., a failing dam upstream) were combined into single events.

[10] The best estimate for frequency uses a simulation of the expected core damage frequencies and expected consequences obtained from the license renewal applications for a number of individual reactors available from the public website of the U.S. Nuclear Regulatory commission at http://www.nrc.gov/reactors/operating/licensing/renewal/applications.html. The data from the license renewal applications is used to perform cost/benefit analyses on reactor upgrades and the baseline data was not developed for use in a general risk assessment. Currently, this is the most recently publicly available data and adequate for order of magnitude estimates in the SNRA. An alternative analysis was also conducted using fatality, injury, and core damage frequency data from NUREG-1150, and the best estimates from this analysis were within an order of magnitude of the results obtained using data from license renewal applications (U.S. Nuclear Regulatory Commission (1990). *NUREG-1150 Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants*. Washington, DC: U.S. NRC). The low frequency estimate is the 5th percentile of the core damage frequencies, taking into account variability across the different reactors and the uncertainty of a single reactor. Note that this frequency incorporates the uncertainty and variability of the expectation and does not directly correspond to the Low consequence values. The high frequency estimate is the 95th percentile of the core damage frequencies, taking into account variability across the different reactors and the uncertainty of a single reactor. This does not correspond to the High consequence values which have likelihoods one to two orders of magnitude lower than the Best CDF value.

[11] The U.S. historic earthquake record for events causing greater than $100 Million in damages was obtained from the published report by Vranes, K. and Pielke, R. (2009). Normalized earthquake damage and fatalities in the United States: 1900-2005. *Natural Hazards Review* 10(3), 84:101.

[12] The U.S. historic flood record for events causing greater than $100 Million in damages was obtained by aggregating flood losses reported by NOAA's National Climactic Data Center (NCDC). Modern flood reporting by NOAA relies on many individual reports that assess damages in a specific area of responsibility. A large scale flood, for example, can result in dozens or hundreds of damage entries that assess damages for specific geographic regions. As flooding passes down the Mississippi, for example, the affected areas can pass from region to region. To capture the transient and distributed nature of flood events, individual flood loss reports were aggregated based on distance and time. Flood damage reports that occurred within 100 miles of one another and within plus or minus one calendar day are aggregated into composite flood events. The composite flood events above the $100 Million (2011 dollar) threshold were used for reporting frequency, fatality, injury, and direct economic loss estimates in the SNRA. All hurricanes were removed from flood events to avoid double-counting flooding damages included in the SNRA hurricane analysis.

[13] Potter, C. W. (2001). A history of influenza. *Journal of Applied Microbiology*, 91, 572-579.

[14] The U.S. historic hurricane record for events causing greater than $100 Million in damages was obtained from the ICAT Damage Estimator (http://www.icatdamageestimator.com), which uses a methodology for computing economic losses similar to that published by Pielke, R.J., Gratz, J., Landsea, C., Collins, D., Saunders, M., and Musulin, R. (2008). Normalized hurricane damage in the United States: 1900-2005. *Natural Hazards Review* 9(1), 29-42.

[15] Kappenman, J. (2010, January). *Geomagnetic Storms and their Impacts on the U.S. Power Grid* (Metatech Publication No. Meta-R-319), Chapter 4, p. 3-13. Prepared for Oak Ridge National Laboratory. Retrieved from http://www.ferc.gov/industries/electric/indus-act/reliability/cybersecurity/ferc_meta-r-319.pdf.

[16] Geologists studying the Cascadia Subduction Zone have concluded that there is a 37 percent chance of an 8.2 or larger magnitude event in the next 50 years and a 10-15 percent chance for a rupture along the entire fault from a 9.0 or larger event in the next 50 years. "Odds are 1-in-3 that a huge quake will hit Northwest in next 50 years," Oregon State University press release, 24 May 2010, announcing preliminary results later published as Goldfinger et al (2012); at http://oregonstate.edu/ua/ncs/node/13426 (accessed 3/17/2013). Risk of giant quake off American west coast goes up. *Nature News*, 31 May 2010, citing results later published as Goldfinger et al (2012); at www.nature.com/news/2010/100531/full/news.2010.270.html. Goldfinger et al, 2012. Turbidite event history – Methods and implications for

Holocene paleoseismicity of the Cascadia Subduction Zone. USGS p 1661-F, 17 July 2012: http://pubs.usgs.gov/pp/pp1661f/ (accessed 3/17/13).

[17] Hoblitt, R. P., Walder, J. S., Driedger, C. L., Scott, K. M., Pringle, P. T., & Wallace, J. W. *Volcano Hazards from Mount Rainier, Washington* (U.S. Geological Survey Open-File Report 98-428). Available from: http://vulcan.wr.usgs.gov/Volcanoes/Rainier/Hazards/OFR98-428/framework.html.

[18] The U.S. historic wildfire record for events causing greater than $100 Million in damages was compiled from the SHELDUS database (Hazards & Vulnerability Research Institute (2011). The Spatial Hazards Events and Losses Database for the United States, Version 8.0 [Online Database]. Columbia, SC: University of South Carolina. Available from http://www.sheldus.org). SHELDUS breaks down wildfire events into separate counties, and sometimes breaks down single wildfires in the same location into separate fires with overlapping date ranges, dividing casualty and damages between them to avoid double-counting. Where this was obviously done (fires reported by counties in the same state having the same time range, or reported in the same city with overlapping or continuously adjacent time ranges) the separately reported portions of a single fire event were consolidated into single events. All wildfires (after consolidation) above the $100 Million threshold in 2011 dollars (a CPI multiplier of 1.0464 was used to convert the December 2009 values given in SHELDUS v8.0 to May 2011 values) from 1970-2009 were used in the SNRA analysis.

APPENDIX C: FATALITY CONSEQUENCE ASSESSMENT

Note that all comparative statements are made within the set of natural and technological hazards treated by this unclassified adaptation of the SNRA Technical Report.

Overview

For events that have occurred in the past, the number of fatalities was estimated primarily from the historical record. For events that have never occurred (primarily in terrorism), consequences were estimated using data from previous DHS risk assessments, which rely on models and simulations.

When interpreting the fatality results presented below, it is important to consider that the consequence data in the SNRA is directly related to the threshold included in each national-level event definition. For example, the results for floods indicate that *floods causing greater than $100 million in direct economic losses* are estimated to cause between 0 and 25 fatalities, with a best estimate of 3 fatalities. For reference, the full national-level event definitions, including thresholds, can be found in Table 2 of the main report.

In many cases, the high estimates for fatalities in the SNRA were constructed from either historic maximums (e.g. natural hazards) or the 95^{th} percentile of a modeled distribution (e.g. terrorism events). Thus, the high estimates associated with each national-level event may not be reflective of the fatalities which may occur from a "worst-case scenario". Additional analysis is necessary to better characterize the "worst-case" upper bounds for fatalities associated with each national-level event.

Major Findings

- At the best estimate, a pandemic influenza outbreak with a 25% gross clinical attack rate and a case fatality rate similar to the 1968-1969 Hong Kong flu pandemic is estimated to result in the most fatalities, given occurrence, of any event among the natural and technological hazards considered by the SNRA. Such a pandemic influenza outbreak is estimated to cause between 140,000 and 440,000 fatalities, with a best estimate of 250,000 fatalities.
- With the exception of a pandemic influenza outbreak, earthquakes are assessed to have the largest expected consequences per occurrence of the natural hazards, at the best estimate. The expected fatalities due to an earthquake are assessed to be of a comparable order of magnitude (hundreds of fatalities) as accidental radiological substance releases, at the best estimate.
- Foot-and-mouth disease (FMD) is assessed to have no potential of causing human fatalities. FMD affects livestock but poses no health risk to humans.

Additional Information

Fatality information of sufficient quality upon which to base comparisons could not be found for every national-level event.

- *Tsunami*: FEMA HAZUS modeling of a tsunami wave hitting the Oregon coast with height 15 meters resulted in estimates ranging from one to 1000 fatalities.
- *Volcanic Eruption:* FEMA analysis of the areal extent of lahar flow from an eruption of Mount Rainier results in estimates ranging from 350 to 800 fatalities.

- *Cyber Events and Space Weather:* Additional analysis is necessary to quantify the fatalities which might result from these events.

Figure C1: Fatalities by National-level Event

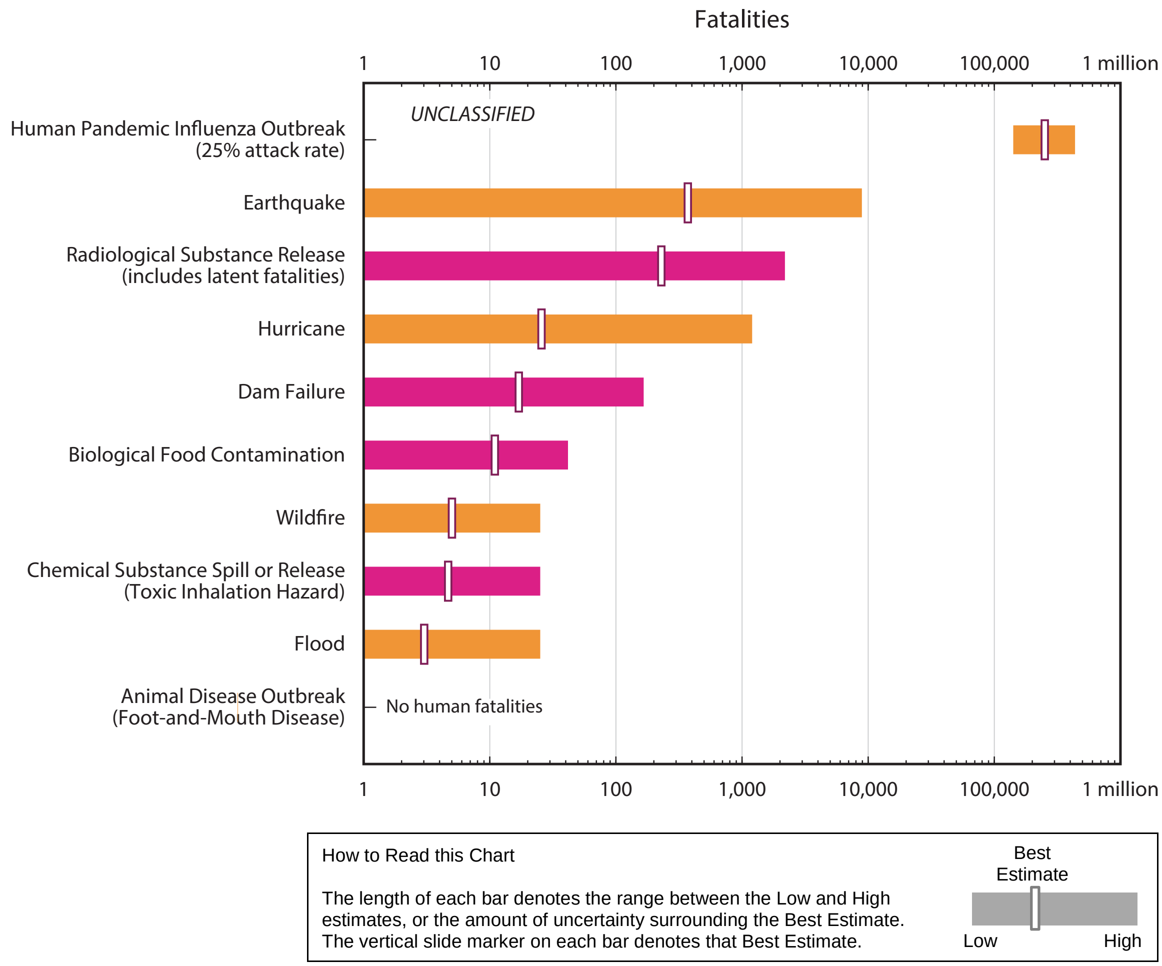


Table C1: SNRA Fatality Data and Sources

Threat/ Hazard Group	Threat/Hazard Type	Fatality Estimates		Source Information
Adversarial/ Human-Caused	Aircraft as a Weapon	Low		Fatality estimates constructed from SNRA project team analysis of historic events in which aircraft intentionally or unintentionally crashed into buildings or crowds of people. The 9/11 attacks in New York are used as a maximum case. The analysis does not take into account higher-consequence events which have not yet occurred.
		Best		
		High		
	Armed Assault	Low		Fatality estimates were calculated using historical data on armed assault events from the Global Terrorism database.[1,2]
		Best		
		High		
	Biological Terrorism Attack (non-food)	Low		Data reflects the 5th percentile, mean, and 95th percentile fatalities associated with events matching the SNRA definition of biological terrorism attacks (non-food) in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Fatality estimates in the SNRA include data for successful attacks, e.g., release of an agent.
		Best		
		High		
	Chemical Terrorism Attack (non-food)	Low		Data reflects the 5th percentile, mean, and 95th percentile fatalities associated with events matching the SNRA definition of chemical terrorism attacks (non-food) in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Fatality estimates in the SNRA include data for successful attacks, e.g., release of an agent.
		Best		
		High		
	Chemical/Biological Food Contamination Terrorism Attack	Low		Data reflects the 5th percentile, mean, and 95th percentile fatalities associated with events matching the SNRA definition of chemical/biological food contamination terrorism attacks (non-food) in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Fatality estimates in the SNRA include data for successful attacks, e.g., release of an agent.
		Best		
		High		
	Cyber Event affecting Data	Low	N/A	Additional analysis is necessary to quantify the fatalities caused by cyber events affecting data. Consequences for the types of attacks in this event category are difficult to quantify, as they depend upon the particular system attacked, the vulnerability and resilience of the network, specific data backup provisions, etc.
		Best	N/A	
		High	N/A	
	Cyber Event affecting Physical Infrastructure	Low	N/A	Additional analysis is required to quantify the fatalities caused by cyber events affecting physical infrastructure. Consequences for the types of attacks in this event category are sector dependent and difficult to quantify. Approximately 85% of critical infrastructure is owned and operated by the private sector, and system vulnerability and resilience is highly sector-dependent and localized. Only attacks resulting in 1 fatality or greater or \$100 Million in losses or greater were considered.
		Best	N/A	
		High	N/A	

Threat/ Hazard Group	Threat/Hazard Type	Fatality Estimates		Source Information
	Explosives Terrorism Attack	Low		Fatality estimates were calculated using historical data on explosives events from the Global Terrorism database.[3]
		Best		
		High		
	Nuclear Terrorism Attack	Low		Data reflects the 5th percentile, mean, and 95th percentile fatalities associated with events matching the SNRA definition of nuclear terrorism attacks in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Fatality estimates in the SNRA include data for successful attacks, e.g., detonation of a device.
		Best		
		High		
	Radiological Terrorism Attack	Low		Data reflects the 5th percentile, mean, and 95th percentile fatalities associated with events matching the SNRA definition of radiological terrorism attacks in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Fatality estimates in the SNRA include data for successful attacks, e.g., detonation of a device or radiation exposure.
		Best		
		High		
Technological/ Accidental	Biological Food Contamination	Low	0	Estimates were obtained from historic events in the CDC's Foodborne Outbreak Online Database (FOOD) which were multistate outbreaks requiring greater than 100 hospitalizations. Years included in FOOD include 1998-2008.[4]
		Best	11	
		High	42	
	Chemical Substance Spill or Release	Low	1	Estimates correspond to the low, average, and high fatalities reported per incident within the U.S. historic data set used for the SNRA analysis.[5]
		Best	5	
		High	25	
	Dam Failure	Low	1	Estimates correspond to the low, average, and high fatalities from U.S. dam failures causing 1 fatality or greater during the time period from 1960-2009.[6]
		Best	17	
		High	170	
	Radiological Substance Release	Low	0	Estimates are drawn from the historic case of Three Mile Island as well as license renewal applications available on the public website of the U.S. Nuclear Regulatory Commission.[7]
		Best	230	
		High	2,200	
Natural	Animal Disease Outbreak	Low	0	There are no significant human health implications of Foot-and-Mouth Disease (FMD), the animal disease considered in the SNRA.
		Best	0	
		High	0	
	Earthquake	Low	0	Estimates correspond to the low, average, and high fatalities from earthquakes causing greater than $100 M in damages from the U.S. historic events between 1906-2011.[8]
		Best	370	
		High	8,900	
	Flood	Low	0	Estimates correspond to the low, average, and high fatalities from floods causing greater than $100M in damages from the U.S. historic events between January 1, 1993 to December 31, 2005.[9]
		Best	3	
		High	25	
	Human Pandemic Outbreak	Low	140,000	Fatality estimates provided by CDC assuming a 25% gross clinical attack rate, using case fatality rates associated with the 1968-1969 Hong Kong flu pandemic.[10]
		Best	250,000	
		High	440,000	

Threat/ Hazard Group	Threat/Hazard Type	Fatality Estimates		Source Information
	Hurricane	Low	0	Estimates correspond to the low, average, and high fatalities from hurricanes causing greater than $100 M in damages from the U.S. historic events between 1970-2010.[11]
		Best	26	
		High	1,200	
	Space Weather	Low	N/A	Credible published estimates for the fatalities due to a space weather event were not found.
		Best	N/A	
		High	N/A	
	Tsunami	Low	1	Estimates were informed by FEMA HAZUS modeling of a tsunami wave of height 15 meters hitting the Oregon coast. It was assumed that 1% of the exposed population may be killed or injured, with 50% counted as killed and 50% counted as injured by the event.[12]
		Best	300	
		High	1,000	
	Volcanic Eruption	Low	340	Estimates were informed by the total population within an inundation zone for Case I Debris Flows near Mount Rainier, as well as the percentage of population killed during the 1980 Mt Saint Helens eruption.[13]
		Best	520	
		High	780	
	Wildfire	Low	0	Estimates correspond to the low, average, and high fatalities from wildfires causing greater than $100 M in damages from the U.S. historic events between 1990-2009.[14]
		Best	5	
		High	25	

[1] The Global Terrorism Database (GTD) is an open-source database including information on terrorism events around the world (including domestic, transnational, and international incidents) from 1970-2010. The GTD is an open-source database including information on terrorist events around the world (including domestic, transnational, and international incidents) from 1970 through 2010. For each GTD incident, information is available on the date and location of the incident, the weapons used and nature of the target, the number of casualties, and - when identifiable - the group or individual responsible. The GTD is maintained at the University of Maryland by the National Consortium for the Study of Terrorism and Responses to Terrorism (START), a DHS Center of Excellence. National Consortium for the Study of Terrorism and Responses to Terrorism (START), 2011. Global Terrorism Database [Data file]. Retrieved from: http://www.start.umd.edu/gtd.

[2] In order to identify events in the GTD database that were most comparable to the SNRA definition of Armed Assault, the following search criteria were used: Attack Type: Armed Assault or Bombing/Explosion; Weapon Type: Require Firearms; Exclude biological, chemical, radiological, nuclear; Terrorism Criteria: Require (a) The act must be aimed at attaining a political, economic, religious, or social goal, (b) There must be evidence of an intention to coerce, intimidate, or convey some other message to a larger audience (or audiences) than the immediate victims, (c) The action must be outside the context of legitimate warfare activities, i.e., the act must be outside the parameters permitted by international humanitarian law; Ambiguous cases, where there is a strong possibility, but not a certainty, that an incident represents an act of terrorism, were excluded; Unsuccessful attacks were excluded. Events that produced zero injuries and zero deaths were removed from the resulting set, in order to meet the SNRA national-level event threshold. All events involving vehicle borne explosives were also removed. The highest injury-producing event (10,000 injured in Peru) was considered an outlier and removed. Incidents that were part of multi-incident events were aggregated to produce more comprehensive injury/death totals. The resulting set included 10,161 incidents, which were then used to calculate the minimum, maximum, and mean, which are presented as low, high, and best estimates in the table above.

[3] In order to identify events in the GTD database that were most comparable to the SNRA definition of Explosives Terrorism Attack, the following search criteria were used: Attack Type: Bombing/Explosion; Weapon Type: Explosives/Bombs/Dynamite OR Incendiary; Terrorism Criteria: Require (a) The act must be aimed at attaining a political, economic, religious, or social goal, (b) There must be evidence of an intention to coerce, intimidate, or convey some other message to a larger audience (or audiences) than the immediate victims, (c) The action must be outside the context of legitimate warfare activities, i.e., the act must be outside the parameters permitted by international humanitarian law; Ambiguous cases, where there is a strong possibility, but not a certainty, that an incident represents an act of terrorism, were excluded; Unsuccessful attacks were excluded; Target Type: limited to Airports and Airlines, Business, Government (Diplomatic), Government (General), Military, Other, Telecommunication, Tourists, Transportation, Unknown, Utilities. Events that produced zero injuries and zero deaths were removed from the resulting set, in order to

meet the SNRA national-level event threshold. The resulting set was then used to calculate the minimum, maximum, and mean, which are presented as low, high, and best estimates in the table above.

[4] Centers for Disease Control and Prevention (CDC) Foodborne Outbreak Online Database (FOOD) is available online at http://www.cdc.gov/foodborneoutbreaks. Reported fatalities were adjusted to account for underreporting or underdiagnosis using the latest multipliers published by the CDC (a factor of 2 for fatalities). The low, best, and high fatality estimates represent the low, average, and high adjusted fatalities in the set of outbreaks meeting the multistate and 100+ reported hospitalizations thresholds. Scallan, E., Hoekstra, R. M., Angulo, F. J., Tauxe, R. V., Widdowson, M. –A., Roy, S. L., et al. (2011). Foodborne illness acquired in the United States – major pathogens. *Emerging Infectious Diseases*, 17(1), 7-15. Available from URL: http://www.cdc.gov/EID/content/17/1/7.htm. Accessed on 22 August 2011.

[5] The set of historic chemical substance release events used for analysis in the SNRA were those which met the following criteria: 1) at least one "public" fatality, defined as one fatality other or in addition to an employee fatality, caused by the hazardous material; or 2) at least one fatality of any kind caused by the hazardous material, plus a reported evacuation or shelter-in-place order. This set came from the set of all reported toxic inhalation hazard (TIH) incidents reported 1994-2010 to either the EPA's Risk Management Program (RMP) accident database for fixed industrial producers and consumers of the listed toxic chemicals above given threshold limits, or to the Department of Transportation's Pipeline and Hazardous Substances Administration (PHMSA)'s database of road, rail, water, and air transportation accidents.

[6] Historic data for U.S. dam failures were provided by the U.S. Bureau of Reclamation via the DHS Office of Infrastructure Protection Dams Sector Branch. Dam failures which were caused by cascading events (e.g., a failing dam upstream) were combined into single events.

[7] The low estimate of zero fatalities is drawn from the Three Mile Island core meltdown (Perham, C. (1980, October). EPA's Role at Three Mile Island. Retrieved from http://www.epa.gov/aboutepa/history/topics/tmi/02.html). The best estimate for fatalities uses a simulation of the expected core damage frequencies and expected consequences obtained from the license renewal applications for a number of individual reactors available from the public website of the U.S. Nuclear Regulatory Commission (NRC) at http://www.nrc.gov/reactors/operating/licensing/renewal/applications.html. The data from the license renewal applications is used to perform cost/benefit analyses on reactor upgrades and the baseline data was not developed for use in a general risk assessment. Currently, this is the most recently publicly available data and adequate for order of magnitude estimates in the SNRA. An alternative analysis was also conducted using fatality, injury, and core damage frequency data from NUREG-1150, and the best estimates from this analysis were within an order of magnitude of the results obtained using data from license renewal applications (U.S. Nuclear Regulatory Commission (1990). *NUREG-1150 Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants*. Washington, DC: U.S. NRC). The expected consequences are weighted by the likelihood of a core damage accident for each reactor using a Crystal Ball simulation to determine the best fatality estimate. The high consequence estimates also come from the license renewal applications; these consequences correspond to the highest consequence scenarios outlined in the report. These usually involve a large, early release and assume that there is not enough time for successful evacuation. The frequency of these events is typically one-to-two orders of magnitude less than the frequency of any core damage event. Note that the frequency values reported in Appendix B do not correspond to the high and low fatality estimates. The fatality estimates include latent cancer fatalities: deaths resulting from cancer that become active after a latent period following exposure to radiation.

[8] The U.S. historic earthquake record for events causing greater than $100 Million in damages was obtained from the published report by Vranes, K. and Pielke, R. (2009). Normalized earthquake damage and fatalities in the United States: 1900-2005. *Natural Hazards Review* 10(3), 84:101. Normalized fatality estimates take into account changes in population densities, community wealth, mitigation factors (such as improved building codes and emergency response), and inflation. A 1% annual mitigation factor was used, as described in Vranes and Pielke (2009).

[9] The U.S. historic flood record for events causing greater than $100 Million in damages was obtained by aggregating flood losses reported by NOAA's National Climactic Data Center (NCDC). Modern flood reporting by NOAA relies on many individual reports that assess damages in a specific area of responsibility. A large scale flood, for example, can result in dozens or hundreds of damage entries that assess damages for specific geographic regions. As flooding passes down the Mississippi, for example, the affected areas can pass from region to region. To capture the transient and distributed nature of flood events, individual flood loss reports were aggregated based on distance and time. Flood damage reports that occurred within 100 miles of one another and within plus or minus one calendar day were aggregated into composite flood events. The composite flood events above the $100 Million (2011 dollar) threshold were used for reporting frequency, fatality, injury, and direct economic loss estimates in the SNRA. All hurricanes were removed from flood events to avoid double-counting flooding damages included in the SNRA hurricane analysis.

[10] Expert judgments provided by CDC subject matter experts to the SNRA project, and informed by similar scenario assumptions and modeling as was used for the National Strategy for Pandemic Influenza and the National Planning Scenarios. All of the estimates are given absent any intervention (i.e., before interventions are applied or attempted).

[11] U.S. historic hurricane record for events causing greater than $100 Million in damages was obtained from the ICAT Damage Estimator (http://www.icatdamageestimator.com), which uses a methodology for computing economic losses similar to that published by Pielke, R.J., Gratz, J., Landsea, C., Collins, D., Saunders, M., and Musulin, R. (2008). Normalized hurricane damage in the United States: 1900-2005. *Natural Hazards Review* 9 (1), 29-42. Fatality estimates are based

directly upon the historic record, published by Blake, E.S., Landsea, C.W., and Gibnew, E.J. (2011, August). *The deadliest, costliest, and most intense United States tropical cyclones from 1851-2010 (and other frequently requested hurricane facts)*. Miami, FL: National Climactic Data Center, National Hurricane Center.

[12] Fatalities were expected to occur in areas that do not receive a warning in time, communities not trained in evacuation, flat areas where no evacuation routes exist, and for persons who do not obey orders or who happen to be in vulnerable areas with no warning systems.

[13] For the low estimate of volcanic eruption fatalities, the total population within lahar hazard areas near Mount Rainier was calculated using a GIS shape file representing the Inundation Zones for Case I Debris Flows. Such zones represent areas that could be affected by cohesive debris flow that originates as enormous avalanches of weak chemically altered rock from the volcano. (Digital Data for Volcano Hazards from Mount Rainier, Washington Revised 1998: Data to accompany U.S. Geological Survey Open-File Report 98-428; USGS; 2007.) For the high estimate of volcanic eruption fatalities, a multiplier of 1% of the total population surrounding Mount Rainier was used, informed by the percentage of the population killed during the 1980 Mount Saint Helens eruption. (USGS Cascades Volcano Observatory, Vancouver, Washington Mount St. Helens “On This Day in 1980” October 6, 1980 http://vulcan.wr.usgs.gov/Volcanoes/MSH/May18/OnThisDay1980/Days/1980October06.html.) The best estimate is the geometric mean of the low and high estimates.

[14] The U.S. historic wildfire record for events causing greater than $100 Million in damages was compiled from the SHELDUS database (Hazards & Vulnerability Research Institute (2011). The Spatial Hazards Events and Losses Database for the United States, Version 8.0 [Online Database]. Columbia, SC: University of South Carolina. Available from http://www.sheldus.org). SHELDUS breaks down wildfire events into separate counties, and sometimes breaks down single wildfires in the same location into separate fires with overlapping date ranges, dividing casualty and damages between them to avoid double-counting. Where this was obviously done (fires reported by counties in the same state having the same time range, or reported in the same city with overlapping or continuously adjacent time ranges) the separately reported portions of a single fire event were consolidated into single events. All wildfires (after consolidation) above the $100 Million threshold in 2011 dollars (a CPI multiplier of 1.0464 was used to convert the December 2009 values given in SHELDUS v8.0 to May 2011 values) from 1970-2009 were used in the SNRA analysis.

APPENDIX D: INJURY/ILLNESS CONSEQUENCE ASSESSMENT

Note that all comparative statements are made within the set of natural and technological hazards treated by this unclassified adaptation of the SNRA Technical Report.

Overview

Injuries and illnesses were estimated similarly to fatalities. For events that have occurred in the past, the number of fatalities was estimated primarily from the historical record. For events that have never occurred, primarily but not limited to the adversarial events, consequences were estimated using data from previous DHS risk assessments which rely on models and simulations.

It is important to note that this consequence category mixed permanent debilitating injuries (such as those resulting from chemical accidents) with temporary illnesses (such as those resulting from pandemic influenza). Therefore, the injury and illness consequences should be considered in context with the types of injuries and illnesses likely to result from each hazard.

When interpreting the injury/illness results presented below, it is important to consider that the consequence data in the SNRA is directly related to the threshold included in each national-level event definition. For example, the results for wildfires indicate that *wildfires causing greater than $100 million in direct economic losses* are estimated to cause between 0 and 190 injuries, with a best estimate of 63 fatalities. For reference, the full national-level event definitions, including thresholds, can be found in Table 2 of the main report.

In many cases, the high estimates for injuries/illnesses in the SNRA were constructed from either historic maximums (e.g. natural hazards) or the 95th percentile of a modeled distribution (e.g. terrorism events). Thus, the high estimates associated with each national-level event may not be reflective of the injuries/illnesses which may occur from a “worst-case scenario”. Additional analysis is necessary to better characterize the “worst-case” upper bounds for injuries/illnesses associated with each national-level event.

Major Findings

- At the best estimate, a pandemic influenza outbreak with a 25% gross clinical attack rate and a case fatality rate similar to the 1968-1969 Hong Kong flu pandemic is estimated to result in the most injuries/illnesses given occurrence of any of the non-adversarial events in the SNRA by more than a factor of one hundred. Such a pandemic influenza outbreak is estimated to cause between 62 million and 110 million illnesses, with a best estimate of 72 million illnesses. These estimates are given absent any intervention (i.e., before interventions are applied or attempted).
- After pandemic influenza, the non-adversarial events in the SNRA with the highest expected illnesses or injuries (at the best estimate) given occurrence include accidental food contamination and earthquakes.
    - The expected injuries/illnesses due to an earthquake are assessed to be of comparable order of magnitude (tens of thousands of injuries) as the accidental biological food contamination event, at the best estimate.
- All natural and technological hazard events in the SNRA are expected to result in non-zero injuries/illnesses, at the best estimate, with the exception of foot-and-mouth disease (FMD) which affects livestock but poses no health risk to humans.

Additional Information

Injury/illness information of sufficient quality upon which to base comparisons could not be found for every national-level event.

- *Tsunami:* FEMA HAZUS modeling of a tsunami wave hitting the Oregon coast with height 15 meters resulted in estimates ranging from one to 1000 injuries.
- *Volcanic Eruption:* FEMA analysis of the areal extent of lahar flow and atmospheric dispersal of ash from an eruption of Mount Rainier results in estimates ranging from 2,000 to 150,000 injuries.
- *Cyber Events and Space Weather:* Additional analysis is necessary to quantify the injuries/illnesses which might result from these events.

Figure D1: Injuries/Illnesses by National-level Event

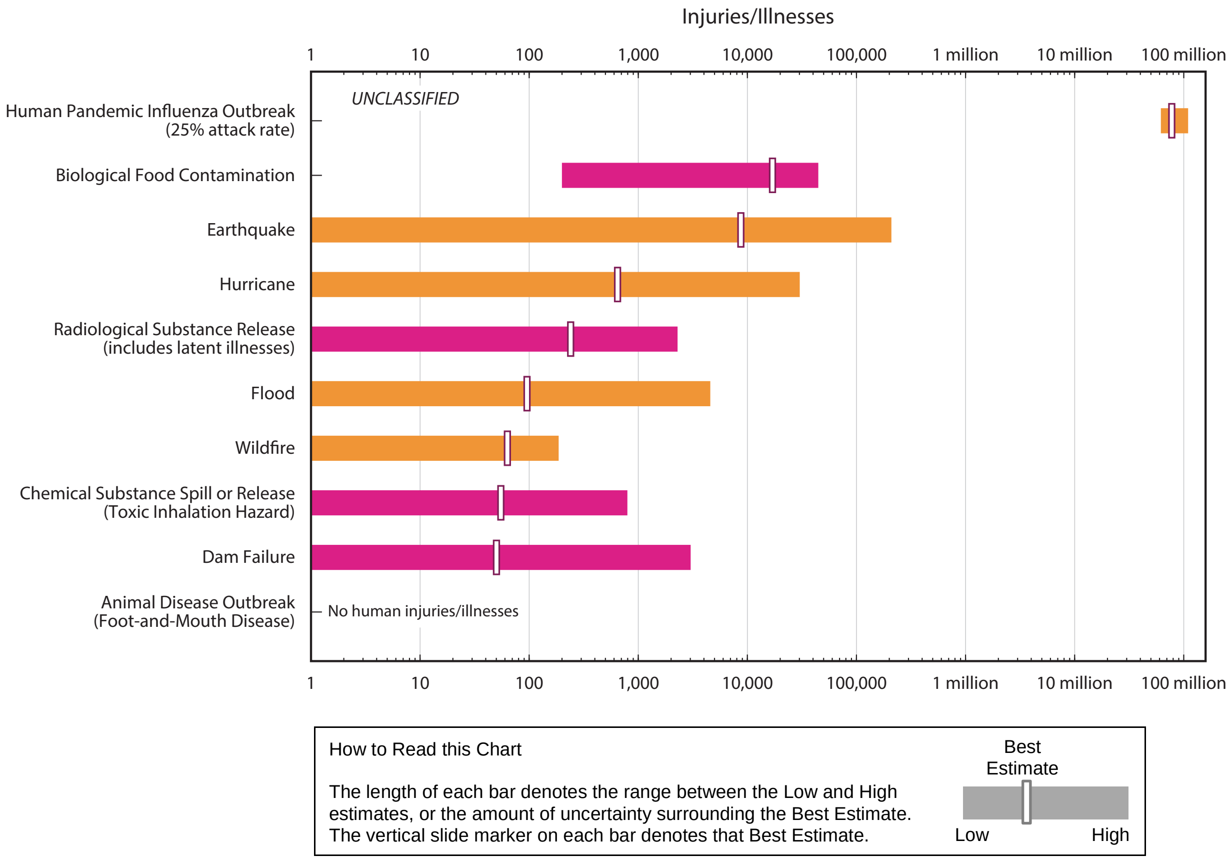


Table D1: SNRA Injury/Illness Data and Sources

Threat/ Hazard Group	Threat/Hazard Type	Injury/Illness Estimates		Source Information
Adversarial/ Human-Caused	Aircraft as a Weapon	Low		Injury estimates constructed from SNRA project team analysis of historic events in which aircraft intentionally or unintentionally crashed into buildings or crowds of people. The 9/11 attacks in New York are used as a maximum case. The analysis does not take into account higher-consequence events which have not yet occurred.
		Best		
		High		
	Armed Assault	Low		Injury estimates were calculated using historical data on armed assault events from the Global Terrorism database.[1,2]
		Best		
		High		
	Biological Terrorism Attack (non-food)	Low		Data reflects the 5th percentile, mean, and 95th percentile injuries/illnesses associated with events matching the SNRA definition of biological terrorism attacks (non-food) in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Injury/illness estimates in the SNRA include data for successful attacks, e.g., release of an agent.
		Best		
		High		
	Chemical Terrorism Attack (non-food)	Low		Data reflects the 5th percentile, mean, and 95th percentile injuries/illnesses associated with events matching the SNRA definition of chemical terrorism attacks (non-food) in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Injury/illness estimates in the SNRA include data for successful attacks, e.g., release of an agent.
		Best		
		High		
	Chemical/Biological Food Contamination Terrorism Attack	Low		Data reflects the 5th percentile, mean, and 95th percentile injuries/illnesses associated with events matching the SNRA definition of chemical/ biological food contamination terrorism attacks in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Injury/illness estimates in the SNRA include data for successful attacks, e.g., release of an agent.
		Best		
		High		
	Cyber Event affecting Data	Low	N/A	Additional analysis is necessary to quantify the injuries/illnesses caused by cyber events affecting data. Consequences for the types of attacks in this event category are difficult to quantify, as they depend upon the particular system attacked, the vulnerability and resilience of the network, specific data backup provisions, etc.
		Best	N/A	
		High	N/A	
	Cyber Event affecting Physical Infrastructure	Low	N/A	Additional analysis is required to quantify the injuries/illnesses caused by cyber events affecting physical infrastructure. Consequences for the types of attacks in this event category are sector dependent and difficult to quantify. Approximately 85% of critical infrastructure is believed to be owned and operated by the private sector, and system vulnerability and resilience is highly sector-dependent and localized.[3]
		Best	N/A	
		High	N/A	

Threat/ Hazard Group	Threat/Hazard Type	Injury/Illness Estimates		Source Information
	Explosives Terrorism Attack	Low		Injury/illness estimates were calculated using historical data on explosives events from the Global Terrorism database.[4]
		Best		
		High		
	Nuclear Terrorism Attack	Low		Data reflects the 5th percentile, mean, and 95th percentile injuries/illnesses associated with events matching the SNRA definition of nuclear terrorism attacks in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Injury/illness estimates in the SNRA include data for successful attacks, e.g., detonation of a device.
		Best		
		High		
	Radiological Terrorism Attack	Low		Data reflects the 5th percentile, mean, and 95th percentile injury/illness estimates associated with events matching the SNRA definition of radiological terrorism attacks in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Injury/illness estimates in the SNRA include data for successful attacks, e.g., detonation of a device or radiation exposure.
		Best		
		High		
Technological/ Accidental	Biological Food Contamination	Low	200	Estimates obtained from historic events in the CDC's Foodborne Outbreak Online Database (FOOD) which were multistate outbreaks requiring greater than 100 hospitalizations. Years included in FOOD include 1998-2008.[5]
		Best	17,000	
		High	45,000	
	Chemical Substance Spill or Release	Low	0	Estimates correspond to the low, average, and high injuries/illnesses reported per incident within the U.S. historic data set used for the SNRA analysis.[6]
		Best	60	
		High	790	
	Dam Failure	Low	0	Estimates correspond to reported injuries from U.S. dam failures causing 1 fatality or greater during the time period from 1960-2009, for which injury reporting was available.[7]
		Best	50	
		High	3,000	
	Radiological Substance Release	Low	0	Estimates are drawn from the historic case of Three Mile Island as well as license renewal applications available on the public website of the U.S. Nuclear Regulatory Commission.[8]
		Best	240	
		High	2,300	
Natural	Animal Disease Outbreak	Low	0	There are no significant human health implications of Foot-and-Mouth Disease (FMD), the animal disease considered in the SNRA.
		Best	0	
		High	0	
	Earthquake	Low	0	Estimates correspond to the low, average, and high injuries from earthquakes causing greater than $100 M in damages from the U.S. historic events between 1906-2011.[9]
		Best	8,700	
		High	210,000	
	Flood	Low	0	Estimates correspond to the low, average, and high injuries from floods causing greater than $100M in damages from the U.S. historic events between January 1, 1993 to December 31, 2005.[10]
		Best	95	
		High	4,500	

Threat/ Hazard Group	Threat/Hazard Type	Injury/Illness Estimates		Source Information
	Human Pandemic Outbreak	Low	62 Million	Illness estimates provided by CDC assuming a 25% gross clinical attack rate, using the case fatality rate associated with the 1968-1969 Hong Kong flu pandemic.[11]
		Best	77 Million	
		High	110 Million	
	Hurricane	Low	0	Estimates correspond to the low, average, and high injuries from hurricanes causing greater than $100 M in damages from the U.S. historic events between 1970-2010.[12]
		Best	650	
		High	30,000	
	Space Weather	Low	N/A	Credible published estimates for the injuries/illnesses due to a space weather event were not found.
		Best	N/A	
		High	N/A	
	Tsunami	Low	1	Estimates were informed by FEMA HAZUS modeling of a tsunami wave of height 15 meters hitting the Oregon coast. It was assumed that 1% of the exposed population may be killed or injured, with 50% counted as killed and 50% counted as injured by the event.[13]
		Best	300	
		High	1,000	
	Volcanic Eruption	Low	2,000	Estimates were informed by the population in the State of Washington Census tracts immediately surrounding Mount Rainier, as well as those susceptible to a potential 60-mile radius ash cloud from Mount Rainier.[14]
		Best	17,000	
		High	150,000	
	Wildfire	Low	0	Estimates correspond to the low, average, and high injuries from wildfires causing greater than $100 M in damages from the U.S. historic events between 1990-2009.[15]
		Best	63	
		High	190	

[1] The Global Terrorism Database (GTD) is an open-source database including information on terrorism events around the world (including domestic, transnational, and international incidents) from 1970-2010. The GTD is an open-source database including information on terrorist events around the world (including domestic, transnational, and international incidents) from 1970 through 2010. For each GTD incident, information is available on the date and location of the incident, the weapons used and nature of the target, the number of casualties, and - when identifiable - the group or individual responsible. The GTD is maintained at the University of Maryland by the National Consortium for the Study of Terrorism and Responses to Terrorism (START), a DHS Center of Excellence. National Consortium for the Study of Terrorism and Responses to Terrorism (START), 2011. Global Terrorism Database [Data file]. Retrieved from: http://www.start.umd.edu/gtd.

[2] In order to identify events in the GTD database that were most comparable to the SNRA definition of complex attack, the following search criteria were used: Attack Type: Armed Assault or Bombing/Explosion; Weapon Type: Require Firearms; Exclude biological, chemical, radiological, nuclear; Terrorism Criteria: Require (a) The act must be aimed at attaining a political, economic, religious, or social goal, (b) There must be evidence of an intention to coerce, intimidate, or convey some other message to a larger audience (or audiences) than the immediate victims, (c) The action must be outside the context of legitimate warfare activities, i.e., the act must be outside the parameters permitted by international humanitarian law; Ambiguous cases, where there is a strong possibility, but not a certainty, that an incident represents an act of terrorism, were excluded; Unsuccessful attacks were excluded. Events that produced zero injuries and zero deaths were removed from the resulting set, in order to meet the SNRA national-level event threshold. All events involving vehicle borne explosives were also removed. The highest injury-producing event (10,000 injured in Peru) was considered an outlier and removed. Incidents that were part of multi-incident events were aggregated to produce more comprehensive injury/death totals. The resulting set included 10,161 incidents, which were then used to calculate the minimum, maximum, and mean, which are presented as low, high, and best estimates in the table above.

[3] Office of Infrastructure Protection, Department of Homeland Security: http://www.dhs.gov/files/partnerships/editorial_0206.shtm.

[4] In order to identify events in the GTD database that were most comparable to the SNRA definition of Explosives Terrorism Attack, the following search criteria were used: Attack Type: Bombing/Explosion; Weapon Type: Explosives/Bombs/Dynamite OR Incendiary; Terrorism Criteria: Require (a) The act must be aimed at attaining a

political, economic, religious, or social goal, (b) There must be evidence of an intention to coerce, intimidate, or convey some other message to a larger audience (or audiences) than the immediate victims, (c) The action must be outside the context of legitimate warfare activities, i.e., the act must be outside the parameters permitted by international humanitarian law; Ambiguous cases, where there is a strong possibility, but not a certainty, that an incident represents an act of terrorism, were excluded; Unsuccessful attacks were excluded; Target Type: limited to Airports and Airlines, Business, Government (Diplomatic), Government (General), Military, Other, Telecommunication, Tourists, Transportation, Unknown, Utilities. Events that produced zero injuries and zero deaths were removed from the resulting set, in order to meet the SNRA national-level event threshold. The resulting set was then used to calculate the minimum, maximum, and mean, which are presented as low, high, and best estimates in the table above.

[5] The Centers for Disease Control and Prevention (CDC) Foodborne Outbreak Online Database (FOOD) is available online at http://www.cdc.gov/foodborneoutbreaks. Reported illnesses were adjusted to account for underreporting or underdiagnosis using the latest multipliers published by the CDC (26.1 for *STEC O157 [E. coli]*, 29.3 for *Salmonella spp., nontyphoidal*, 2.1 for *Listeria monocytogenes*). Scallan, E., Hoekstra, R. M., Angulo, F. J., Tauxe, R. V., Widdowson, M. –A., Roy, S. L., et al. (2011). Foodborne illness acquired in the United States – major pathogens. *Emerging Infectious Diseases*, 17(1), 7-15. Available from URL: http://www.cdc.gov/EID/content/17/1/7.htm. Accessed on 22 August 2011.

[6] The set of historic chemical substance release events used for analysis in the SNRA were those which met the following criteria: 1) at least one "public" fatality, defined as one fatality other or in addition to an employee fatality, caused by the hazardous material; or 2) at least one fatality of any kind caused by the hazardous material, plus a reported evacuation or shelter-in-place order. This set came from the set of all reported toxic inhalation hazard (TIH) incidents reported 1994-2010 to either the EPA's Risk Management Program (RMP) accident database for fixed industrial producers and consumers of the listed toxic chemicals above given threshold limits, or to the Department of Transportation's Pipeline and Hazardous Substances Administration (PHMSA)'s database of road, rail, water, and air transportation accidents.

[7] Historic data for U.S. dam failures were provided by the U.S. Bureau of Reclamation via the DHS Office of Infrastructure Protection Dams Sector Branch. Dam failures which were caused by cascading events (e.g., a failing dam upstream) were combined into single events. Injuries were not reported in this dataset and were obtained separately for a limited set of dam failures. Of this set, the low number of injuries was 2 (Bergeron Pond Dam failure, New Hampshire, 1996; http://www.uswaternews.com/archives/arcsupply/6newhamp.html) and the high number of injuries was 3000 (Canyon Lake Dam, South Dakota, 1972; http://www.damsafety.org/media/Documents/PRESS/US_FailuresIncidents(1).pdf). It was assumed that a reasonable low estimate for injuries was 1 and the high estimate of 3000 was used. The best estimate used in the SNRA is the geometric mean of the low and high estimates. Injury reports for additional dams suggest that such an assumption may be warranted; reports of injuries numbering less than 10 were found for some dam failures, as well as reports of injuries greater than 800 for other dam failures.

[8] The low estimate of zero injuries/illnesses is drawn from the Three Mile Island core meltdown (Perham, C. (1980, October). EPA's Role at Three Mile Island. Retrieved from http://www.epa.gov/aboutepa/history/topics/tmi/02.html.) The best estimate for injuries/illnesses uses a simulation of the expected core damage frequencies and expected consequences obtained from the license renewal applications for a number of individual reactors available from the public website of the U.S. Nuclear Regulatory Commission (NRC) at http://www.nrc.gov/reactors/operating/licensing/renewal/applications.html. The data from the license renewal applications is used to perform cost/benefit analyses on reactor upgrades and the baseline data was not developed for use in a general risk assessment. Currently, this is the most recently publicly available data and adequate for order of magnitude estimates in the SNRA. An alternative analysis was also conducted using fatality, injury, and core damage frequency data from NUREG-1150, and the best estimates from this analysis were within an order of magnitude of the results obtained using data from license renewal applications (U.S. Nuclear Regulatory Commission (1990). *NUREG-1150 Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants*. Washington, DC: U.S. NRC). The expected consequences are weighted by the likelihood of a core damage accident for each reactor using a Crystal Ball simulation to determine the best injury/illness estimate. The high consequence estimates also come from the license renewal applications; these consequences correspond to the highest consequence scenarios outlined in the report. These usually involve a large, early release and assume that there is not enough time for successful evacuation. The frequency of these events is typically one-to-two orders of magnitude less than the frequency of any core damage event. Note that the frequency values reported in Appendix B do not correspond to the high and low injury/illness estimates. The injury/illness estimates include latent cancer morbidities.

[9] The U.S. historic earthquake record for events causing greater than $100 Million in damages was obtained from the published report by Vranes, K. and Pielke, R. (2009). Normalized earthquake damage and fatalities in the United States: 1900-2005. *Natural Hazards Review* 10(3), 84:101. Normalized consequence estimates take into account changes in population densities, community wealth, mitigation factors (such as improved building codes and emergency response), and inflation. A 1% annual mitigation factor was used, as described in Vranes & Pielke (2009). Since published normalized injury estimates were not available, a linear multiplier of the normalized fatalities reported by Vranes *et al* was used; this was deemed of sufficient precision for the purposes of the SNRA. The linear model assumed 23.5 injuries per fatality, based on New Madrid Seismic Zone estimates published by Elnashai et al. (2009), *Impact of New Madrid Seismic Zone earthquakes on the Central USA, Vol. 1*. Mid America Earthquake Center: University of Illinois. Available online at: http://hdl.handle.net/2142/14810.

[10] The U.S. historic flood record for events causing greater than $100 Million in damages was obtained by aggregating flood losses reported by NOAA's National Climactic Data Center (NCDC). Modern flood reporting by NOAA relies on many individual reports that assess damages in a specific area of responsibility. A large scale flood, for example, can result in dozens or hundreds of damage entries that assess damages for specific geographic regions. As flooding passes down the Mississippi, for example, the affected areas can pass from region to region. To capture the transient and distributed nature of flood events, individual flood loss reports were aggregated based on distance and time. Flood damage reports that occurred within 100 miles of one another and within plus or minus one calendar day were aggregated into composite flood events. The composite flood events above the $100 Million (2011 dollar) threshold were used for reporting frequency, fatality, injury, and direct economic loss estimates in the SNRA. All hurricanes were removed from flood events to avoid double-counting flooding damages included in the SNRA hurricane analysis.

[11] Expert judgments provided by CDC subject matter experts to the SNRA project, and informed by similar scenario assumptions and modeling as was used for the National Strategy for Pandemic Influenza and the National Planning Scenarios. The central estimate of 77 million is tied to the 25% attack rate of the scenario (25% of the 2009 U.S. population of 307 million falls clinically ill at the best estimate). All of the estimates are given absent any intervention (i.e., before interventions are applied or attempted).

[12] U.S. historic hurricane record for events causing greater than $100 Million in damages was obtained from the ICAT Damage Estimator (http://www.icatdamageestimator.com), which uses a methodology for computing economic losses similar to that published by Pielke, R.J., Gratz, J., Landsea, C., Collins, D., Saunders, M., and Musulin, R. (2008). Normalized Hurricane Damage in the United States: 1900-2005. *Natural Hazards Review* 9: 29-42. Injury/illness estimates were produced for each hurricane based on a linear model relating fatalities to injury and illness. The model is derived from Hurricane Andrew in 1992; the CDC published injury/illness and fatality estimates for 19 parishes during Andrew and there were approximately 25 injuries to every fatality in the study group (CDC (1993). Injuries and Illnesses Related to Hurricane Andrew – Louisiana, 1992. *Morbidity and Mortality Weekly Report (MMWR)*, 42, 243-246.). It is important to note that evacuees can travel hundreds of miles before receiving medical attention, making it difficult to account for the number of storm-related injuries (Faul, M., Weller, N. F., and Jones, J. A. (2011, September). Injuries after Hurricane Katrina among Gulf Coast Evacuees Sheltered in Houston, Texas. *Journal of Emergency Nursing*, 37 (5), 460-468.

[13] Injuries were expected to occur in areas that do not receive a warning in time, communities not trained in evacuation, flat areas where no evacuation routes exist, and for persons who do not obey orders or who happen to be in vulnerable areas with no warning systems.

[14] For the low estimate of injuries/illnesses due to volcanic eruption, the population in the State of Washington U.S. Census tracts immediately surrounding Mt. Rainier was used. Approximately 20,000 people live in the surrounding Census tracts, and it was assumed that 10% of this population would be vulnerable to injury or illness as a result of ashfall. (10% figure: Blong, R. J. (1984). *Volcanic hazards: a sourcebook on the effects of eruptions*. Australia: Academic Press, p. 424. Population estimates were constructed using U.S. Census Data obtained from http://factfinder2.census.gov, accessed on September 18, 2011.) For the high estimate of injuries/illnesses due to volcanic eruption, a 60-mile radius ashfall centered at Mount Rainier was overlaid on 2000 U.S. Census block data. 1.5 million people were estimated to live within this radius, and it was assumed that 10% of this population would be susceptible to injury/illness from ashfall (see Blong (1984) reference above). The best estimate is the geometric mean of the low and high estimates.

[15] The U.S. historic wildfire record for events causing greater than $100 Million in damages was compiled from the SHELDUS database (Hazards & Vulnerability Research Institute (2011). The Spatial Hazards Events and Losses Database for the United States, Version 8.0 [Online Database]. Columbia, SC: University of South Carolina. Available from http://www.sheldus.org). SHELDUS breaks down wildfire events into separate counties, and sometimes breaks down single wildfires in the same location into separate fires with overlapping date ranges, dividing casualty and damages between them to avoid double-counting. Where this was obviously done (fires reported by counties in the same state having the same time range, or reported in the same city with overlapping or continuously adjacent time ranges) the separately reported portions of a single fire event were consolidated into single events. All wildfires (after consolidation) above the $100 Million threshold in 2011 dollars (a CPI multiplier of 1.0464 was used to convert the December 2009 values given in SHELDUS v8.0 to May 2011 values) from 1970-2009 were used in the SNRA analysis.

APPENDIX E: DIRECT ECONOMIC CONSEQUENCE ASSESSMENT

Note that all comparative statements are made within the set of natural and technological hazards treated by this unclassified adaptation of the SNRA Technical Report.

Overview

The direct economic losses associated with each national-level event were estimated in the SNRA. Direct costs include:

- *Decontamination, Disposal, and Physical Destruction:* DDP costs covered the repair, replacement, and environmental clean-up costs. It was assumed that the government would recoup this spending through tax increases, causing a reduction of household spending of that same amount. However, this spending would be received as income by some sectors, such as waste management and environmental consulting services. The increase in spending into the waste management and environmental consulting services sectors is treated as increase in annual output for these sectors.
- *Business Interruption:* Business interruption impacts considered losses due to decreased output at the target area, along with other increases and decreases to related sectors due to behavioral changes resulting from the event.
- *Loss in Spending from Fatalities:* A loss in spending of $42,500 was estimated for each fatality. In addition, $6,000 was included as increased output for mortuary services for each fatality.[1]
- *Medical Costs:* Costs of medical mitigation were considered to be borne through private spending and insurance companies, while the hospital sector received an offsetting increase in output.

For each national-level event, an attempt was made to assess each of the above types of direct costs. In some cases, this was not possible or it was judged that one type of direct costs would dominate the others such that the other types of direct costs were assumed to be negligible. In other cases, economic analysis from previous assessments or studies was leveraged for the SNRA even though the methodology for calculating direct costs differed somewhat from what is listed above. Details of the assumptions and approach used to estimate direct costs for each national-level event are provided in Table E1.

Due to time and resource constraints on the execution of the SNRA, indirect and induced economic impacts, which are often larger than direct losses, are not included in this assessment. This is a serious limitation that will be corrected in a future iteration of the SNRA. Indirect economic impacts include costs incurred by the suppliers and vendors in the associated expenditure sectors for the industries impacted by the direct costs above. Induced costs include those incurred due to reduced spending by households with members employed in any of the directly or indirectly affected industries. Induced costs can also include substitution effects or likely transfers of economic activity from one set of sectors to another set, such as avoidance of air or other travel or altered transportation mode preferences to other sectors following an attack on the commercial air transport sector.

[1] These figures were chosen for consistency with the 2011 ITRA. DHS Directorate of Science & Technology (2011), Integrated CBRN Terrorism Risk Assessment (reference is SECRET/NOFORN; extracted information is UNCLASSIFIED).

When interpreting the direct economic loss results presented below, it is important to consider that the consequence data in the SNRA is directly related to the threshold included in each national-level event definition. For example, the results for wildfires indicate that *wildfires causing greater than $100 million in direct economic losses* are estimated to cause between $100 million and $3 billion in direct losses, with a best estimate of $800 million. For reference, the full national-level event definitions, including thresholds, can be found in Table 2 of the main report.

In many cases, the high estimates for direct economic losses in the SNRA were constructed from either historic maximums (e.g. natural hazards) or the 95th percentile of a modeled distribution (e.g. terrorism events). Thus, the high estimates associated with each national-level event may not be reflective of the direct economic losses which may occur from a "worst-case scenario". Additional analysis is necessary to characterize the "worst-case" upper bounds for direct economic losses associated with each national-level event.

Major Findings

- When considering the SNRA economic findings, it is important to remember that the direct economic losses are often dwarfed by the indirect and induced economic losses that occur in the aftermath of an event. The direct economic losses alone do not represent the full picture of the economic impacts to the Nation given the occurrence of a national-level event.
- The event among the natural and technological hazards treated by the SNRA having the highest direct economic losses given occurrence is a pandemic influenza outbreak with a 25% gross clinical attack rate and a case fatality rate similar to the 1968-1969 Hong Kong flu pandemic.
    - Such a pandemic influenza outbreak is estimated to cause between $85 billion and $255 billion in direct economic losses, with a best estimate of $170 billion.
- Many events in the SNRA have best estimates for direct economic losses on the order of $10 billion, including foot-and-mouth disease ($15B), earthquakes ($9B), accidental radiological substance releases ($9B), and hurricanes ($6B). However, the uncertainty and variability associated with the direct economic losses for each of these events varies significantly.
    - The uncertainty and variability associated with accidental radiological substance releases and foot-and-mouth disease is approximately a factor of ten and one hundred, respectively.
    - The uncertainty and variability associated with earthquakes and hurricanes is approximately a factor of one thousand.
- The following events have best estimates for direct economic losses which are $1 billion or less, with associated high estimates less than $20 billion: wildfires, floods, and accidental chemical substance releases (toxic inhalation hazards). Even though these events are estimated to have comparatively lower direct economic losses given occurrence, extreme cases of these events could still result in relatively significant losses.

Additional Information

Direct economic loss information of sufficient quality upon which to base comparisons could not be found for every national-level event. Source documents for the events discussed below are provided in the annotations to Table E1.

- *Space Weather:* Additional analysis is needed to better quantify the direct economic losses which may be caused due to a space weather event which disrupts power to a significant portion of the United States for months to years. The August 2003 blackout in the Eastern U.S. caused an estimated $4-10 billion in economic losses; this blackout was smaller in extent than the estimate for a national-level space weather event and was only hours to days in duration. One published estimate suggests that a space weather event could cause $1-2 trillion in the first year after the event, with a potential total duration of 4-10 years.

- *Tsunami:* FEMA HAZUS modeling of a tsunami wave hitting the Oregon coast with height 13 to 17 meters resulted in direct economic loss estimates ranging from $700 million to $3 billion. Costs are dominated by building losses.
- *Volcanic Eruption:* FEMA and USGS analysis estimates the direct economic impacts of an eruption of Mount Rainer to range from $4 billion to $16 billion.
- *Dam Failure:* Additional analysis is required to estimate the direct economic impacts of dam failure. Studies of some specific dams have estimated economic impacts in the hundreds of millions to billions of dollars, but may not be representative of the full set of dams in the United States.
- *Accidental Biological Food Contamination:* Additional analysis is required to estimate the direct economic impacts of accidental biological food contamination. Estimates for lost productivity and medical costs in the CDC's Foodborne Outbreak Online Database (FOOD) range from $3-11 million, but business interruption costs could be found only for the 2006 *E. coli* – spinach outbreak ($61.4 million).
- *Cyber Events:* The potential economic consequences of cyber events are sector-dependent and difficult to quantify.

Figure E1: Direct Economic Loss by National-level Event

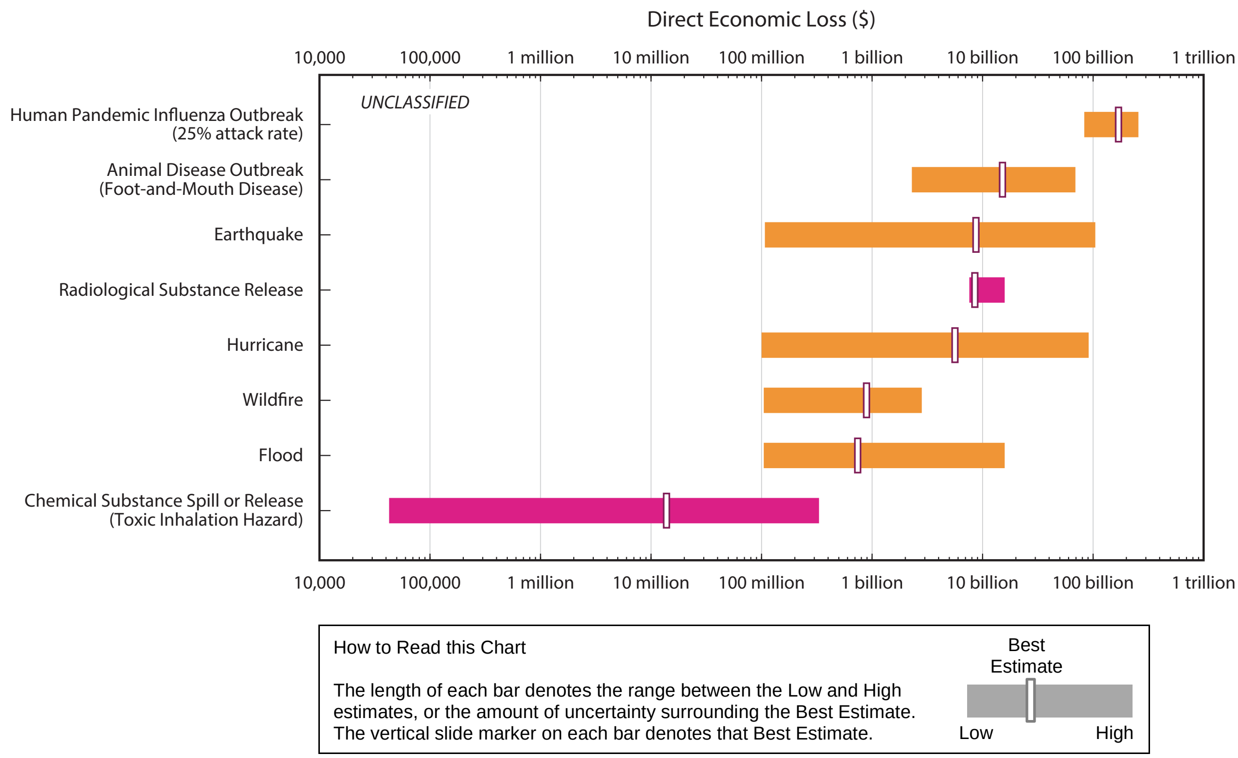


Table E1: SNRA Direct Economic Loss Data and Sources

Threat/ Hazard Group	Threat/Hazard Type	Direct Economic Loss Estimates ($ Millions)		Source Information
Adversarial/ Human-Caused	Aircraft as a Weapon	Low		Direct economic costs were estimated using the 2010 DHS RAPID methodology for the economic consequences of explosives/kinetic/incendiary (EKI) events.[1]
		Best		
		High		
	Armed Assault	Low		Direct economic costs were estimated using an approach similar to the 2010 DHS RAPID methodology for the economic consequences of explosives/kinetic/incendiary (EKI) events.[2]
		Best		
		High		
	Biological Terrorism Attack (non-food)	Low		Data reflects the 5th percentile, mean, and 95th percentile direct economic costs associated with events matching the SNRA definition of biological terrorism attacks (non-food) in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Direct economic cost estimates in the SNRA include data for successful attacks, e.g., release of an agent.[3]
		Best		
		High		
	Chemical Terrorism Attack (non-food)	Low		Data reflects the 5th percentile, mean, and 95th percentile direct economic costs associated with events matching the SNRA definition of chemical terrorism attacks (non-food) in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Direct economic cost estimates in the SNRA include data for successful attacks, e.g., release of an agent.
		Best		
		High		
	Chemical/Biological Food Contamination Terrorism Attack	Low		Data reflects the 5th percentile, mean, and 95th percentile direct economic costs associated with events matching the SNRA definition of chemical/biological food contamination terrorism attacks in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Direct economic cost estimates in the SNRA include data for successful attacks, e.g., release of an agent.
		Best		
		High		
	Cyber Event affecting Data	Low	1,000	Additional analysis is necessary to quantify the direct economic losses caused by cyber events affecting data. Consequences for the types of attacks in this event category are difficult to quantify, as they depend upon the particular system attacked, the vulnerability and resilience of the network, specific data backup provisions, etc. The minimum direct economic loss considered in the definition of this national-level event in the SNRA is $1 B.
		Best	N/A	
		High	N/A	
	Cyber Event affecting Physical Infrastructure	Low	100	Additional analysis is required to quantify the direct economic losses caused by cyber events affecting physical infrastructure. Consequences for the types of attacks in this event category are sector dependent and difficult to quantify. Approximately 85% of critical infrastructure is believed to be owned and operated by the private sector, and system vulnerability and resilience is highly sector-
		Best	N/A	
		High	N/A	

Threat/ Hazard Group	Threat/Hazard Type	Direct Economic Loss Estimates ($ Millions)		Source Information
				dependent and localized.[4] Only attacks resulting in 1 fatality or greater or $100 Million in direct economic losses or greater were considered.
	Explosives Terrorism Attack	Low		Direct economic costs were estimated using the 2010 DHS RAPID methodology for the economic consequences of explosives/kinetic/incendiary (EKI) events.[5]
		Best		
		High		
	Nuclear Terrorism Attack	Low		Data reflects the 5th percentile, mean, and 95th percentile direct economic costs associated with events matching the SNRA definition of nuclear terrorism attacks in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Direct economic cost estimates in the SNRA include data for successful attacks, e.g., detonation of a device.
		Best		
		High		
	Radiological Terrorism Attack	Low		Data reflects the 5th percentile, mean, and 95th percentile injury/illness estimates associated with events matching the SNRA definition of radiological terrorism attacks in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Direct economic cost estimates in the SNRA include data for successful attacks, e.g., detonation of a device or radiation exposure.
		Best		
		High		
Technological/ Accidental	Biological Food Contamination	Low	N/A	Additional analysis is required to estimate the direct economic impacts of accidental biological food contamination. Estimates for lost productivity and medical costs in the CDC's Foodborne Outbreak Online Database (FOOD) range from $3-11 Million[6], but business interruption costs could be found only for the 2006 *E. Coli* – spinach outbreak ($61.4M).[7]
		Best	N/A	
		High	N/A	
	Chemical Substance Spill or Release	Low	0.04	Estimates correspond to the low, average, and high direct economic loss reported per incident within the U.S. historic data set used for the SNRA analysis.[8]
		Best	14	
		High	330	
	Dam Failure	Low	N/A	Additional analysis is required to estimate the direct economic impacts of dam failure. Studies of some specific dams have estimated economic impacts in the hundreds of millions to billions of dollars, but may not be representative of the full set of dams in the U.S.[9]
		Best	N/A	
		High	N/A	
	Radiological Substance Release	Low	7,500	Estimates are drawn from the historic case of Three Mile Island as well as license renewal applications available on the public website of the U.S. Nuclear Regulatory Commission.[10]
		Best	8,600	
		High	16,000	
Natural	Animal Disease Outbreak	Low	2,300	Direct economic cost estimate informed by a case study of the impacts of an introduction of the disease into dairy herds in California.[11]
		Best	15,200	
		High	69,000	
	Earthquake	Low	107	Estimates correspond to the low, average, and high direct economic losses from earthquakes causing greater than $100 M in damages from the U.S. historic events between 1906-2011.[12]
		Best	8,700	
		High	105,000	

Threat/ Hazard Group	Threat/Hazard Type	Direct Economic Loss Estimates ($ Millions)		Source Information
	Flood	Low	104	Estimates correspond to the low, average, and high direct economic losses from floods causing greater than $100 M in damages from the U.S. historic events between January 1, 1993 to December 31, 2005.[13]
		Best	740	
		High	16,000	
	Human Pandemic Outbreak	Low	84,000	Direct economic cost estimates provided by CDC assuming a 25% attack rate, using case fatality rates associated with the 1968-1969 Hong Kong flu pandemic.[14]
		Best	170,000	
		High	260,000	
	Hurricane	Low	100	Estimates correspond to the low, average, and high injuries from hurricanes causing greater than $100 M in damages from the U.S. historic events between 1970-2010.[15]
		Best	5,700	
		High	92,000	
	Space Weather	Low	N/A	Additional analysis is needed to better quantify the direct economic losses which may be caused due to a space weather event. The August 2003 blackout in the Eastern U.S. caused an estimated $4-10 Billion in economic losses; this blackout was smaller in extent than the estimate for a national-level space weather event and was only hours to days in duration. One published estimate suggests that a space weather event could cause $1-2 trillion in the first year after the event, with a potential total duration of 4-10 years.[16]
		Best	N/A	
		High	N/A	
	Tsunami	Low	700	Low, best, and high estimates were determined by FEMA HAZUS modeling of a tsunami wave hitting the Oregon coast of height 13, 15, and 17 meters, respectively. Costs are dominated by building losses.
		Best	1,500	
		High	3,300	
	Volcanic Eruption	Low	4,300	Estimates informed by FEMA and USGS economic analysis of the economic impacts of an eruption of Mount Rainier.[17]
		Best	10,000	
		High	16,000	
	Wildfire	Low	100	Estimates correspond to the low, average, and high economic costs from wildfires causing greater than $100 M in damages from the U.S. historic events between 1990-2009.[18]
		Best	900	
		High	2,800	

[1] RAPID, or the Risk Informed Process for Improved Decision-making, includes business interruption costs, disposal, decontamination, and physical destruction (DDP) costs, medical costs, and lost demand from fatalities in its estimates of direct economic impact.

[2] The direct economic analysis for Armed Assault included: Business interruption costs from the 2010 RAPID EKI models for government sector buildings, commercial sector buildings, and national monuments and icons as targets; DDP cost assumptions for an EKI man portable IED from the 2010 RAPID EKI models for government buildings, commercial sector buildings, national monuments and icons, and airports as targets; medical costs based on assumptions for the 2010 RAPID EKI incident set; and lost demand from fatalities based on assumptions from the 2010 RAPID assessment.

[3] Direct costs in the 2011 ITRA include business interruption costs, DDP costs, medical costs, and lost demand from fatalities.

[4] Office of Infrastructure Protection, Department of Homeland Security: http://www.dhs.gov/files/partnerships/editorial_0206.shtm.

[5] The direct economic analysis for Explosives Terrorism Attacks included: Business interruption costs and DDP costs from the 2010 RAPID EKI models for man portable IED, vessel IED, and vehicle borne IED against all target classes; medical costs based on assumptions for the 2010 RAPID EKI incident set; and lost demand from fatalities based on assumptions from the 2010 RAPID assessment.

[6] The Centers for Disease Control and Prevention (CDC) Foodborne Outbreak Online Database (FOOD) is available online at http://www.cdc.gov/foodborneoutbreaks. Estimates were obtained from historic events in FOOD which were multistate outbreaks requiring greater than 100 hospitalizations. Years included in FOOD include 1998-2008. To compute lost productivity due to illness and medical costs, the USDA's Economic Research Service's Foodborne Illness Cost Calculator was used, with the Value of a Statistical Life (VSL) set to $0. (http://www.ers.usda.gov/Data/FoodBorneIllness; accessed on 19 August 2011.)

[7] Arnade, C., Calvin, L., & Kuchus, F. (2010, March). *Consumers' response to the 2006 foodborne illness outbreak linked to spinach*. United States Department of Agriculture, Economic Research Service. Available from: http://www.ers.usda.gov/AmberWaves/March10/Features/OutbreakSpinach.htm. Accessed on 19 August 2011.

[8] The set of historic chemical substance release events used for analysis in the SNRA were those which met the following criteria: 1) at least one "public" fatality, defined as one fatality other than or in addition to an employee fatality, caused by the hazardous material; or 2) at least one fatality of any kind caused by the hazardous material, plus a reported evacuation or shelter-in-place order. This set came from the set of all reported toxic inhalation hazard (TIH) incidents reported 1994-2010 to either the EPA's Risk Management Program (RMP) accident database for fixed industrial producers and consumers of the listed toxic chemicals above given threshold limits, or to the Department of Transportation's Pipeline and Hazardous Substances Administration (PHMSA)'s database of road, rail, water, and air transportation accidents. Direct economic damages which fixed facilities are required to report, and update for accuracy, to the RMP database are property damage to equipment or the facility itself, and all known or readily knowable property damage outside the facility. Direct economic damages which transport carriers are required to report to the PHMSA transportation database are the value of the material (spilled chemical) which was lost, physical damage sustained by the carrier (vehicles or other cargo), damage caused to public or private property, the dollar value of the response cost, and the dollar value of any remediation and clean-up cost. These damages do not include business interruption costs, medical or insurance costs, or litigation or settlement costs not overlapping with the costs listed above. The SNRA project team added medical cost estimates ($6,600 per injury/illness) and the loss in demand due to fatalities ($42,000 per fatality) to the direct economic costs above for consistency with the terrorism events. Business interruption costs were not considered in this analysis but judged to be low relative to the included costs.

[9] Examples of studies of the direct economic consequences of dam failure include: estimates ranging from $400M to $2.9B for failures of the Miller Dam and Mansfield Dam in Austin, Texas (Texas Colorado River Floodplain Association, *Creating a Disaster-Resistant Lower Colorado River Basin*, Section 15); estimates ranging from $78M to $1.3B for the failure of dams in Northeastern Idaho (*Regional All-Hazards Mitigation Plan for Northeastern Idaho*); and an estimate of approximately $20 B for a catastrophic failure of the Hills Creek Dam in Oregon (Goettel, K. A. (2001). *Regional All Hazard Mitigation Master Plan for Benton, Lane, and Linn Counties, Phase Two*. Prepared for the Benton County Project Impact and the Oregon Cascades Regional Emergency Management Coordinating Council).

[10] The best estimate for direct economic loss uses a simulation of the expected core damage frequencies and expected consequences obtained from the license renewal applications for a number of individual reactors available from the public website of the U.S. Nuclear Regulatory Commission (NRC) at http://www.nrc.gov/reactors/operating/licensing/renewal/applications.html. The data from the license renewal applications is used to perform cost/benefit analyses on reactor upgrades and the baseline data was not developed for use in a general risk assessment. Currently, this is the most recently publicly available data and adequate for order of magnitude estimates in the SNRA. The expected consequences are weighted by the likelihood of a core damage accident for each reactor using a Crystal Ball simulation to determine the best direct economic loss estimate. The low and high consequence estimates also come from the license renewal applications; these consequences correspond to the most frequent types of core damage accidents in each report and the highest consequence scenarios outlined in each report, respectively. For the low estimates, the economic costs are mostly fixed values associated with business interruption and are consistent with the $1B in decontamination costs from the shutdown of Reactor 2 at Three Mile Island (14-Year Cleanup at Three Mile Island Concludes. *New York Times*, August 15, 1993). The highest consequence scenarios usually involve a large, early release and assume that there is not enough time for successful evacuation. The frequency of these events is typically one-to-two orders of magnitude less than the frequency of any core damage event. Note that the frequency values reported in Appendix B do not correspond to the high and low direct economic loss estimates.

[11] Carpenter, T. E., O'Brien, J. M., Hagerman, A. D., McCarl, B. A. (2011). Epidemic and economic impacts of delayed detection of foot-and-mouth disease: A case study of an outbreak in California. *Journal of Veterinary Diagnostic Investigation*, 23, 26-33. The direct economic impact of an FMD outbreak will come from an immediate reduction in lost international trade as well as disease control and eradication efforts, which can include the cost of maintenance of animal movement controls, control areas, intensified border inspections, vaccines, depopulation, carcass disposal, indemnification to farmers for losses, and disinfection and decontamination efforts.

[12] The U.S. historic earthquake record for events causing greater than $100 Million in damages was obtained from the published report by Vranes, K. and Pielke, R. (2009). Normalized earthquake damage and fatalities in the United States: 1900-2005. *Natural Hazards Review* 10(3), 84:101. Normalized economic estimates take into account changes in population densities, community wealth, mitigation factors (such as improved building codes and emergency response), and inflation. A 1% annual mitigation factor was used, as described in Vranes & Pielke (2009).

[13] The U.S. historic flood record for events causing greater than $100 Million in damages was obtained by aggregating flood losses reported by NOAA's National Climactic Data Center (NCDC). Modern flood reporting by NOAA relies on many individual reports that assess damages in a specific area of responsibility. A large scale flood, for example, can result in dozens or hundreds of damage entries that assess damages for specific geographic regions. As flooding passes down the Mississippi, for example, the affected areas can pass from region to region. To capture the transient and distributed nature of flood events, individual flood loss reports were aggregated based on distance and time. Flood damage reports that occurred within 100 miles of one another and within plus or minus one calendar day were aggregated into composite flood events. The composite flood events above the $100 Million (2011 dollar) threshold were used for reporting frequency, fatality, injury, and direct economic loss estimates in the SNRA. All hurricanes were removed from flood events to avoid double-counting flooding damages included in the SNRA hurricane analysis.

[14] Meltzer, M.I., Cox, N.J., and Fukuda, K. (1999). The economic impact of pandemic influenza in the United States: Priorities for intervention. *Emerging Infectious Diseases* 5, 659-671. The pandemic influenza scenario is based upon a U.S. population of approximately 307 million; all of the estimates are given absent any intervention (i.e., before interventions are applied or attempted). The economic impact for the 1968 scenario was taken from Meltzer *et al.* and updated from 1995 values to 2010 dollar estimates, using the Consumer Price Index conversion factor (CPI – 1.431 conversion factor. http://www.bls.gov/data). The dollar values provided estimates for lost productivity due to time off work to either convalesce or care for a family member who is ill. Approximately 83% of the estimated impact for this scenario is associated with the value of lost productivity due to premature death. Beyond the inclusion of value of time lost from work, these estimates do not include any valuation for lost economic activity, such as business closing or notable reduction in economic activity.

[15] The U.S. historic hurricane record for events causing greater than $100 Million in damages was obtained from the ICAT Damage Estimator (http://www.icatdamageestimator.com), which uses a methodology for computing economic losses similar to that published by Pielke, R.J., Gratz, J., Landsea, C., Collins, D., Saunders, M., and Musulin, R. (2008). Normalized hurricane damage in the United States: 1900-2005. *Natural Hazards Review* 9: 29-42. Historic economic damage estimates were updated to a 2011 base year by taking into account changes in populations, building structures, and infrastructure. These estimates potentially include indirect economic losses. There is not a clear disambiguation for economic loss estimates as there is no readily available record for each loss estimate. Due to this ambiguity, economic loss estimates have the potential to be biased high.

[16] Committee on the Societal and Economic Impacts of Space Weather Events, National Research Council (2008). *Severe space weather events – understanding societal and economic impacts: A workshop report*, p. 77. Washington, DC: National Academies Press. Available from http://www.nap.edu/catalog.php?record_id=12507.

[17] To calculate the low estimate of direct economic losses for volcanic eruption, the Mount Rainier Inundation Zone for Case I Debris Flows GIS boundary (Hoblitt, R. P., Walder, J. S., Driedger, C. L., Scott, K. M., Pringle, P. T., & Wallace, J. W. (1998), *Volcano Hazards from Mount Rainier, Washington*. U.S. Geological Survey Open-File Report 98-428 [Data file]. Available from: http://vulcan.wr.usgs.gov/Volcanoes/Rainier/Hazards/OFR98-428/framework.html) was overlaid on 2000 U.S. Census data in HAZUS. The General Building Stock Exposure (replacement amount) designated by occupancy in census blocks was used to calculate the total dollar exposure of the combined amounts for commercial, industrial, agricultural, religion, government, and educational industries. To calculate the high estimate of direct economic losses, USGS analysis was used (Wood, N. J. & Soulard, C. E. (2009, September 16). *Community exposure to lahar hazards from Mount Rainier, Washington*. USGS Scientific Investigations Report 2009-5211). The best estimate is the geometric mean of the low and high estimates.

[18] The U.S. historic wildfire record for events causing greater than $100 Million in damages was compiled from the SHELDUS database (Hazards & Vulnerability Research Institute (2011). The Spatial Hazards Events and Losses Database for the United States, Version 8.0 [Online Database]. Columbia, SC: University of South Carolina. Available from http://www.sheldus.org). SHELDUS breaks down wildfire events into separate counties, and sometimes breaks down single wildfires in the same location into separate fires with overlapping date ranges, dividing casualty and damages between them to avoid double-counting. Where this was obviously done (fires reported by counties in the same state having the same time range, or reported in the same city with overlapping or continuously adjacent time ranges) the separately reported portions of a single fire event were consolidated into single events. All wildfires (after consolidation) above the $100 Million threshold in 2011 dollars (a CPI multiplier of 1.0464 was used to convert the December 2009 values given in SHELDUS v8.0 to May 2011 values) from 1970-2009 were used in the SNRA analysis. Economic losses reported in SHELDUS include property and crop losses. These were judged to dominate any business interruption, medical costs, or loss in spending due to fatalities.

APPENDIX F: SOCIAL DISPLACEMENT CONSEQUENCE ASSESSMENT

All social displacement consequence estimates in the SNRA are unclassified.

Overview

In the SNRA, social displacement is defined as the number of people forced to leave their home for a period of two days or longer due to a national-level event. Displacement estimates were obtained primarily by research staff at the National Consortium for the Study of Terrorism and Responses to Terrorism (START),[1] who consulted the open social sciences literature and various open source databases for historical events and relevant models providing analysis and results comparable to the national-level events described in the SNRA. Additional social displacement inputs were obtained from FEMA technical staff providing modeling support using HAZUS MH software, and SNRA project team analysis of open source literature and incident management databases.

The Department of Homeland Security (DHS) Office of Risk Management (RMA), in partnership with the DHS Science and Technology (S&T) Human Factors/Behavioral Sciences Division (HFD),[2] utilized START's network of experts for advice on social displacement data and metrics. Experts advised that displacement is a reasonable first proxy for many additional social impact metrics, while also noting the importance of accounting for the time dimension in displacement. There is a significant difference between short-term evacuation for a week versus longer-term permanent relocation, and the SNRA displacement measure of number of people displaced currently does not differentiate between these two types of displacement. Because of this, the experts emphasized extreme caution in using these social consequence results, particularly when this metric is being considered in isolation.

The initial SNRA social displacement analysis presented below was conducted to support the development of the National Preparedness Goal. The resulting data have not undergone extensive review by any Federal Agency, and have not been extensively verified and validated by social sciences academic researchers.

The Department of Homeland Security and its partner organizations are funding social and behavioral research to better understand the psychosocial impacts of terrorist acts, natural disasters, and technological accidents. In addition to providing means for more accurately assessing these impacts, this research will inform programs that have been developed to promote resilience in individuals, organizations, communities, and at the national level. Results and new insights for preparedness are expected over the next five years.

Major Findings

The highest potential for adverse social displacement results from nuclear attack and hurricane events.

There is substantial uncertainty about the social displacement that would be caused by a space weather event. Since a space weather event has the potential to significantly disrupt the electric grid, communications and GPS services, and damage critical infrastructure (i.e., power

[1] START is a Department of Homeland Security University Center of Excellence that focuses on social and behavioral aspects of terrorism, natural disasters, and technological accidents, and the social, behavioral, cultural and economic factors influencing responses to and recovery from catastrophes. Based at the University of Maryland, START supports research efforts of leading social scientists at more than 50 academic and research institutions.

[2] DHS/S&T Resilient Systems Division (RSD) is the current (2015) organizational successor to Human Factors Division.

transformers), the affected areas are essentially out of commission, leaving the population(s) literally and figuratively "in the dark" for weeks to months.[3] However, the potential for a space weather event to cause large-scale consequences is under debate.

Estimates for displacement due to a nuclear terrorism attack range from 330,000 to 3 million, and are informed by published evacuation/shelter-in-place estimates for a detonated 10-kiloton improvised nuclear device. Hundreds of thousands of people in the affected area may seek shelter in safe areas or shelter-in-place in their residence as the plume moves across the region, and many more may self-evacuate from major urban areas. Chemical, radiological, and biological terrorism attacks may also cause significant displacement: this is dependent upon agent, dispersal mechanism, and target location.

Conventional terrorism attacks (e.g., explosives and armed assaults) and cyber events are judged to have relatively lower displacement than many events in the assessment, but high estimates for the displacement due to these events were not available in the time frame of this initial assessment. The evacuations from Lower Manhattan following the use of aircraft as a weapon in the September 11, 2001 attacks illustrates the potential for non-CBRN adversarial/human-caused events to cause significant displacement.

Hurricanes have the potential to displace millions of people from their homes for two days or longer, but much of this displacement is proactive short-term evacuation intended to prevent loss-of-life or injuries, in addition to the long-term or permanent displacement caused by the destruction of housing. Many of the natural hazard and technological/accidental hazard events, including earthquakes, floods, tsunamis, volcanoes, and dam failure, also have the potential to cause long-term/permanent displacement in addition to temporary evacuations.

Displacement due to natural hazards is better understood overall than displacement from adversarial or accidental events, but recent natural hazards (i.e., Hurricanes Katrina, Rita, Gustav, and Ike) have demonstrated the lack of available, high quality social science research focusing on the social consequences of these types of catastrophes and how to best mitigate them.

Given the diversity of hazards and the range of communities in the United States, it will remain difficult to predict with absolute certainty how a specific event will affect a specific community. It is, however, both possible and necessary to improve our understanding of the social impacts of events and to use this knowledge to inform risk assessment and management strategies.

[3] Jaggard, V. (2011, August 3). As sun storms ramp up, electric grid braces for impact. *National Geographic News*. Retrieved from http://news.nationalgeographic.com/news/energy/2011/08/110803-solar-flare-storm-electricity-grid-risk/ (accessed August 8, 2011).

Figure F1: Social Displacement by National-level Event

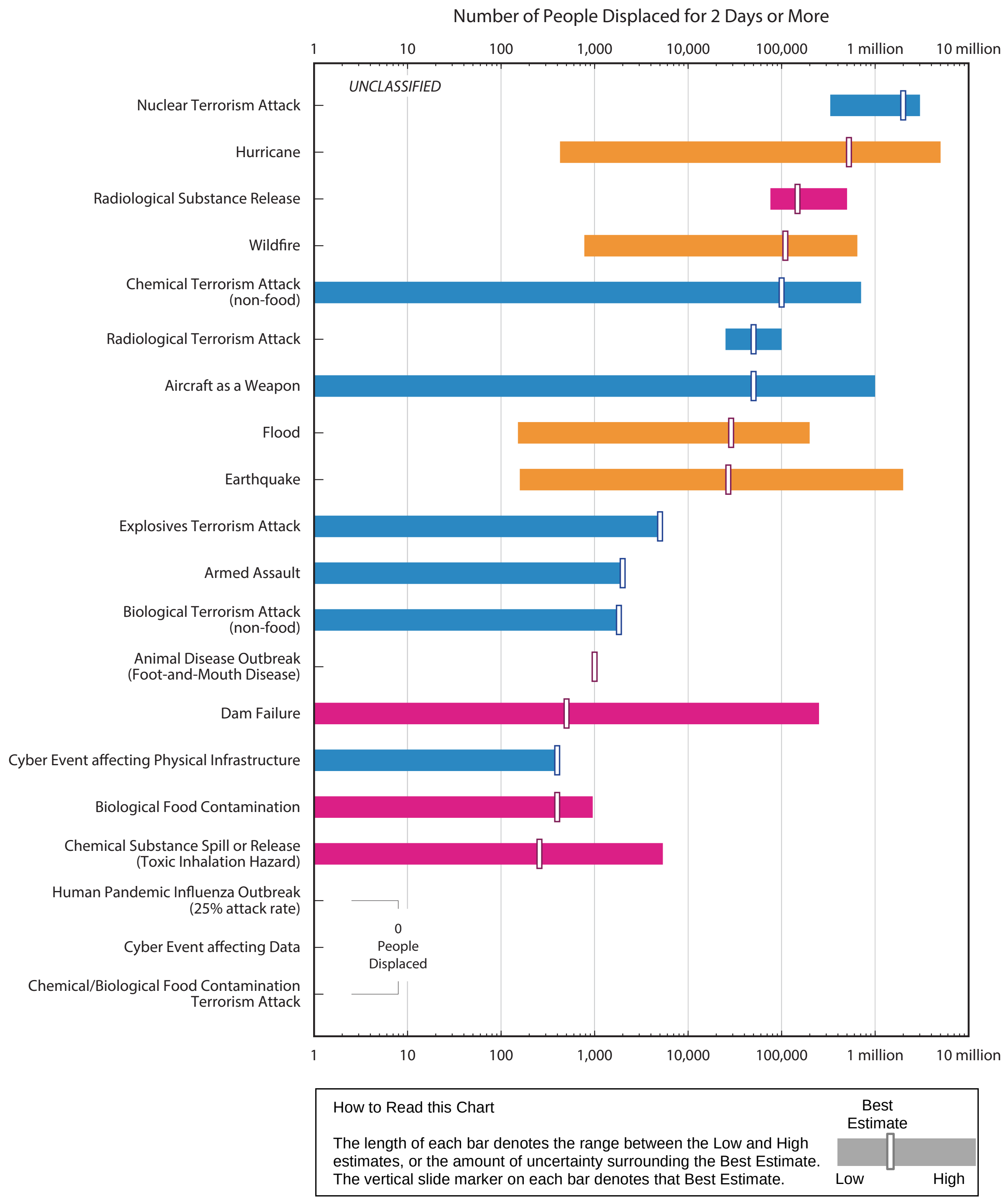


Table F1: SNRA Social Displacement Data and Sources

Threat/ Hazard Group	Threat/Hazard Type	Displacement Estimate		Source Information
Adversarial/ Human-Caused	Aircraft as a Weapon	Low	0	Low estimate assumed to be zero.
		Best	50,000	Expert judgment.
		High	1,000,000	Displacement estimate from Lower Manhattan after 9/11.[1]
	Armed Assault	Low	0	Low estimate assumed to be zero.
		Best	2,000	Expert judgment.
		High	N/A	High estimate not available.
	Biological Terrorism Attack (non-food)	Low	0	Low estimate assumed to be zero.
		Best	1,800	Historical displacement due to a natural outbreak is used as a proxy estimate for a small-scale, deliberate dissemination of a contagious agent.[2]
		High	N/A	High estimate not available.
	Chemical Terrorism Attack (non-food)	Low	0	Low estimate assumed to be zero.
		Best	100,000	Estimated evacuation and dispersal number for a chemical attack (blister agent) aimed at a large gathering such as a football game.[3]
		High	700,000	Estimated evacuation and dispersal number for a chemical attack (industrial chemicals) where a terrorist uses explosive devices aimed at a petroleum plant.[3]
	Chemical/Biological Food Contamination Terrorism Attack	Low	0	Low estimate assumed to be zero.
		Best	N/A	Best and high estimates not available. Experts judged that displacement is likely to be minimal.
		High	N/A	
	Cyber Event affecting Data	Low	0	No physical damage or harm, so no displacement expected.
		Best	0	
		High	0	
	Cyber Event affecting Physical Infrastructure	Low	0	Low estimate assumed to be zero.
		Best	400	Estimate based on case study of Army base evacuation due to accidental power outage, judged to be a proxy estimate for an intentional outage.[4]
		High	N/A	High estimate not available. Experts noted that a prolonged power outage over a large area could result in several thousand evacuating, regardless of outage cause.
	Explosives Terrorism Attack	Low	0	Low estimate assumed to be zero.
		Best	5,000	Expert judgment based on an evacuation radius of several blocks from the location of an improvised explosive device (IED).
		High	N/A	High estimate not available.
	Nuclear Terrorism Attack	Low	330,000	Low, high, and best estimates are informed by published evacuation/shelter-in-place estimates for a detonated 10 kiloton improvised nuclear device.[5]
		Best	2,000,000	
		High	3,000,000	
	Radiological Terrorism Attack	Low	25,000	Low, best, and high estimates are informed by published evacuation/shelter-in-place estimates for a radiological dispersal device (RDD).[6]
		Best	50,000	
		High	100,000	

Threat/ Hazard Group	Threat/Hazard Type	Displacement Estimate		Source Information
Technological/ Accidental	Biological Food Contamination	Low	0	Low estimate assumed to be zero.
		Best	400	Expert judgment.
		High	950	High estimate based on historic case study of *E. coli* in town water supply.[7]
	Chemical Substance Spill or Release	Low	0	Low, best, and high estimates obtained from analysis of the EPA Risk Management Program and the DOT Pipeline and Hazardous Substance Management Agency databases for the defined national-level event.[8]
		Best	255	
		High	5,400	
	Dam Failure	Low	1	Low estimate assumed to be 1 (minimal).
		Best	500	Best estimate computed as the geometric mean of the low and high estimate.
		High	250,000	High estimate informed by published displacement estimates for the Hills Creek Dam in Oregon and the Folsom Dam in California.[9]
	Radiological Substance Release	Low	76,000	Low and best estimates reflect published estimates of displacement from the Three Mile Island incident.[10]
		Best	150,000	
		High	500,000	High estimate reflects published estimates of displacement from the Chernobyl incident.[11]
Natural	Animal Disease Outbreak	Low	0	Low estimate assumed to be zero.
		Best	1,000	Expert judgment. Those working on or near farms may be asked to relocate to reduce the chance of transmitting foot-and-mouth disease to other livestock.
		High	N/A	High estimate not available.
	Earthquake	Low	160	Estimates reflect historic low and average reports of “total affected” for earthquakes causing greater than $100 M in economic damage as recorded in EM-DAT during the time period 1970-2011.[12]
		Best	27,000	
		High	2,000,000	Expert judgment provided by FEMA.
	Flood	Low	150	Estimates reflect historic low, average, and high reports of “total affected” for floods causing greater than $100 M in economic damage as recorded in EM-DAT during the time period 1970-2011.[12]
		Best	29,000	
		High	200,000	
	Human Pandemic Outbreak	Low	0	Negligible displacement assumed. Hospitalizations of 2 days or greater are not counted as displacement in this assessment.
		Best	0	
		High	0	
	Hurricane	Low	430	Estimates reflect historic low, average, and high reports of “total affected” for hurricanes causing greater than $100 M in economic damage as recorded in EM-DAT during the time period 1970-2011.[12]
		Best	520,000	
		High	5,000,000	
	Space Weather	Low	N/A	Additional analysis is needed to understand the potential for social displacement due to a space weather event.
		Best	N/A	
		High	N/A	
	Tsunami	Low	8,600	Estimates provided by FEMA based on HAZUS modeling of tsunami hitting the Oregon coast.
		Best	15,000	
		High	N/A	High estimate not available.

Threat/ Hazard Group	Threat/Hazard Type	Displacement Estimate		Source Information
	Volcanic Eruption	Low	1,300	Low, best, and high estimates based on USGS and HAZUS modeling of eruption of Mount Rainier.
		Best	130,000	
		High	2,100,000	
	Wildfire	Low	770	Estimates reflect historic low, average, and high reports of "total affected" for wildfires causing greater than $100 M in economic damage as recorded in EM-DAT during the time period 1991-2011.[12]
		Best	110,000	
		High	640,000	

[1] Sources for the Aircraft as a Weapon displacement estimates include: (1) Fritsch, Jane (2001, September 12). A day of terror – the response: rescue workers rush in, and many do not return, *The New York Times*; and (2) Marine Log (2001, September 19). Boats evacuated one million New Yorkers after WTC attack. Retrieved from http://www.marinelog.com/DOCS/NEWSMM/MMISep19.html. The high estimate may count residents as well as non-resident workers evacuating from Lower Manhattan, and thus may be an overestimate of displacement.

[2] The best estimate of displacement for a Biological Terrorism Attack is based on the number evacuated in East Timor in 1999 during a natural outbreak of tuberculosis. Source: Connolly, Maire (1999). Communicable Disease Surveillance and Control in East Timor. Geneva: World Health Organization. Retrieved from http://www.who.int/disasters/repo/7839.doc. Subject matter experts consulted for the SNRA noted that this estimate is arbitrary given the large range of potential biological attack scenarios; the high estimate could be significantly higher than the best estimate provided if there is a need to decontaminate a large area.

[3] Bea, Keith (2005, March 10). *National Preparedness System: Issues in the 109th Congress*. Congressional Research Service Report for Congress.

[4] Reed, C. & Okubo, G. (2010, July 6). Flooding, power outages force evacuations at Yokota. *Stars and Stripes.* Retrieved from http://www.stripes.com/news/pacific/japan/flooding-power-outages-force-evacuations-at-yokota-1.110071.

[5] Davis, Tracy C. (2007). *Stages of Emergency: Cold War Nuclear Civil Defense*. Durham NC: Duke University Press; Meade C., Molander R. C. (2006). *Considering the Effects of a Catastrophic Terrorist Attack*. Santa Monica, CA: RAND Center for Terrorism Risk Management Policy. Retrieved from http://www.rand.org/pubs/technical_reports/2006/RAND_TR391.pdf; National Security Staff Interagency Policy Coordination Subcommittee for Preparedness and Response to Radiological and Nuclear Threats (2010). *Planning Guidance for Response to a Nuclear Detonation* (2nd ed.). Retrieved from http://www.remm.nlm.gov/PlanningGuidanceNuclearDetonation.pdf.

[6] Worcester, Maxim (2008). *International Terrorism and the Threat of a Dirty Bomb*. Berlin: Institute Für Strategie-Politik-Sicherheits-und Wirtschaftsberatung. Available from http://www.isn.ethz.ch/isn/Digital-Library/Publications/Detail/?id=46567.

[7] Contamination of the water by *E. coli* in the Ontario community of Kashechewan forced the evacuation of the town. Source: Virchez, J. & Brisbois, R. (2007). A historical and situational summary of relations between Canada and the First Nations: The case of the community of Kashechewan in Northern Ontario. *Revista Mexicana de Estudios Canadienses (nueva época), otoño-invierno*, 014, 87-100. Note that contamination of the food supply is likely to cause minimal displacement (see Chemical/Biological Food Contamination Terrorism Attack estimate).

[8] The set of historic chemical substance release events used for analysis in the SNRA were those which met the following criteria: 1) at least one "public" fatality, defined as one fatality other than or in addition to an employee fatality, caused by the hazardous material; or 2) at least one fatality of any kind caused by the hazardous material, plus a reported evacuation or shelter-in-place order. This set came from the set of all reported toxic inhalation hazard (TIH) incidents reported 1994-2010 to either the EPA's Risk Management Program (RMP) accident database for fixed industrial producers and consumers of the listed toxic chemicals above given threshold limits, or to the Department of Transportation's Pipeline and Hazardous Substances Administration (PHMSA)'s database of road, rail, water, and air transportation accidents. For consistency with the other national-level events, reported numbers of total people evacuated were counted only for those events where the reported total evacuation time (PHMSA) or total release duration of the toxic chemical (RMP) was 48 hours or more. Since evacuations may last longer (to ensure the released chemical has fully dissipated) or shorter (when they begin after a delay from the onset of the toxic leak) than the chemical release duration, the events from the RMP database meeting this criterion may be somewhat more or fewer than the ones counted here: but given that these are variations in hours compared with the minimum inclusion of two days, a substantial deviation is unlikely. It is important to note that there is international precedent for displacement in the hundreds of thousands, including the chlorine leakage caused by a railroad accident in Mississauga, Canada, and the explosion at a Union Carbide plant and subsequent release of methylisocynate (MIC) in Bhopal, India (Soffer, Y., Schwartz,

D., Goldberg, A., Henenfeld, M., & Bar-Dayan, Y. (2008). Population evacuations in industrial accidents: A review of the literature about four major events. *Prehospital and Disaster Medicine*, 23(3), 276-281.)

[9] Source for Hills Creek Dam: Oregon Partnership for Disaster Resilience. (2009, October). *Eugene/Springfield multi-jurisdictional natural hazards mitigation plan: Prepared for the cities of Eugene and Springfield, Oregon*. Retrieved from: http://www.eugene-or.gov/portal/server.pt/gateway/PTARGS_0_2_355923_0_0_18/NHMP09.pdf. Source for Folsom Dam: Ayyaswamy, P., Hauss, B., Hseih, T., Moscati, A., Hicks, T. E., & Okrent, D. (1974, March). *Estimates of the Risks Associated with Dam Failure* (UCLA-ENG-7434). Los Angeles, CA: UCLA School of Engineering and Applied Science.

[10] Sources for the low and best estimates of displacement due to Accidental Radiological Substance Release are: Cutter, S. & Barnes, K. (1982). Evacuation Behavior and Three Mile Island. *Disasters*, 6(2): 116-124; and Soffer, Y., Schwartz, D., Goldberg, A., Henenfeld, M., & Bar-Dayan, Y. (2008). Population Evacuations in Industrial Accidents: A Review of the Literature about Four Major Events. *Prehospital and Disaster Medicine*, 23(3), 276-281.

[11] Soffer, Y., Schwartz, D., Goldberg, A., Henenfeld, M., & Bar-Dayan, Y. (2008). Population Evacuations in Industrial Accidents: A Review of the Literature about Four Major Events. *Prehospital and Disaster Medicine*, 23(3), 276-281.

[12] Centre for Research on the Epidemiology of Disasters (2011). EM-DAT: The OFDA/CRED International Disaster Database. [Data file]. Brussels: Université Catholique de Louvain. Available from http://www.emdat.be. EM-DAT, an emergency events database maintained by the World Health Organization Collaborating Centre for Research on the Epidemiology of Disasters with support from USAID, provides estimates of the "total number affected" by disaster events. The "total affected" measure includes the number of people needing immediate assistance, which can include displacements and evacuations; the number of people needing immediate assistance for shelter; and the number of people injured. Because EM-DAT includes injuries in the "total affected" measure, there is potential for double-counting between the SNRA injury and displacement estimates for this event. However, displacement due to natural disasters is typically significantly greater than the number of injuries, so using EM-DAT's "total affected" measure was judged to provide an estimate of social displacement of sufficient precision for the SNRA. Note that the low estimate may be biased low due to incomplete reporting of displacement and evacuations in EM-DAT.

APPENDIX G: PSYCHOLOGICAL DISTRESS CONSEQUENCE ASSESSMENT

Note that all comparative statements based upon quantitative findings are made within the set of natural and technological hazards treated by this extract from the SNRA.

Overview

The DHS Office of Risk Management (RMA), in partnership with DHS Science and Technology (S&T) Human Factors/Behavioral Sciences Division (HFD),[1] consulted with several nationally recognized academic researchers investigating psychosocial impacts of disasters and terrorism, including the effects on public health, civil society, and public trust. These experts recommended a methodology to assess psychological distress which would permit comparison across national-level events included in the SNRA.

Methodology

Substantial academic research has been conducted on the psychological consequences of disasters.[2,3,4,5] This research primarily has focused on individual, family, and community impacts rather than the strategic, national-level impacts of interest in this assessment. However, the results have provided a scientific basis for preliminary methodologies for estimating psychological consequences in the SNRA.

The DHS Office of Risk Management (RMA), in partnership with DHS Science and Technology (S&T) Human Factors/Behavioral Sciences Division (HFD), consulted with several nationally recognized academic researchers investigating psychosocial impacts of disasters and terrorism, including the effects on public health, civil society, and public trust. These experts recommended a methodology to assess psychological distress which would permit comparison across national-level events included in the SNRA.

Experts recommended that *significant and/or prolonged psychological distress* caused by national-level events would be the most meaningful psychological metric for strategic capabilities planning and national preparedness. *Fear* is pervasive during the initial impact of a disaster. It is natural and normal, virtually universal, and not harmful within limits (although it can have more serious and lasting consequences under certain conditions). In contrast, the concept of *distress* goes beyond the reactions experienced only at the time of disaster impact. Past research has documented a wide range of psychosocial consequences, including various psychological problems such as depression, anxiety, and posttraumatic stress disorder (PTSD); physical health problems, such as sleep disruption, somatic complaints, and impaired immune function; chronic problems in living, such as troubled interpersonal relationships and financial stress; and resource loss, such as declines in perceived control and perceived social support. The field of disaster behavioral health often distinguishes between *distress* and *disorder*, the latter of which refers to specific criterion-based conditions that may require professional intervention. *Distress* is a broader outcome,

[1] DHS/S&T Resilient Systems Division (RSD) is the current (2015) organizational successor to Human Factors Division.

[2] Bonanno, G. A., Brewin, C. R., Kaniasty, K., & La Greca, A. M. (2010). Weighing the costs of disaster: consequences, risks, and resilience in individuals, families, and communities. *Psychological Science in the Public Interest*, 11(1), 1-49.

[3] Norris, F. H., & Wind, L. (2009). The experience of disaster: trauma, loss, adversities, and community effects. In Neria, Y., Galea, S., & Norris, F. (Eds.), *Mental Health and Disasters* (pp. 29-44). New York, NY: Cambridge University Press.

[4] Norris, F. H., Friedman, M. J., Watson, P. J., Byrne, C. M., Diaz, E., & Kaniasty, K. (2002). 60,000 disaster victims speak: Part I. An empirical review of the empirical literature, 1981-2001. *Psychiatry*, 65, pp. 207-239.

[5] Norris, F. H., Friedman, M. J., & Watson, P. J. (2002). 60,000 disaster victims speak: Part II. Summary and implications of the disaster mental health research. *Psychiatry*, 65, 240-260.

referring to a combination of cognitive, behavioral, and emotional reactions that do not necessarily conform to specific diagnostic criteria but nonetheless are serious enough to impair daily role functioning and quality of life. For the SNRA psychological consequences index, experts focused on distress rather than disorder, and used labels such as "significant" or "prolonged" distress to indicate that they would not include mild distress, such as would be expected in any person who has experienced a stressful event.

Prevalence estimates of distress (and disorder) vary markedly across studies. About 10% of the time, there is little or only very fleeting distress. About 50% of the time, distress is common, but rates of psychopathology are below 25%. About 40% of the time, distress is common with rates of psychopathology at 25% or greater. Published studies are biased toward more devastating events and vulnerable populations, and thus an interpretation that 40% of disasters have severe consequences for 25% or more of the population may not be fully justified. However, because the national-level events included in the SNRA all have the potential to be severe, this broad summary conclusion may be reasonable.

One challenging aspect of assessing psychological distress in the SNRA is the requirement to estimate the impacts of specific national-level events. Existing research on psychological consequences is not well-aligned with a focus on specific events or hazards. In general, researchers have learned that the type of event is not as important as it was once assumed to be in disaster mental health. What matters most is the scope and severity of an event, i.e., the prevalence of serious stressors that place great demands on the coping ability of the public. Disaster-related stressors that matter for mental health can be grouped into four broad categories: trauma, loss, ongoing adversities, and event familiarity/dread. The primary sources of trauma are threat to life, injury, and exposure to horrible sights, smells, and sounds. The primary sources of loss are property damage, such as to homes and vehicles, financial loss, and declines in psychosocial resources. Deaths cause both trauma and loss for survivors. Ongoing adversities include the challenges of living in damaged housing and communities, dealing with insurance companies and aid, or being displaced. Displacement causes both losses and adversities. Event familiarity/dread captures the intangible, subjective aspects of disaster exposure. All other things being equal, human-caused disasters, especially when intentional, are generally believed to be more distressing than others. Disasters that are followed by uncertainty regarding unseen consequences or fear of recurrence likewise are more distressing.

Such empirical findings indicate that the psychological consequences of a disaster may follow from the other types of consequences being assessed in the SNRA. To apply this working knowledge, a consequence index[6] for significant psychological distress was proposed by the experts that used the SNRA estimates for deaths, injuries, and displacement related to each national-level event. To reflect the empirical findings that losing a loved one is the most severe stressor, followed by injury, followed by displacement, the following formula for a Significant Distress Index was proposed:

[6] The consequence index used in the SNRA for psychological distress is analogous to a risk index, an approach which allows multiple factors which affect the level of risk to be incorporated into a single numerical score for the level of risk. For more information see: Information Standards Organization (2009). *Risk management – risk assessment techniques* (ISO 31010).

$$N_{SD} = C_{EF} \times \left(5\ N_F + N_I + \tfrac{1}{2}\ N_D\right)$$

N_{SD} : number of persons with significant distress
N_F : number of fatalities
N_I : number of injuries/illnesses
N_D : number of people displaced
C_{EF} : Event Familiarity Factor

This formula suggests that, on average, there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. Note also that an Event Familiarity Factor is applied as an attempt to capture the extent to which psychosocial consequences might be exacerbated by an event entailing an ongoing threat with uncertainty about long term effects, that is unfamiliar, or that people dread. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA. Thus unfamiliar events (terrorism events, earthquake, chemical or radiological substance release, etc.) are weighted to have more psychological consequences compared to more familiar events (pandemic, flood, hurricane, etc.).

Uncertainty in the significant psychological distress caused by an event is captured by applying the formula to low, best and high estimates of deaths, injuries, and number displaced. Thus the formulaic approach yields a low-best-high index estimate for significant psychological distress. In addition, experts recommended that events scoring higher than 1,000,000 on this index could be considered to result in "high" psychological distress; events scoring between 50,000 to 1,000,000 on this index could be considered to result in "moderate" psychological distress; and events scoring less than 50,000 on this index could be considered to result in "low" psychological distress, in a relative sense.

Limitations

The methodological approach for psychological distress used in the SNRA represents a first attempt to include psychological consequences in a strategic, national-level risk assessment focused on national preparedness. While this approach is straightforward and transparent, it also has important limitations that should be considered when interpreting the psychological distress results:

- Time limitations for completing the SNRA did not allow for a thorough investigation of the structural form of the equation used for computing psychological distress or weights used in the equation. Additional analysis is required to verify and validate this approach, and the sensitivity of the results to the selection of weights in the formula should also be explored. The resulting data and initial analysis have not undergone extensive review by any Federal agency, and have not been extensively verified and validated by the broader community of academic researchers focused on psychosocial effects of disasters.
- The index approach currently does not include a component for translating economic losses into psychological distress. If estimates of homes destroyed and jobs lost (rather than overall direct economic losses) are obtained as consequence estimates for various national-level events, it would be possible to capture financial loss as part of the equation for psychological distress in future iterations of the SNRA.

- The current social displacement measure (counting people as displaced if they are forced to leave home for two or more days) does not differentiate between short term displacement (i.e., short term evacuation) and long term permanent displacement (i.e., the home is destroyed). Ideally, the psychological consequence index would differentiate these two types of displacement, because the long term displacement is much more impactful for "significant distress" and "prolonged distress" psychological consequences.
- The duration of distress is an important factor which is not considered in the current approach. Most people do recover over time, although individuals vary greatly in the speed with which they rebound. Empirical evidence suggests that four out of five people with significant disaster-related distress will recover. In combination with the formula used, this means that the experts consulted estimated that there is 1 psychological casualty (i.e., a person with serious and prolonged distress) for each life lost, for every 5 injures, and for every 10 displacements.

The Department of Homeland Security and its partner organizations are funding social and behavioral science research to better understand how to anticipate, prepare for, counteract, and mitigate the effects of terrorist acts, natural disasters, and technological accidents. This research is intended to explore psychosocial factors that enable resilience and affect recovery in individuals, organizations, communities, and at the national level. Additional results and new insights for preparedness are expected over the next five years. Experts consulted about the psychological consequences measures have emphasized *extreme caution* in using these psychological consequence results. A collection of articles published in a September 2011 special issue of the journal *American Psychologist*[7] relates a succession of mistakes in dealing with psychosocial effects after the attacks. Experts greatly overestimated the number of people in New York who would suffer lasting emotional distress from the September 11, 2001 terrorist attacks, and therapists used methods to soothe victims that later proved to be harmful to some.[8,9]

Major Findings

- Among natural and technological hazards, a pandemic influenza outbreak with similar gross clinical attack rate and case fatality rate to the 1968-1969 Hong Kong pandemic flu has the highest "significant distress" index score for psychological consequences due to deaths and injuries. Its index score is over an order of magnitude greater than that of any other non-adversarial event in the SNRA.
- Hurricanes also are estimated to have high psychological distress index scores in the SNRA. This event is very different in character than pandemic influenza. Pandemic influenza would result in extensive fatalities and illnesses, while the high score of hurricanes is driven primarily by displacement.
- Event preparedness and evacuation planning can reduce "significant distress" by reducing injuries. However, it is difficult to plan capabilities to address long term social displacement when events such as floods, earthquakes, hurricanes, dam failures, etc. cause loss of homes.

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[7] Special issue: "9/11: Ten Years Later." (2011, September 6). *American Psychologist*, 66(6). Available from http://www.apa.org/pubs/journals/special/4016609.aspx.

[8] Carey, B. (2011, July 28). Sept. 11 revealed psychology's limits, review finds. *The New York Times*, A18. Retrieved from http://www.nytimes.com/2011/07/29/health/research/29psych.html.

[9] Cohen Silver, R. (2005, November 10). Psychological Responses to Natural and Man-made Disasters. *The role of social science research in disaster preparedness and response: Hearing before the Subcommittee on Research of the Committee of Science, U.S. House of Representatives, 109th Session* (24-463PS). Washington, DC: U.S. Government Printing Office.

- Experts commented that preparedness and resilience of individuals and communities can be improved over time. As noted, roughly 20% of the exposed population will still experience "prolonged distress" due to an event, but this percentage can be reduced, perhaps down to 5% to 10%, with good community preparedness and resilience. Ongoing social science research will assist federal, state, and local government in better understanding and investing in preparedness and resilience capabilities.

Figure G1: Psychological Distress by National-level Event

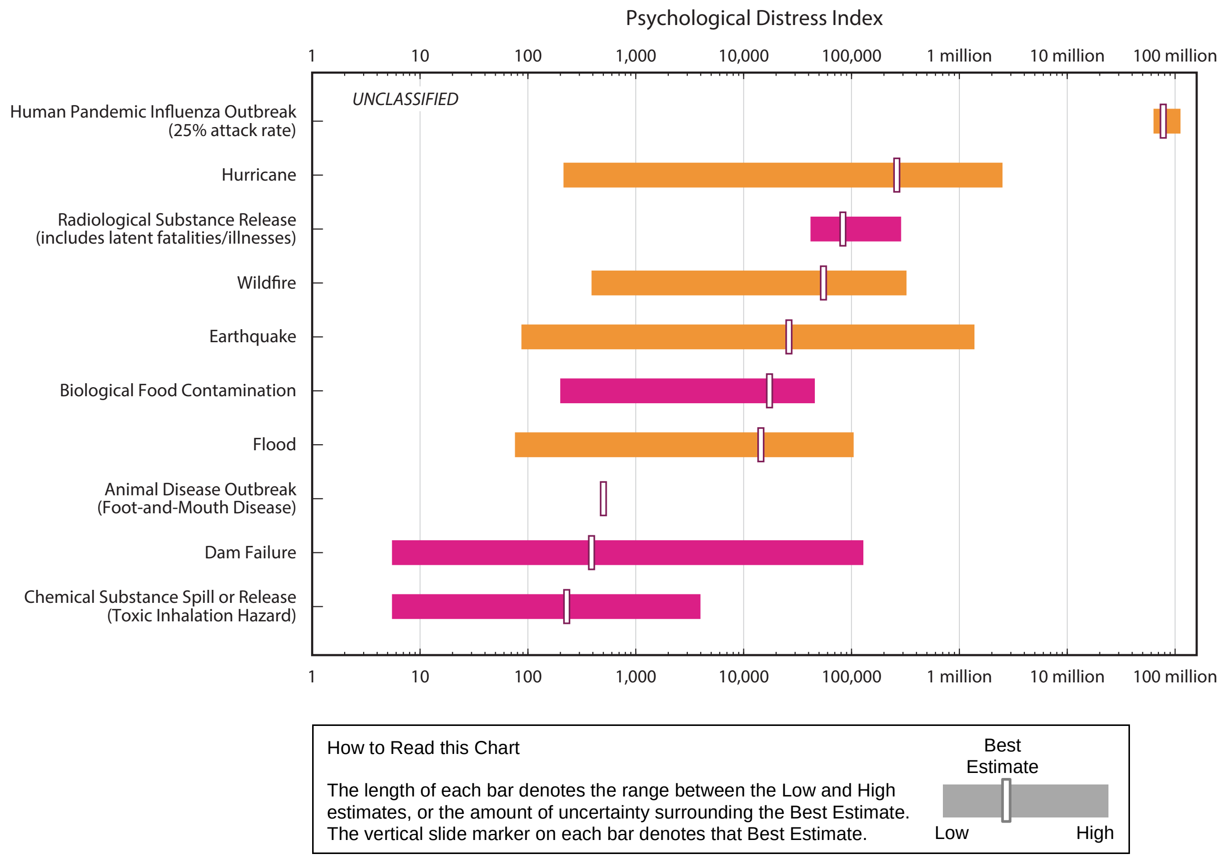

Table G1: SNRA Psychological Distress Data

Threat/ Hazard Group	Threat/Hazard Type	Event Familiarity Factor	Significant Distress Index		Notes/Comments
Adversarial/ Human-Caused	Aircraft as a Weapon	1.2	Low		
			Best		
			High		
	Armed Assault	1.1	Low		
			Best		
			High		
	Biological Terrorism Attack (non-food)	1.3	Low		
			Best		
			High		
	Chemical Terrorism Attack (non-food)	1.3	Low		
			Best		
			High		
	Chemical/Biological Food Contamination Terrorism Attack	1.3	Low		
			Best		
			High		
	Cyber Event affecting Data	1.0	Low	N/A	Index cannot be computed since insufficient information is available for fatalities, injuries, and social displacement.
			Best	N/A	
			High	N/A	
	Cyber Event affecting Physical Infrastructure	1.0	Low	N/A	Index cannot be computed since insufficient information is available for fatalities, injuries, and social displacement.
			Best	N/A	
			High	N/A	
	Explosives Terrorism Attack	1.2	Low		
			Best		
			High		
	Nuclear Terrorism Attack	1.3	Low		
			Best		
			High		
	Radiological Terrorism Attack	1.3	Low		
			Best		
			High		
Technological/ Accidental	Biological Food Contamination	1.0	Low	200	
			Best	17,000	
			High	46,000	
	Chemical Substance Spill or Release	1.1	Low	6	
			Best	230	
			High	4,000	
	Dam Failure	1.0	Low	6	
			Best	390	
			High	130,000	
	Radiological Substance Release	1.1	Low	42,000	
			Best	82,000	
			High	290,000	

Threat/ Hazard Group	Threat/Hazard Type	Event Familiarity Factor	Significant Distress Index		Notes/Comments
Natural	Animal Disease Outbreak	1.0	Low	N/A	Only a best estimate is available because of the underlying displacement data.
			Best	500	
			High	N/A	
	Earthquake	1.1	Low	90	
			Best	27,000	
			High	1,400,000	
	Flood	1.0	Low	75	
			Best	15,000	
			High	100,000	
	Human Pandemic Outbreak	1.0	Low	63,000,000	
			Best	78,000,000	
			High	110,000,000	
	Hurricane	1.0	Low	220	
			Best	260,000	
			High	2,500,000	
	Space Weather	1.0	Low	N/A	Index cannot be computed since insufficient information is available for fatalities, injuries, and social displacement.
			Best	N/A	
			High	N/A	
	Tsunami	1.0	Low	4,300	These estimates are constructed for the case of a tsunami originating from the Cascadia Subduction Zone striking the Oregon coast.
			Best	9,200	
			High	13,000	
	Volcanic Eruption	1.0	Low	4,400	These estimates are constructed for the case of a significant eruption of Mount Rainier.
			Best	85,000	
			High	1,200,000	
	Wildfire	1.0	Low	390	
			Best	55,000	
			High	320,000	

APPENDIX H: ENVIRONMENTAL CONSEQUENCE ASSESSMENT

Note that all comparative statements refer to unclassified assessed consequences, not risks which are in part derived from classified frequency information for the adversarial events.

Overview

The U. S. Environmental Protection Agency (EPA) convened an *ad hoc* group of environmental experts to develop environmental impact estimates for the SNRA. The group of experts included representation from the fields of environmental science, ecological risk, toxicology, and disaster field operations management. The resulting comments and rankings have not undergone review by the EPA and only represent the opinions of the group.

For the purposes of the SNRA, environmental risk was defined as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.[1] Environmental effects within urban areas and all human health effects were not included within the scope of this environmental risk assessment, because these impacts were already addressed separately in the other consequence analyses for the SNRA.

EPA experts judged the relative environmental impact of each national-level event by selecting one of four categories of severity: *de minimis* (or minimal), low, moderate, and high. In doing so, the experts considered the areal extent of the impact, the potential for adverse consequences, and the severity of adverse consequences. The four categories of severity used in the SNRA allow for a relative comparison of environmental impacts between events, but do not provide absolute estimates of impacts for use outside the context of this assessment.

For each event, EPA experts provided a best estimate and a secondary estimate. This was done to capture variability in the potential location of the event, how it might unfold, and/or its areal extent, as well as uncertainty about the adverse environmental consequences associated with the event.

The estimates provided in this environmental impact assessment were developed using rudimentary assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables, such as chemical or biological agent, contamination extent, persistence and toxicity (both chronic and acute), or infectivity.

Major Findings

- Nuclear terrorism attacks and volcanic eruptions were assessed to have high potential for adverse environmental impacts relative to other events, at the best estimate. Both events have in common the potential to disrupt ecosystems over a large area through either airborne nuclear fallout or volcanic ash. The experts used their second choice to mark the chemical terrorism attack (non-food), accidental chemical substance release, accidental radiological substance release, hurricane, earthquake, and tsunami events as having the potential for high environmental impacts. Of all the events, only nuclear terrorism attacks were judged as high environmental consequence events with minimal uncertainty.

[1] This definition is aligned with the EPA's definition of environmental risk. Accessed at: http://www.epa.gov/OCEPAterms/eterms.html .

- Multiple events were judged to have *de minimis* potential for adverse environmental impacts at the best estimate, including armed assaults, cyber events affecting data, cyber events affecting physical infrastructure, and space weather events. Of these, armed assaults and cyber events affecting data were judged to have *de minimis* impacts with high certainty. If the space weather event or cyber event affecting physical infrastructure were to result in extended power outages, the potential for environmental impacts would increase to low/moderate as chemical and treatment plants failed.
- Many terrorism events, with the exception of nuclear and chemical terrorism attacks, are judged to have low or *de minimis* potential for adverse environmental impacts at the best estimate. This is primarily driven by the relatively low areal extent of many terrorism events when compared to natural disasters, especially outside urban areas.
- The meteorological/geological natural hazard events were judged to have moderate or high potential for adverse environmental impacts at the best estimate, with the exception of space weather. This is driven by the potential for large areal extent.
- All events in the technological/accidental hazards category, including biological food contamination, chemical substance release, dam failure, and radiological substance release, were judged to have moderate environmental impacts at the best estimate.

Table H1: SNRA Environmental Impact Data and Comments

Threat/ Hazard Group	Threat/Hazard Type	Best Estimate	Second-Best Estimate	Comments
Adversarial/ Human-Caused	Aircraft as a Weapon	Low	Moderate	Low; one airplane could cause tens of acres of environmental impact of a limited duration, likely within an urban environment. Could be moderate depending upon the target (e.g., a chemical plant).
	Armed Assault	*De minimis*	*De minimis*	Minimal environmental impact.
	Biological Terrorism Attack (non-food)	Low	Low	Depends upon agent and persistence, but potential for environmental consequences is low given focus on human disease. Highest environmental consequences would be an incident resulting in an increase in animal disease. Disposal of contaminated waste could result in higher consequences.
	Chemical Terrorism Attack (non-food)	Moderate	High	Aquatic run-off could disseminate a persistent chemical and increase the impact on the environment, depending upon the chemical. Toxicity, spread, and persistence of chemical agent would be the defining characteristics that change the impacts from moderate to high (or low).
	Chemical/Biological Food Contamination Terrorism Attack	Low	Moderate	Since the effect is directed toward humans, this should have low impact. If introduced into an agricultural setting, there could be impact on the local ecosystem. There could be a waste disposal issue, and depending upon the contaminant and the volume of material this could be significant.
	Cyber Event affecting Data	*De minimis*	*De minimis*	Minimal environmental impact.
	Cyber Event affecting Physical Infrastructure	*De minimis*	Low	Depends upon target and duration. For a short power outage (day to few days), the impact would be relatively minimal. If a power outage persisted for weeks, then there is potential for failure of backup systems. Once backup systems (diesel fuel delivery, etc.) fail, treatment plants and chemical plants failing could have a significant impact.
	Explosives Terrorism Attack	Low	Moderate	Low, but if a water treatment plant or chemical plant were targeted, the impact could increase to moderate.
	Nuclear Terrorism Attack	High	High	High, due to duration, size of affected area, and toxicity. A large, dirty device detonated in a metropolitan area could create a large fallout trail of highly persistent material. There may be high levels of fallout material for dozens of miles, and outside the city limits. The long-term environmental impact may be moderate; the isotopes could be remediated, and if the area is zoned off-limits for human use (similar to Chernobyl), there is potential for the environment to return to a state that is more

Threat/ Hazard Group	Threat/Hazard Type	Best Estimate	Second-Best Estimate	Comments
				pristine than the initial state.
	Radiological Terrorism Attack	Low	Moderate	Likely low, given the relatively low toxicity of the likely materials and the relatively low area for dispersion. Moderate if there is fallout outside the urban area.
Technological/ Accidental	Biological Food Contamination	Moderate	Low	Moderate, but could be low if the specific event involves a biological agent with a low probability of impacting native species. Moderate impacts would most likely result from either waste disposal (e.g., disposing of food supply that had become contaminated) or dissemination of an infectious agent through some type of accidental application (e.g., pesticide application in crops). If the agent just affects people, the environmental/ecological impact would be low.
	Chemical Substance Spill or Release	Moderate	High	Widespread release of an acutely toxic compound would result in moderate impacts. Could impact tens to thousands of acres with lethal material. Release of acutely toxic materials in a low-populated area would lead to greater ecological damage than a release in an urban area. The more persistent the chemical, the greater the impact. There is a potential for water contamination, which could elevate this to a high impact.
	Dam Failure	Moderate	Moderate	Water released could impact a significant area, but the duration of impact would likely be relatively short term, with a year or more for recovery.
	Radiological Substance Release	Moderate	High	Nuclear power plant disruption (e.g., Fukushima) could cause radioactive airborne releases that could travel for large distances and settle into down-range eco-systems, with possible disruptions. In addition, releases into water bodies may have impacts on aquatic life.
Natural	Animal Disease Outbreak	Low	Moderate	Depends upon the acreage required for disposal of infected carcasses. There is some potential for introduction into wild animal populations, which could lead to re-introduction into crop animal species from the wild animals and greater economic losses.
	Earthquake	Moderate	High	Debris, devastation, and resulting chemical/contaminant releases have the potential to impact large areas.
	Flood	Moderate	Moderate	Flooding of agricultural areas is a typical impact. The severity of the impact depends upon whether there is release of contaminants from urban areas.
	Human Pandemic Outbreak	Low	Moderate	Impacts become moderate in cases where the pandemic is significant enough that

Threat/ Hazard Group	Threat/Hazard Type	Best Estimate	Second-Best Estimate	Comments
				environmental protection resources are diminished (e.g., garbage collection is halted due to sanitation workers not working due to illness or concern about becoming ill).
	Hurricane	Moderate	High	Hurricanes can cause ecological impacts, beach erosion, nutrient loading, chemical contamination, salt water intrusion into fresh water bodies, and removal of plants leading to erosion. Large areas can experience impacts.
	Space Weather	*De minimis*	Moderate	Depends upon duration of power outage. For a short outage (day to few days), the impact would be relatively minimal. If a power outage persisted for weeks, then there is potential for failure of backup systems. Once backup systems (diesel fuel delivery, etc.) fail, treatment plants and chemical plants failing could have a significant impact. The difference between this event and the Cyber Event affecting Physical Infrastructure event is that a space weather event would most likely affect a much greater geographic area and has the potential for a longer duration.
	Tsunami	Moderate	High	Depends upon the precise location, barriers, and channels along the coast.
	Volcanic Eruption	High	Moderate	Potential for disruption of aquatic life, ecosystems, etc., over a large area. In addition, there is potential for long-term climate change effects if the airborne plume is extreme.
	Wildfire	Low	High	Many wildfires have low long-term effects on ecosystems and can provide longer-term benefits such as reseeding of plants and assisting the growth of forested areas. If the wildfire threatens an urban U.S. setting, the fire could envelop oil/chemical storage tanks and cause widespread release of such materials, resulting in high environmental impacts.

APPENDIX I: THRESHOLDS IN THE SNRA

National-Level Events

To inform homeland security preparedness and resilience activities, the SNRA evaluated the risk from known threats and hazards that have the potential to significantly impact the Nation's homeland security. These included natural hazards, technological/accidental hazards, and adversarial, human-caused threats/hazards.

For assessment in the initial SNRA, participating stakeholders – including Federal agencies, DHS Components, and the intelligence community, among others – developed these threats and hazards into a list of ***national-level events*** having the potential to test the Nation's preparedness.

For the purposes of the assessment, DHS analysts identified thresholds of consequence necessary to create a national-level event. These thresholds were informed by subject matter expertise and available data, and are given in Table 2 at the front of this report.

The selection of appropriate thresholds for each event was among the most significant challenges for the SNRA project.

- As the Nation's preparedness may be challenged by events having impacts across any or all of the consequence categories of the SNRA, it is not possible to identify any one generic consequence threshold capable of adequately capturing this distinction for all the hazards in the SNRA.
- Wherever possible, common thresholds across multiple events were sought to minimize the total number of different threshold criteria needed to define the set of national-level events as a whole. However, the unique impacts of each event, and in many cases data availability,[1] precluded the assignment of every event to a larger, harmonized-threshold class.

Since there is no one objective or context-independent answer to this question, these determinations ultimately came down to the best, but human, judgment of the SNRA project team.

- For some events, economic consequences were used as thresholds. For others, fatalities or injuries/illnesses were deemed more appropriate as the threshold to determine a national-level incident.
- In no case, however, were economic and casualty thresholds treated as equivalent to one another (i.e., dollar values were not assigned to fatalities).

Event descriptions in Table 2 that do not explicitly identify a threshold signify that no minimum consequence threshold was employed. This allows the assessment to consider events for which the

[1] During the SNRA's review process, several stakeholders noted that the SNRA's thresholds tend to be on the low side compared with what many people consider to be a truly catastrophic event (for instance, the threshold of NOAA's Billion Dollar Disaster List). As noted below, a low choice of threshold may not appreciably affect a best estimate risk calculated by multiplying the average likelihood and consequence measure of a set of events. However, it can significantly depress best estimate consequences when they are calculated as an average of the set of events, and the low and high consequence estimates when they are calculated as percentiles of the distribution defined by the set.

For many events, however, limited quantitative data comprised a significant constraint on the range of thresholds which could be practically selected in the SNRA. Although the high-consequence 'tail' of more catastrophic incidents may be of greater interest for many purposes, the higher the threshold selected to isolate these incidents the sparser becomes the data set used to determine the estimates characterizing the event. By including more historical incidents or modeled data points within the scope of an event, lower thresholds maximize the data fidelity of the set used to determine quantitative estimates and hence the defensibility of these estimates.

psychological impact of an event could cause it to become a national-level event even though it may result in a low number of casualties or a small economic loss.

- For example, any terrorist attack resulting in the successful release or detonation of a chemical, biological, radiological, or nuclear weapon, even if it resulted in no fatalities or injuries, would be considered a national-level event for the purposes of the SNRA.
- By contrast, a much higher threshold was set for the accidental Biological Food Contamination event, requiring a multi-state outbreak resulting in 100 or more hospitalizations[2] for an incident to be considered a national-level event. Unintentional food poisoning is estimated to cause 3,000 deaths, 128,000 hospitalizations, and 48 million illnesses every year in this country.[3] However, the very ubiquity of this hazard makes it such a part of the background level of risk addressed by steady-state national capabilities that only the largest and most consequential outbreaks were considered to rise to a level of impact characteristic of a national-level event.[4]

Assessed best estimates of annualized *risk*, when calculated by multiplying the average likelihood and average consequences of a set of incidents, may be relatively insensitive to threshold choices. However, this is not generally true for the best estimates of *likelihood* and *consequence* individually reported by the SNRA, or for those high estimates of consequence which represent percentiles of a distribution. These differences can have significant implications for risk communication, and are discussed at further length below.

Best Estimates in the SNRA

The best estimates of consequence measures in the SNRA were assessed by different methods, depending on the particular consequence type and event.

Social displacement best estimates, with a few exceptions, were chosen according to the best judgment of subject matter experts and analysts who conducted the research for these estimates. The qualitative environmental impact estimates represent subject matter expert judgment. Some of the SNRA national level events leverage subject matter expert judgment for their best estimates on other consequence metrics as well.

For most events in the SNRA, best estimates for fatality, injury/illness, and direct economic consequence measures represent the weighted average consequences over a distribution of possible consequences, given an event occurrence. Weighted average consequence is a measure of the average impact (number of fatalities, illnesses/injuries, or cost) across a set of scenarios.

[2] Note that neither of these two criteria, nor the successful-release criterion of the CBRN terrorist attack events, directly corresponds to measures of consequence used by the SNRA. These further illustrate the difficulty of capturing the factors elevating an incident to the level of a 'national-level event' capable of challenging national preparedness by some single, simple and uniform quantitative measure.

[3] U.S. Centers for Disease Control and Prevention (2011). *CDC Estimates of Foodborne Illness in the United States.*

[4] Since this highly restrictive definition excludes all but a very few incidents of this type, the SNRA's reported consequence estimates for accidental food contamination are lower than these annual national totals by two orders of magnitude. This discrepancy may give the appearance that the SNRA substantially understates the risks from a well known hazard. The reason for this apparent discrepancy is that the SNRA attempts to capture not the annual death toll of known and constant hazards which are handled by steady-state capabilities, but the small set of exceptional incidents having disproportionate potential to cause harm and disruption because steady state capabilities are not prepared to handle them. For the accidental food contamination event, such incidents comprise only a very small subset of all such accidents, even of those causing injury, illness, and death, occurring every day in this country.

- For estimates derived from a data set of historical incidents, the weighted average is simply the average of the set.
- For estimates derived from modeled distributions, weighted average consequences are constructed by weighting each scenario in the set by its relative likelihood, such that more probable scenarios have greater influence on the mean impact.[5]

When a set of incidents (or a modeled distribution) chosen to represent a national-level event has consequences distributed over several orders of magnitude – that is, there are many small-consequence incidents and a few very large-consequence incidents – a best estimate of risk that is calculated by multiplying an average likelihood of occurrence by a weighted average consequence is relatively insensitive to the choice of minimum threshold that is used to define the national-level event.

- As a concrete illustration, a set of historical incidents for a set defined by a threshold of 1 or more fatalities might have ten incidents with fatalities {1, 1, 1, 1, 2, 2, 3, 5, 9, 200}, occurring over ten years. The average frequency of occurrence is 1 per year (10 in 10 years = 1/year). The average of the set is 22.5 fatalities. Then the best estimate fatality risk would be 1 event/year × 22.5 average fatalities/incident = 22.5 fatalities/year.
- Selecting a different threshold of 100 fatalities will reduce the set to only one member, {200}. Because only one incident in ten years is counted instead of ten, the likelihood (1 in 10 years = 0.1 incidents/year) of this set is one-tenth of what it was before. However, the average of this new set is 200 fatalities. The best estimate risk would then be 0.1 incident/year × 200 average fatalities/incident = 20 fatalities per year. This is similar to the calculated risk of the original set, even though it is defined by a much higher threshold.[6]

While resourcing decisions often use best-estimate annualized risk as a primary measure of comparison, operational planning and policy decisions must consider a more complex picture of risk which focuses on measures of likelihood and consequence separately. This is especially true for decisions taken from a preparedness standpoint. Continuing the example above, front-line stakeholders must be able to effectively respond to both the frequent 1 fatality incidents and the rare 200 fatality catastrophe, not the 22.5 average fatality incident which is never seen. For such decisions, the use of a weighted average may be misleading.

For hazards dominated by a large number of low-consequence incidents and a relatively smaller number of very high-consequence incidents, the average-consequence best estimates may mask the low and high consequence scenarios which will be of most interest to decision-makers in many contexts. Communicating information about higher and lower consequence scenarios is one of the reasons for the SNRA's emphasis on representing variability and uncertainty in its estimates.

[5] Description of weighted average consequence adapted from the 2011 ITRA, page 2-7. DHS Directorate of Science & Technology (2011), Integrated CBRN Terrorism Risk Assessment (reference is SECRET/NOFORN; extracted information is UNCLASSIFIED).

[6] It is worth noting that the annualized risk is actually *higher* for the set having a lower threshold. Lower minimum thresholds only add more incidents to the set being counted as a whole. This counterintuitive property is generically true for any annualized risk measure calculated in this manner.

Variability and Uncertainty in the SNRA

The SNRA reports both high and low bounds, in addition to best estimates, as part of its treatment of uncertainty in frequency and consequence. Uncertainty in the SNRA includes both uncertainty in our *knowledge* about an event, and *variability* over a known range or distribution of consequences for an event.[7,8] This distribution, if known, may indicate the relative probabilities of different consequences should an incident of this type occur. However, it is insufficient to definitively predict what the magnitude of the *next* incident will be.

Examples of sources of uncertainty include incomplete knowledge of adversary capabilities and intent, uncertainty in the effectiveness of countermeasures, variability in possible event severity and location, and lack of historical precedence.

The SNRA captures uncertainty in various ways, depending on the data source:

- For frequencies derived from the historical record, upper and lower bounds are estimated using the historic maximum number of occurrences per year and the longest time gap between historic occurrences.
- For frequencies derived from expert elicitation, uncertainty is captured using structured techniques to determine the 5th and 95th percentile confidence intervals.[9]
- For consequences derived from the historical record, upper and lower bounds are estimated from the highest and lowest consequences in the observed set of past events.
- For consequences derived from previous terrorist risk assessments, 5th and 95th percentile confidence intervals were estimated, which take into account terrorist capabilities and preferences in weapon and target selection.

In many cases, the high estimates for consequence measures in the SNRA were constructed from either historic maximums (e.g., natural hazards) or the 95th percentile of a modeled distribution (e.g., terrorism events). These measures were chosen for defensibility, and for consistency with common practice of reporting the 95th percentile as a "reasonable worst-case scenario" useful for many decision contexts.

However, this reporting choice means that the high estimates associated with each national-level event may not be reflective of the consequences which may occur from what would be considered a "worst-case scenario" in other decision contexts. For planning purposes, in particular, it may be important to recognize that consequences of events have a small probability of being higher than the estimates of consequences reported in the SNRA. By definition, there is a 5% chance that the consequences given an attack or incident could be higher than an estimate drawn from the 95th percentile.

To help illustrate this concept, Figure I1 displays an alternate visualization of the fatality consequence data for the SNRA natural hazard events taken as a whole, incorporating the full range of consequences reflected by the data.[10]

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[7] These two types of uncertainty are sometimes referred to as epistemic (knowledge) uncertainty, and aleatory (probabilistic) uncertainty.

[8] This description is something of an oversimplification for explanatory purposes. For events such as natural hazards where the range of frequencies come from a well-defined historical record and represent the observed variability in timing between successive incidents (inter-arrival times), reported frequency ranges represent variability (the measure from the data set) as much as uncertainty in our knowledge (of how representative the historical data set will be of similar events over the next 3-5 years [the timeframe of the SNRA]).

[9] It is important to note that, however they are determined, low and high frequency estimates do not correspond to the low and high consequence estimates. In other words, the high frequency is not the expected frequency of an incident occurring which results in the high consequences on one or more metrics.

Figure I1: Natural Hazard Risk: Probability of Exceedance given Event Occurrence (Fatalities)

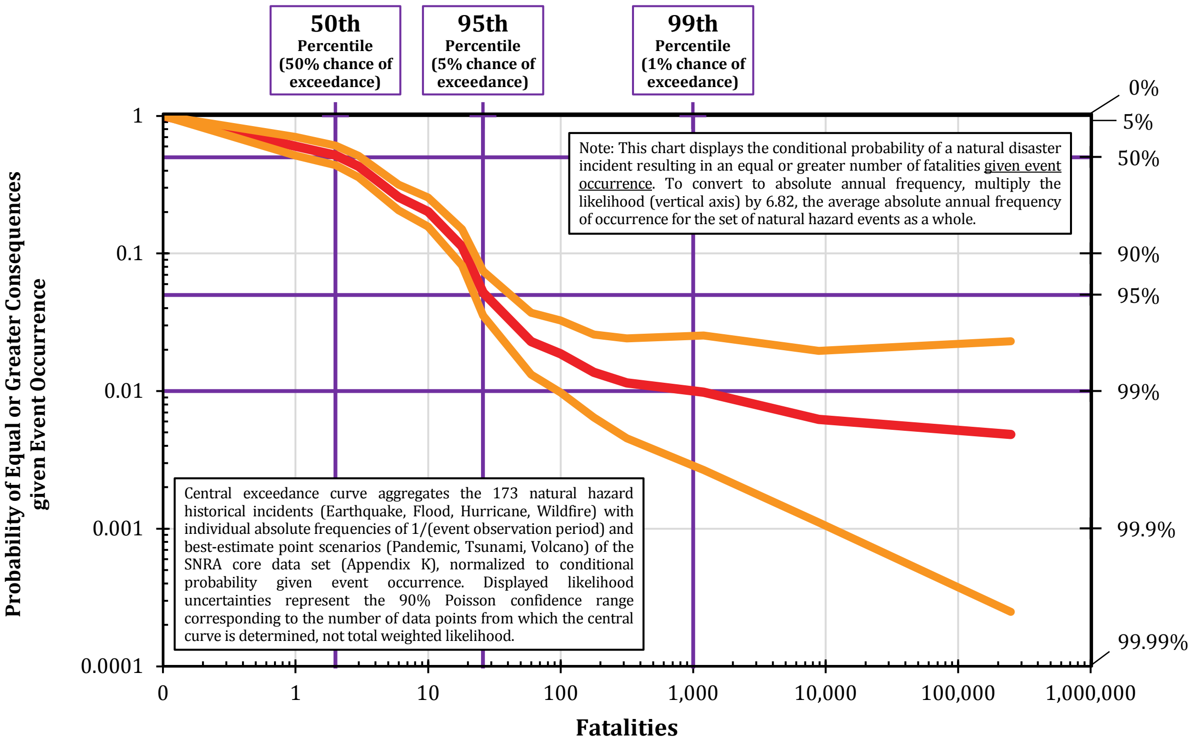

Figure I1 displays a set of *exceedance curves.* These represent the estimated frequency with which a natural hazard event, given occurrence, will[11] be equal to or greater than the corresponding consequence according to this model.[12] The middle curve represents the best estimate (expected) exceedance curve, while the surrounding curves represent the uncertainty. The violet crosshairs indicate the 50th percentile (median), 95th percentile, and 99th percentile of consequences, in this case fatalities.

- The 50th percentile disaster, on the best estimate (middle) curve, corresponds to two fatalities. This means, given the occurrence of a natural hazard incident from the set of events meeting the thresholds of inclusion for the SNRA (e.g. an earthquake, flood, hurricane, or wildfire causing $100 million or greater of direct economic damage, or

[10] Note that all charted uncertainties correspond to the 90% Poisson confidence interval for the corresponding number of events, plotted as ratios of the central estimate, following the convention of WASH-1400 chapter 6 (footnote 12). This includes the point scenario events (Pandemic, Tsunami, Volcano): although low and high likelihood estimates were provided by the same methods as the best estimate for these events, their comparability with the 90% Poisson interval used for historical incident data points was unknown and so the best estimate likelihood was used uniformly, including the largest-fatality point (Pandemic).

[11] All instances of "will" in the following mean "according to this model, will". Additionally, all statements in the following refer only to the best estimate (red) exceedance curve, and do not account for the model uncertainties represented in part by the orange lines, nor to the substantial additional uncertainties deriving from the many significant limitations of the SNRA method and data set.

[12] This type of exceedance curve, where the event is assumed to have already occurred (the total probability is normalized to 100%), is called a conditional cumulative distribution function (CCDF). Exceedance curves can also show the absolute likelihood of an event of a particular magnitude (or greater) occurring: these are sometimes referred to as F-N curves. A good example of exceedance curves used in a context similar to that of the SNRA may be found in chapter 6 of the 1975 Reactor Safety Study (WASH-1400), also referred to as the Rasmussen Report. Rasmussen, Norman, U.S. Nuclear Regulatory Commission (1975, October). *Reactor Safety Study: An assessment of accident risks in U.S. commercial nuclear power plants.* WASH-1400 (NUREG 75/014). Available at http://teams.epri.com/PRA/Big%20List%20of%20PRA%20Documents/WASH-1400/02-Main%20Report.pdf.

pandemic, animal disease, tsunami, or volcano events on the scale of the SNRA best-estimate scenarios[13]), 50% of these incidents will result in zero or one fatalities, and 50% will result in two or more, at the best estimate.

  - Although not marked on the chart, one fatality is approximately the 40th percentile on the best estimate curve. This means that while 60% of the natural disaster events considered in the 2011 SNRA will result in one or more human fatalities, 40% – nearly half – will result in no human fatalities at all, at the best estimate.

- The 95th percentile disaster in terms of fatalities is 26, on the best estimate curve. This means that 95 out of a hundred such disasters (95%) will result in 25 or fewer fatalities, but five out of a hundred (5%) will result in 26 or more, at the best estimate.
- The 99th percentile disaster on the best estimate curve is approximately one thousand fatalities.[14] This means that 99 out of every 100 such disasters will result in fewer than 1,000 fatalities. However, one in a hundred such disasters will result in 1,000 fatalities or more, at the best estimate.[15]
- Other percentiles corresponding to specific consequence thresholds (i.e. 10, 50, 100) may be read by drawing crosshairs centered on the red exceedance curve: after drawing a vertical line from the consequence (horizontal) axis, the horizontal crosshair will indicate the corresponding percentile on the likelihood (vertical) axis.

These curves are normalized to relative frequencies (a maximum of 100%) to illustrate the use of percentiles for reporting consequence estimates in the SNRA, and to illustrate how different selections of percentile can result in seemingly dramatically different "reasonable worst-case" scenarios being reported from the same underlying data.

These relative frequencies can be converted to absolute frequencies (actual number of events occurring per year) by multiplying by 6.82, the total annual frequency of occurrence of this set of events as a whole. In other words, the Nation may expect to be challenged by an average of seven natural disaster incidents (including human pandemics) meeting the minimum threshold of the SNRA every year, or about one every two months on the average. Nearly half of these will result in no human fatalities at all. However, half will result in two or more, five of every hundred will result in more than 25, and one of every hundred will result in 1,000 fatalities or greater, at the best estimate.

As noted above, high estimates of consequences for many events in the SNRA correspond to the 95th percentile.[16] However, significant dialogue within the preparedness community is needed to define the level of potential consequences for which the community should be planning. The SNRA is the first U.S. national all-hazards risk assessment reporting its findings as quantitative and directly comparable measures of risk: among its contributions are a methodology and an initial data set which make it possible to ask this question, and see what different answers would look like. One such choice of levels, determined by the data and reporting thresholds selected for the first

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[13] The tsunami and volcano event scenarios are included: their partial coverage of the national risk space which precluded event-to-event comparison in the SNRA's charts and findings does not present an issue for aggregation across events.

[14] Within the degree of precision of the data set (173 points) and the numerical interpolation of the charted curve.

[15] The data points in this 1% include the 1906 San Francisco earthquake, Hurricane Katrina, and the Human Pandemic Influenza Outbreak scenario (Appendix K).

[16] For individual natural hazard events leveraging finite data sets, high estimates also correspond to the highest percentile of each event's data set. For example, the high value of a set of twenty data points also represents the 95th exceedance percentile of that set (the top 5% or top 1/20th), and the high value of a set of fifty data points represents the 98th exceedance profile (the top 2%) of that set.

iteration of the SNRA, may be seen in the visual depictions of the SNRA's likelihood and consequence estimates presented throughout this report.

However, it is only one such choice, and one which was primarily motivated by data availability and past practice in the Department which led the execution of the first SNRA. Many other choices are possible, and equally valid. These considerations pertain not just to the internal math and methodology of the SNRA, but political, normative, and practical considerations determined by the larger context for which the SNRA was commissioned and used. For this reason, active stakeholder engagement across the emergency preparedness community, the federal interagency, and the homeland security enterprise will be key to improving and refining the thresholds and measures used in the next iteration of the SNRA.

APPENDIX J: RISK SUMMARY SHEETS

Contents

For each national-level event, the research, assumptions, and data which were used to produce the low, best, and high estimates of likelihood and measures of consequence were documented in an event-specific risk summary sheet by the SNRA project team. Summary sheets with common reporting formats to document staff research and analysis of individual hazards have been used by past comparative risk assessments, in part because of their utility in guiding research efforts to identify data capable of being expressed in terms of a predetermined set of measures designed to be comparable across all events.[1]

The risk summary sheets shared a standardized data table format to facilitate the comparability and harmonization of estimates across diverse events (Table J1). This table specified the categories, types, and most importantly the metrics which were to be used to measure likelihood and each type of consequence. Each of these was baked into the table to ensure that what the numbers meant would be communicated with them. As space considerations precluded printing the whole table in each summary sheet in this compilation, the original is presented below so that it will accompany them as a set.

Because of the heterogeneity and roughness of these internal risk summary sheets, they were not originally included with the review drafts of the SNRA technical report. However, stakeholder concerns raised in the review process, which could not be answered without reference to the source documentation contained in the individual event risk summary sheets, made it apparent that the SNRA results as otherwise presented could not be fully understood or replicated without the additional documentation they provided: and so they are included here.

In their present form, these summary sheets are essentially the staff research notes of the SNRA project team. At the time of their finalization, they were not contemplated as potential parts of the ultimate SNRA documentation for external stakeholders. They are highly heterogeneous in style, format, depth, and approach. No attempt has been made to standardize them beyond correcting typos, clarifying obscure points, and fixing or completing missing documentation such as incomplete footnotes, broken links, or omitted sources. The reader should expect such variations and use these sheets as supplementary documentation to the main report as needed, rather than as polished products intended to stand on their own.

Other than substantial reformatting to compress them into a minimum number of pages, few significant changes have been made to the 2011 summary sheet drafts for the natural hazard, technological accident, and cyber events. The summary sheets for the remaining adversarial events required substantial rewriting to remove For Official Use Only text.[2] For the most part, however, these U//FOUO portions were provided as general overview and background text for the different events rather than SNRA-specific analysis or explanation of data origins. These extended overview and background portions were removed wholesale, and replaced with text content from DHS and USG documents prepared with the same purpose but for the public.

- The most significant losses, unfortunately, included details of the economic modeling performed for several adversarial events using the Risk Informed Process for Improved Decision-making (RAPID) calculational engine, the flagship analytic product of the former DHS Office of Risk Management & Analysis (RMA) which led the design and execution of the first SNRA. As much generic non-FOUO description of the procedures and parameters used for the economic modeling as possible was included to communicate the flavor and general approach of its methodology. However, as nearly all details of the RAPID model are FOUO it was not possible to communicate sufficient detail for end users to replicate the method for use in other contexts.

Other than these differences, incorporation of data missing from the summary sheets but communicated to FEMA separately, and a few minor corrections, the unclassified data and analysis communicated in the following pages are the same unclassified data and analysis communicated to FEMA in September 2011 to inform the National Preparedness Goal.

The primary documentation of how the (classified) quantitative frequency, fatality, injury/illness, and economic damage estimates for the five CBRN terrorist attack events were obtained are the reports of the 2011 Integrated CBRN Terrorism Risk Assessment (ITRA), and the Biological, Chemical, and Radiological-Nuclear Terrorism Risk Assessments (BTRA, CTRA, RNTRA) which the ITRA integrates and harmonizes. Because of the great complexity of these computational engines, other than the unclassified event overviews and documentation for the social displacement, psychological distress, and environmental consequence measures, the summary sheets for these events include only those parameters needed to validate or replicate the SNRA's results using the ITRA engine.

All frequency estimates for the adversarial events, including the cyber events, and all the fatality, injury/illness, and economic consequence estimates for the five CBRN events are classified SECRET or SECRET// NOFORN.[3] For these data and the U//FOUO conventional terrorist consequence data discussed above, the reader is directed to the appendices of the full SNRA technical documentation.

[1] Lundberg, Russell (2013, September). Comparing homeland security risks using a deliberative risk ranking methodology. Dissertation, Pardee RAND Graduate School, RAND document RGSD319; at http://www.rand.org/about/people/l/lundberg_russell.html#publications. Willis et al (2012). Comparing security, accident, and disaster risks to guide DHS strategic planning. *Current Research Synopses* paper 43, RAND Corporation, and the National Center for Risk and Economic Analysis of Terrorism Events (CREATE), University of Southern California. Near-final draft versions of the ten risk summary sheets in the back of Dr Lundberg's dissertation were kindly provided to the SNRA project by RAND in early 2011 to assist in project formulation. Lundberg's dissertation research paralleled (and in a number of ways went further than) the SNRA project: it is the only other current comparative U.S. national risk assessment and is comparable to the SNRA in scope, methodological approach, and source research.

The risk summary sheet documentation has been used in the past for comparative ecological risk assessments in particular: see Willis et al (2004, April), Ecological risk ranking: development and evaluation of a method for improving public participation in environmental decision making, *Risk Analysis* 24(2) 363-78; Florig et al (2001), A deliberative method for ranking risks (Parts I, II), *Risk Analysis* 21(5) 913-937; and Fisheries and Oceans Canada (2012), Terms of Reference, Risk-based Assessment of Climate Change Impacts and Risks on the Biological Systems and Infrastructure within Fisheries and Oceans Canada's Mandate: http://www.dfo-mpo-gc.ca/csas-ssca/Schedule-Horraire/2012/11_15-17-eng.html (electronic resource: retrieved July 2013). See Lundberg (2013) for additional discussion of risk summary sheets in comparative risk assessment.

[2] There are also classified versions of the risk summary sheets, but as these exist on compartmented systems only the FOUO versions were needed for this section.

[3] No quantitative fatality, injury/illness, or economic consequence estimates were determined for the two cyber events.

Table J1: SNRA Risk Summary Sheet Data Table

TABLE OF FINDINGS

Category		Description	Metric	Low	Best	High
CONSEQUENCE	Health and Safety	Fatalities	Number of Fatalities			
		Injuries and Illnesses	Number of Injuries or Illnesses			
	Economic	Direct Economic Loss	U.S. Dollars			
		Indirect Economic Loss	U.S. Dollars			
	Social	Social Displacement	Number of Displaced from Homes for ≥ 2 Days			
	Psychological	Psychological Distress	Qualitative Bins			
	Environmental	Environmental Impact	Qualitative Bins			
LIKELIHOOD		Frequency of Events	Number per Unit of Time			

Animal Disease Outbreak

An unintentional introduction of the foot-and-mouth disease (FMD) virus into the domestic livestock population in a U.S. state.

Data Summary

In the following table, note that the low and high likelihoods do not correspond to the low and high consequences. In addition, low and high consequences are not necessarily correlated with each other between different consequence categories.

Description	Metric	Low	Best	High
Fatalities	Number of Fatalities	0[1]		
Injuries and Illnesses	Number of Injuries and Illnesses			
Direct Economic Loss	U.S. Dollars	$2.3 Billion	$15.2 Billion	$69.0 Billion
Social Displacement[2]	Displaced from Homes ≥ 2 Days	0	1,000	N/A[3]
Psychological Distress	Qualitative Bins	See text		
Environmental Impact	Qualitative Bins[4]	Low[5]		
Frequency of Events	Number per Year[6]	0.04	0.1	0.1

Event Background

Foot and mouth disease (FMD) is one of the most devastating diseases affecting cloven-hoof animals such as cattle, swine, sheep and deer. The viral disease is highly contagious, with 7 types and more than 80 sub-types, and vaccination for one type does not confer immunity to the others. Additionally, the FMD virus can survive freezing temperatures but not temperatures above 50 degrees Celsius.[7] Thus far, a pan-viral vaccination that would protect against all types has not been developed. FMD is easily transmitted and spreads rapidly through respiration and through contact with milk, semen, blood, saliva and feces. Pigs are particularly efficient amplifiers of the disease as they shed large amounts of virus into the air, while cattle are highly susceptible to the airborne-transmitted virus, owing to the large lung capacity and high volumes of air these animals respire. The FMD virus remains viable for long periods of time in both animate and inanimate objects and can be spread by contact with:

- Animals
- Animal products, such as meat, milk, hides, skins and manure
- Transport vehicles and equipment
- Clothes and shoes
- Hay, feed and other veterinary biologics
- Human nasal passages and skin

While there are no significant human health implications of FMD, an outbreak of the disease can have important economic consequences. FMD is found in 60 percent of the world's countries and is endemic in many countries in South America, Africa, Asia and the Middle East. The international community values products that come from FMD-free countries and typically restricts trade in FMD-susceptible products from endemic countries or those affected by an ongoing outbreak. The Office International des Epizooties (OIE), an intergovernmental organization comprised of 158 member countries, was established in 1924 to guarantee the sanitary safety of world trade by developing rules for international trade in animals and animal products. OIE classifies member countries, or zones within countries, as being FMD-free with or without vaccination; the U.S. currently does not vaccinate for FMD and maintains an FMD-free without vaccination status. When an outbreak of FMD occurs in an FMD-free without vaccination country, OIE standards require that country wait 3 months after the last reported case of FMD when a "stamping out" approach has been used for eradication to apply for reinstatement of FMD-free status. If vaccination is used in the eradication process, the country cannot apply for reinstatement of FMD-free status until 3 months after the last vaccinated animal is slaughtered, or 6 months if the animal(s) are vaccinated and not slaughtered. In all cases, serological surveillance evidence must be submitted to prove the disease has been eradicated.

Given the value placed on FMD-free status, a confirmed case of FMD in the U.S. would result in an immediate restriction of exports. The current control strategy (9 CFR 53.4 Destruction of Animals with FMD) in USDA Animal and Plant Health Inspection Service (APHIS) regulations to regain FMD-free status is to stamp out, or cull all infected and susceptible animals.[8] The APHIS Administrator has discretion to examine other options based on the size and/or extent of an outbreak.

Assumptions

Economic Impact

For this scenario, a potential introduction of the disease in California is considered. Although limited to one state, a single case of FMD can be considered a national-level event with repercussions across the country.

Carpenter et al[9] studied epidemic and economic impacts of FMD virus spread and control using epidemic simulation and economic optimization models. The simulated index herd was a single 2,000 cow dairy herd located in California. Although the initial infection was presumed to come from an FMD infected feral swine, similar results would come from any single infected animal introduced to the herd. Disease spread was limited to California, but economic consequences, including international trade effects, were felt throughout the U.S. There were five separate index detection delays examined, ranging from 7 to 22 days, with 100 iterations each. This led to a median economic impact estimated at $2.3-$69.0 billion, depending on the number of days delay until detection of disease. The "Low" and "High" estimates on economic burden are extrapolated from these numbers. Similarly direct costs and indirect costs are calculated from these totals. The indirect costs may be significantly higher given the variability in the potential costs listed above. The best case estimate is based on a detection delay of 14 days. This number is extremely difficult to estimate since the actual time from infection to diagnosis is impossible to ascertain.

The direct economic impact of an FMD outbreak will come from an immediate reduction in lost international trade as well as disease control and eradication efforts, which include the cost of:

- Maintenance of animal movement controls
- Control areas
- Intensified border inspections
- Vaccines
- Depopulation
- Carcass disposal
- Indemnification to farmers for losses
- Disinfection and decontamination efforts

Indirect costs can include:

- Impacts on local economies
- Loss in upstream/downstream industries
- Reduction in visitorship and tourism loss
- Treatment of groundwater or other environmental remediation necessitated by carcass disposal or burning
- Land value implications on animal disposal property
- Changes in livestock and meat industry structure
- Short term adjustments in meat consumption based on real or uncertain information[10]

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as

[1] There are no significant human health implications resulting from a foot and mouth disease outbreak.
[2] See discussion.
[3] A high estimate was not determined.
[4] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.
[5] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'Best' estimate.
[6] Estimates provided by subject matter experts from the Office of Health Affairs (OHA), DHS.
[7] United States General Accounting Office, July 2002; Foot and Mouth Disease: To Protect U.S. Livestock, USDA Must Remain Vigilant and Resolve Outstanding Issues; GAO-02-808; at http://www.gao.gov/new.items/d02808.pdf (accessed 10 March 2013).

[8] United States General Accounting Office, July 2002; Foot and Mouth Disease: To Protect U.S. Livestock, USDA Must Remain Vigilant and Resolve Outstanding Issues; GAO-02-808; at http://www.gao.gov/new.items/d02808.pdf (accessed 10 March 2013).
[9] Carpenter, T.E. O'Brien, J.M. Hagerman, A.D. McCarl, B.A. Epidemic and economic impacts of delayed detection of foot-and-mouth disease: a case study of an outbreak in California. *Journal of Veterinary Diagnostic Investigation*, 23, 26-33 (2011); at http://www.ncbi.nlm.nih.gov/pubmed/21217024, http://vdi.sagepub.com/content/23/1/26.long (accessed 10 March 2013).
[10] Hagerman, USDA Office of Economic Research Services, unpublished.

the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

- For the Animal Disease national-level event, the SNRA project team assumed a low estimate for social displacement of zero.[11]
- The best estimate of 1,000 was provided by subject matter experts from National Consortium for the Study of Terrorism and Responses to Terrorism (START).[12] Experts noted that those working on or near farms may be asked to relocate to reduce the chance of transmitting foot-and-mouth disease to other livestock.
- A high estimate for social displacement was not determined for this event.

Psychological Distress

Psychological consequences for the SNRA focus on significant distress and prolonged distress, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[13] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental consequences as "Low." Experts indicated that the consequences could be higher depending on the acreage required for disposal of infected carcasses. Additionally, there is some potential for contamination to spread into wild animal populations.

Potential Mitigating Factors

In the event that an FMD outbreak does occur in the U.S., there are four possible strategies for control and eradication of FMD in domestic livestock in the event of an outbreak. Each is supported by critical activities that include surveillance, biosecurity, decontamination, epidemiological activities, movement control, and communication. These four strategies are recognized by the OIE in Article 8.5.47 of the Terrestrial Animal Health Code (2010):[14]

- Stamping out or slaughter of all clinically affected and in-contact susceptible animals.
- Stamping out, modified with emergency vaccination-to-slaughter, which includes slaughter of all clinically affected and in-contact susceptible animals and vaccination of at-risk animals, with subsequent slaughter of vaccinated animals.
- Stamping out modified with emergency vaccination-to-live, which includes slaughter of all clinically infected and in-contact susceptible animals and vaccination of at-risk animals, without subsequent slaughter of vaccinated animals.
- Vaccinate-to-live without stamping out. Vaccination used without slaughter of infected animals or subsequent slaughter of vaccinated animals.

Many factors will be considered when determining whether a particular response strategy would be appropriate and advantageous. While no factor will independently dictate a response strategy, or a decision to employ emergency vaccination, there are many factors that will influence the decision of whether to vaccinate or not. Factors will include:[15]

- Disruptions to interstate commerce
- Disruptions to international trade
- Acceptance of response strategy or strategies
- Scale of outbreak
- Rate of outbreak spread
- FMD vaccine availability
- Resources available to implement response strategies

Additional Relevant Information

Similar to estimating the economic implications, establishing the frequency of an occurrence of FMD is difficult. An outbreak of FMD has not occurred in the U.S. since 1929, so any estimate of frequency or consequence can only be based on data from other countries where recent outbreaks have occurred, as well as estimates based on models from current U.S. industry information. The United States has experienced nine known outbreaks of FMD from its first occurrence in 1870 to its final eradication in 1929, indicating a low frequency estimate of approximately 0.04, or 9 events in 235 years in the U.S.[16,17] The highest frequency of occurrence is an estimation based on the recent outbreaks during the previous decade in the United Kingdom, Japan and South Korea. DHS Office of Health Affairs experts estimate a high frequency of once per decade, or 0.1 in a given year. Since FMD is a highly communicable disease that is resilient and easily obtained, the SNRA project team selected 0.1 in a given year as the best estimate for this event.

While there is no historical data from the U.S. from which to estimate the cost of an FMD outbreak, there have been several outbreaks in other countries in the past decade which emphasize the severity of the impact. Examples of outbreaks include the following:

- In 2001, the United Kingdom (UK) suffered one of the largest FMD epidemics to occur in a developed country in several decades. Approximately 7 million animals were culled and their corpses burned on pyres. The outbreak devastated the nation's farming industry and cost the UK an estimated $11.9-$18.4 billion, including $4.8 billion in losses to agriculture, the food industry and the public sector, $4.2-$4.9 billion in lost tourism and $2.9-$3.4 billion in indirect losses.[18]
- The FMD outbreak in South Korea that occurred in late 2010 and ended in April of 2011 is estimated to have cost that country over $2.6 billion U.S. dollars and resulted in the loss of 3.47 million livestock.[19]
- Japan suffered a similar outbreak in 2010, which cost an estimated $3.14 billion U.S. The Japan and South Korea outbreaks are believed to have been caused by the same FMD virus serotype. The source of the Japan outbreak is believed to be contaminated wheat straw imported from China.[20]

[11] Farm animals removed for euthanization as part of control efforts are not included in the SNRA's measure of social displacement.

[12] START is a Department of Homeland Security University Center of Excellence that focuses on social and behavioral aspects of terrorism, natural disasters, and technological accidents, and the social, behavioral, cultural and economic factors influencing responses to and recovery from catastrophes.

[13] A Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\,Fat + Inj + \tfrac{1}{2}\,D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.
The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: Animal Disease Outbreak was given a C_{EF} of 1.0.
The numerical estimates calculated from this formula are reported in Appendix G. The semi-quantitative risk matrix is discussed in the Findings (Psychological Distress Risk).

[14] Foreign Animal Disease Preparedness & Response Plan (FAD PReP)/Foot-and-Mouth Disease Response Plan (The Red Book) USDA Animal and Plant Inspection Service (USDA-APHIS). Chapter 5, General FMD Response, November 2010 draft, at http://www.aphis.usda.gov/animal_health/acah/downloads/documents/FMD_Response_Plan_November_2010_FINAL.pdf; Chapter 4, FMD Response Goals and Strategy, updated (June 2012) draft citing 2011 OIE Terrestrial Animal Health Code, at http://www.aphis.usda.gov/animal_health/emergency_management/downloads/fmd_responseplan.pdf.

[15] Ready Reference Guide to Foot and Mouth Disease (FMD) Response and Emergency Vaccination Strategies, USDA APHIS Veterinary Services, 7/27/2011; incorporated as section 4.4.1 (General Factors that Influence the Response Strategy) of Foreign Animal Disease Preparedness & Response Plan (FAD PReP)/Foot-and-Mouth Disease Response Plan (The Red Book) USDA Animal and Plant Inspection Service (USDA-APHIS), June 2010; at http://www.aphis.usda.gov/animal_health/emergency_management/downloads/fmd_responseplan.pdf.

[16] Foot and Mouth Disease Factsheet. American College of Veterinary Pathologists, July 2012; at http://www.acvp.org/media/factsheet/FootMouth.cfm (accessed 10 March 2013).

[17] Foot and Mouth Disease: A threat to U.S. agriculture. Congressional Research Service, RS-20890, April 16, 2001; at http://www.nationalaglawcenter.org/assets/crs/RS20890.pdf (accessed 10 March 2013).

[18] Carpenter, T.E. O'Brien, J.M. Hagerman, A.D. McCarl, B.A. Epidemic and economic impacts of delayed detection of foot-and-mouth disease: a case study of an outbreak in California. *Journal of Veterinary Diagnostic Investigation*, 23, 26-33 (2011); full text http://www.ncbi.nlm.nih.gov/pubmed/21217024, http://vdi.sagepub.com/content/23/1/26.long (accessed 10 March 2013).

[19] 'South Korea reports another FMD case'. Xinhua [China Radio International], April 20, 2011. At http://english.cri.cn/6966/2011/04/20/2821s633266.htm (accessed 10 March 2013).

[20] APHIS Evaluation of the Foot and Mouth Disease Status of Japan. Veterinary Services, Animal and Plant Health Inspection Service, USDA, April 1, 2011. At http://www.r-calfusa.com/Animal_Health/110401APHISJapanFMDEvaluation.pdf (accessed 10 March 2013).

Earthquake

An earthquake occurs within the U.S. resulting in direct economic losses greater than $100 Million.

Data Summary

Table 1 shows the minimum, average, and maximum values for frequencies and consequences of national level earthquakes. Note that the low and high likelihoods do not correspond to the low and high consequences. In addition, low and high consequences are not necessarily correlated with each other between different consequence categories. A detailed descripton for all results is located in the Event Description and Analytical Methods section.

Description	Metric	Low	Best	High
Fatalities	Number of Fatalities[1]	0	370	8,900
Injuries and Illnesses	Number of Injuries or Illnesses[1]	0	8,700	210,000
Direct Economic Loss	U.S. Dollars[1]	$110 Million	$8.7 Billion	$105 Billion
Social Displacement[2]	Number of Displaced from Homes for ≥ 2 Days[3]	160	27,000	2 Million
Psychological Distress	Qualitative Bins	See text		
Environmental Impact	Qualitative Bins[4]	High[5]		
Frequency of Events	Number per Year[6]	0.11	0.27	2

Table 1

Event Description and Analytical Methods

For planning purposes, a national-level earthquake is defined as an earthquake producing direct economic loss in excess of $100 million dollars. The historical record of U.S. earthquakes during the 105-year time period from 1906 to 2011 was used estimate the interarrival rates/frequencies and consequences for earthquakes exceeding the $100 million threshold. To provide an accurate assessment for current year planning, historic damage estimates have been updated to estimate consequences for a 2011 base year. Economic and health & safety consequences, derived directly from historic record, are updated based on changes in populations, building structures, and infrastructure. In total, 27 earthquakes[7] exceeding the $100 million threshold are aggregated in the findings of this report. The full list of national level earthquakes is located in Table 4.

Table 1 reports the maximum, average, and minimum frequency with which such earthquakes occurred in the United States, as well as the maximum, average, and minimum fatalities, injuries, and direct economic losses associated with earthquakes in the set. The oldest event included is the 1906 San Francisco earthquake and the most recent is the 2003 Paso Robles/San Simeon earthquake.

To obtain consequence estimates, normalized fatality and economic loss estimates for United States historic earthquakes reported by Vranes and Pielke (2009) were used.[8] Normalization of consequences from historic record to present day values is performed by estimating changes in consequence levels due to changes in population densities, community wealth, mitigation factors, and inflation. For most historic events, the present day community, with modern day structures and infrastructure, has a greater financial value than the community at the time of an event. Population densities have also changed. As the population increases, so too do the fatality and injury estimates for a given event. These increases, however, are offset, at least partially, by improving mitigation strategies. Improved building codes and emergency response substantially decrease the consequences caused by modern earthquakes. The consequence estimates reported by Vranes and Pielke (2009) take into account the changes in mitigation strategies, population densities and wealth profiles when normalizing loss estimates to a 2005 base year. Because of the substantial changes in mitigation factors over the historical time period analyzed, a mitigation strategy was used in the normalization routine to relate loss rates to the year an event occurred. Three alternative mitigation rates were published by Vranes and Pielke (2009): no mitigation, a 1% per annum loss mitigation rate and a 2% per annum loss mitigation rate. The 2% mitigation rate was shown to have a lower correlation when compared to damage estimates normalized by magnitude and inflation[9] than the 1% mitigation rate; therefore, the 1% mitigation rate was chosen as the best available consequence normalization factor available for the purposes of this analysis. In other words, the normalized losses were reduced by 1% for each year since the event occurred. The CPI deflator was used to convert reported economic loss estimates from 2005 to 2011 dollars; for fatality estimates, the 2005 base year was maintained. For more detailed information on the normalization routine and raw event data used in this report, please refer to Vranes and Pielke (2009).

Normalized estimates were not available for injuries. To estimate injuries, a linear model was generated that relates normalized fatalities to injuries based on the ratio of injuries to fatalities for a New Madrid event as reported by Elnashai, *et al.*[10] The linear model produces a multiplier that models the correlation between fatalities and injuries. Based on the New Madrid event estimates, a multiplier of 23.5 injuries per fatality was utilized in this report.

Low, best and high estimates were developed in the following manner from the normalized consequence estimates and historic record. For fatalities, injuries and economic loss, the low estimate is the smallest consequence for events that exceed $100 million. For economic loss, $107 million (1992 Ferndale/Fortuna/Petrolia, California earthquake) is the smallest normalized historic loss that exceeded $100 million. Six historic events exceeding the economic threshold did not result in any fatalities and, consequently, were not estimated to cause any injuries resulting in a minimum for both fatalities and injuries of zero. For event frequency, the low estimate is derived from the greatest time gap, t_{max}, between two events. The greatest gap occurs between the 1906 San Francisco and the 1915 El Centro earthquakes. This nine year time lapse between national level earthquakes results in an interarrival frequency of 0.11, or $1/t_{max}$.

The best estimate is the average consequence for events that exceed $100 million. The average economic consequence is $8.7 billion per event. On average, 370 fatalities occur per event. An average of 8,700 injuries per event is using the multiplier technique described above. The average time between national level events is 3.7 years, resulting in 0.27 events expected per year. An estimate of the average annual loss for each consequence type (e.g., fatalities per year or economic loss per year) can be obtained by multiplying the average frequency by the average consequence in a category. The average annual fatality and economic losses for the set of 27 historic events analyzed are approximately 100 fatalities per year and approximately $2.3 billion per year. The average annual economic loss estimate computed using this subset of events is 50% less than FEMA's average annual loss estimate of $5.3 billion for the full set of earthquake hazards, computed using HAZUS modeling.[11] More information about the FEMA average annual loss estimate is provided below.

The meanings of the high estimates for consequence and frequency differ. For consequences, the high estimates reflect the largest losses seen within the set of national level event earthquakes, i.e., those above the $100 million economic loss threshold. The high fatality estimate, for example, is the normalized estimate for the 1906 San Francisco earthquake of approximately 9,000 fatalities if it were to happen in the present day; this is the highest normalized fatality estimate for the events included in the analysis. A high estimate of 210,000 injuries per event is using the multiplier technique described above. The high estimate for frequency is

[1] Low, best, and high estimates for fatalities, injuries and illnesses, and direct economic loss are the historical minimum, average, and maximum for each consequence type in the event set. Extremal events for one consequence type may but generally do not correspond to those for other consequence types.
[2] See discussion in text.
[3] See Social Displacement section in this summary sheet for details.
[4] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories. Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'best' estimate.
[5] Earthquakes were given a best estimate of 'High' with a second best estimate of 'Moderate'. Experts assessed that the debris, devastation, and resulting chemical/contaminant releases which may be caused by an earthquake would have the potential to impact large areas.
[6] Historical lowest, average, and maximum number of events per year (calculated from interarrival times).
[7] The April 1946 earthquake near Unimak Island, Hawaii resulting in a tsunami causing twelve fatalities and $200 million in inflation-adjusted property damage was excluded from the set to avoid double-counting with the Tsunami event.
[8] Vranes, K. and Pielke, R. (2009). Normalized Earthquake Damage and Fatalities in the United States: 1900-2005. *Natural Hazards Review* 10(3): 84-101.
[9] Ibid, p. 90.
[10] Elnashai, A.S., Jefferson, T., Cleveland, L. J., and Gress, T. (2009) Impact of New Madrid Seismic Zone earthquakes on the Central USA, Vol. 1. 2009 Mid-America Earthquake Center: University of Illinois. Available online at https://www.ideals.illinois.edu/handle/2142/14810. Accessed September 28, 2011.
[11] FEMA Publication 366: Hazus-MH Estimated Annualized Earthquake Losses for the United States, April 2008.

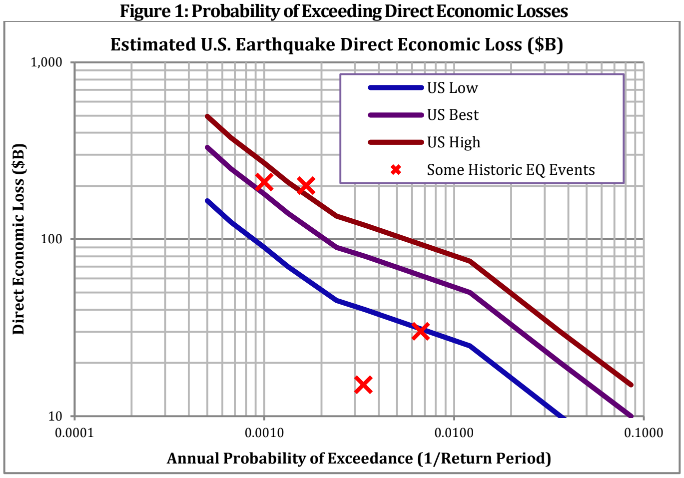
the maximum number of times an earthquake resulting in losses greater than $100 million has occurred in a calendar year, or 2 times per year.

It is important to note that the frequency estimates reported here differ from probabilities. The frequency of a national-level earthquake can be greater than one, while a probability cannot. Additionally, while the average estimates for consequences and frequency are correlated and approximate the average annual loss when multiplied together, the maximum and minimum historical values for consequence and frequency are uncorrelated and do not have meaning when multiplied together.

Expected Loss versus Return Period

Major earthquakes are commonly evaluated based on return period and expected loss. The return period vs. loss is an important perspective when evaluating historic data. The 105-year range used for consequences in Table 1 does not provide a record of all possible consequences. Low frequency events have the capacity to eclipse the greatest damage reports from historic events. Earthquake modeling can be used to estimate losses for events with limited historical precedence in the modern era. Figure 1 relates modeled earthquake economic losses to the annual probability of exceedance.[12] It is important to note that this is a modeled estimate, not actualized measured events.

Figure 1: Probability of Exceeding Direct Economic Losses



Social Displacement Estimates

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of 2 days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

Social displacement estimates for national-level earthquakes were constructed from multiple data sources. The high estimate was provided by subject matter experts at FEMA and informed by experience with Hazus modeling as well as studies such as the analysis by Elnashai *et al.* (2009) of the number of people displaced from their homes and/or without electricity for greater than 3 days due to an earthquake in the New Madrid Seismic Zone.[13] The order of magnitude of the SNRA high estimate for the number of people displaced from home for 2 days or greater was validated for this earthquake event by a subject matter expert affiliated with the National Consortium for the Study of Terrorism and Responses to Terrorism (START), who noted that "displacement in millions due to fires, damaged critical infrastructure, damaged residential areas" was plausible for the scenario of a 7.8 magnitude earthquake occurring on the San Andreas fault in the Los Angeles metropolitan area studied by the U.S. Geological Survey (USGS).[14] As a further validation point, note that displacement due to a 1906 San Francisco earthquake repeating itself in modern times were reported by Kircher *et al.* (2006) to be approximately 400,000-600,000 people due to damaged residences.[15] The latter estimates are likely to underestimate the SNRA social displacement metric because the study did not account for the effects of fires or damage to transportation and utility systems on displacement.

Low and best estimates for social displacement were constructed in an ad-hoc manner by examining published reports of displacement in the recent U.S. historic earthquake record. The low estimate is the minimum of the social displacement estimates reported below, and the best estimate is the average value of the social displacement estimates reported below. This approach, while resulting in crude estimates, was chosen so that the low and best estimates were a reflection of the best available recent historic data. The low estimate reflects the observed occurrence of earthquakes which cause more than $100M in losses while having relatively minor impact on human populations. The best estimate begins to approach the same order of magnitude of social displacement as observed from the two most costly U.S. earthquakes of the past 40 years (the 1981 Loma Prieta earthquake and the 1994 Northridge earthquake).

Table 2: Social Displacement Estimates

Date	Earthquake Name/Location	Displacement Estimate	Source
10/1/1987	Whittier, Los Angeles, Calif.	9,000	16
10/18/1989	Loma Prieta, SF Bay Area, Calif.	32,500	17
6/28/1992	Landers, Calif.	750	18
1/17/1994	Northridge, Calif.	120,000	19
2/28/2001	Seattle area, Wash.	400	20
12/22/2003	San Robles, Calif.	160	20

Note that the best estimate of social displacement is not necessarily correlated to the best estimate of frequency reported in Table 1. Also note that historic estimates reported in the table above are likely underestimates of social displacement as defined for the SNRA, because they are predominantly based upon permanent destruction of housing and may not include temporary displacement.

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[21] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Consequences

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that

[12] Source: Modeling done by FEMA HAZUS contract support for the SNRA project team.
[13] Elnashai, A.S., Jefferson, T., Cleveland, L. J., and Gress, T. (2009) Impact of New Madrid Seismic Zone earthquakes on the Central USA, Vol. 1. 2009 Mid-America Earthquake Center: University of Illinois; at: https://www.ideals.illinois.edu/handle/2142/14810. Accessed on: September 28, 2011.
[14] USGS Circular 1324. (2008). The ShakeOut Earthquake Scenario – A Story that Southern Californians are Writing; at: http://pubs.usgs.gov/circ/1324/c1324.pdf. Accessed September 28, 2011.
[15] Kircher, C.A., Seligson, H.A., Bouabid, J., and Morrow, G.C. (2006). When the Big One Strikes Again – Estimated Losses due to a Repeat of the 1906 San Francisco Earthquake. *Earthquake Spectra* 22(82): 8297-8339.

[16] Whitter Daily News (2011). Whitter Narrows Earthquake: 20 Years Later. Article date 9/28/2011. At http://www.whittierdailynews.com/earthquake (accessed March 2013).
[17] U.S. Geological Survey (1998). The Loma Prieta, California Earthquake of October 17, 1989 - Building Structures. USGS Professional Paper 1552-C; http://pubs.usgs.gov/pp/pp1552/pp1552c/pp1552c.pdf (accessed March 2013). Notes 13,000 uninhabitable housing units; assumed 2.5 people per household.
[18] John A. Martin & Associates (unknown date). The Landers/Big Bear Earthquakes of June 28, 1992. At http://www.johnmartin.com/earthquakes/eqshow/lan_0000.htm (accessed March 2013).
[19] USGS (1998), *op cit*. Notes 48,000 uninhabitable housing units; assumed 2.5 people per household.
[20] EM-DAT, number of "total affected". EM-DAT: The OFDA/CRED International Disaster Database – www.emdat.be, Université Catholique de Louvain, Brussels (Belgium). Accessed on September 28, 2011. The number of "total affected" includes injuries, people needing immediate assistance for shelter, and people needing immediate assistance, including displacements and evacuations. The inclusion of injuries in this metric makes it imperfect for use in the SNRA; it is used for earthquake events when better estimates of displacement could not be found.
[21] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\,Fat + Inj + \frac{1}{2} D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.
The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: earthquakes were given a C_{EF} of 1.1.
The numerical estimates calculated from this formula are reported in Appendix G. The semi-quantitative risk matrix is discussed in the Findings (Psychological Distress Risk).

occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).

- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental consequences as "moderate." Debris, devastation, and chemical or contaminant releases from damaged facilities have the potential to impact large areas.

Assumptions

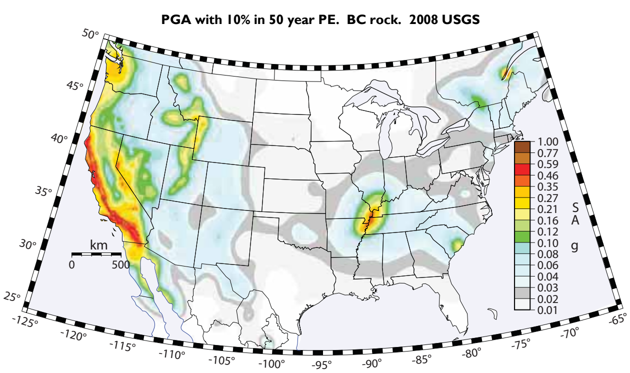
The SNRA project team used the following assumptions to estimate health and safety consequences caused by an earthquake event:

- Earthquake mitigation has improved by 1% annually.
- A linear multiplier of fatalities is sufficient for estimating the injuries associated with earthquakes to the desired precision of the SNRA (i.e., within an order of magnitude).
- The SNRA project team used the following assumptions to estimate direct economic consequences caused by an earthquake event:
- Indirect losses included in historic records do not significantly bias direct economic loss estimates.
- Correcting for inflation only from 2005-2011 does not significantly bias direct economic estimates. (Published normalized economic losses incorporating population, wealth, and mitigating factors were only available through 2005.)

Potential Mitigating Factors

The following key factors can mitigate the potential consequences caused by earthquakes: population and wealth/assets density, land use, construction type and quality, adherence to building codes in design, level of preparedness and awareness in dealing with disasters, and the potential/extent for liquefaction.

Figure 2: Peak Acceleration With 10 Percent Probability of Exceedance in 50 Years



Additional Relevant Information

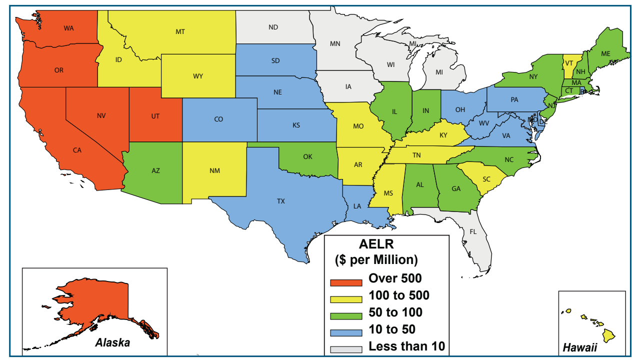
Figure 2 shows, from a national perspective, the probability that ground motion would reach a certain level during an earthquake. The data show peak horizontal ground acceleration (the fastest measured change in speed for a particle at ground level that is moving horizontally due to an earthquake) with a 10 percent probability of exceedance in 50 years. The map was compiled by the USGS Geologic Hazards Team.

As shown in Figure 2, the areas with the highest probability of seismic impacts in the U.S. are in western California, with moderate probability across larger areas of the western U.S., the Midwest, and around Charleston, SC.

In 2008, FEMA estimated average annualized losses from earthquakes for the entire nation by state. The estimated average annualized loss (AAL) addresses risk by estimating the probability of loss occurring in the study area (largely a function of building construction type and quality). By annualizing estimated losses, the AAL factors in historic patterns of frequent, smaller events with infrequent but larger events to provide a balanced presentation of risk. The AAL analysis yielded an estimate of the national AAL of $5.3 billion per year. This estimate does not include lifeline infrastructure losses or indirect (long-term) economic losses, and is therefore, a minimum estimate of the potential losses. Moreover, the estimate represents a long-term average and actual losses in any single year may be much larger or smaller.

The annualized loss ratio (ALR) represents the AAL as a fraction of the replacement value of the local inventory. The ALR gauges the relationship between average AAL and replacement value. This ratio can be used as a measure of vulnerability in the areas and, because it is normalized by replacement value, it can be directly compared across different geographic units such as metropolitan areas or counties.

Figure 3: Hazus-MH Annualized Earthquake Loss Ratios (AELR) by State.



Source: FEMA, April 2008[22]

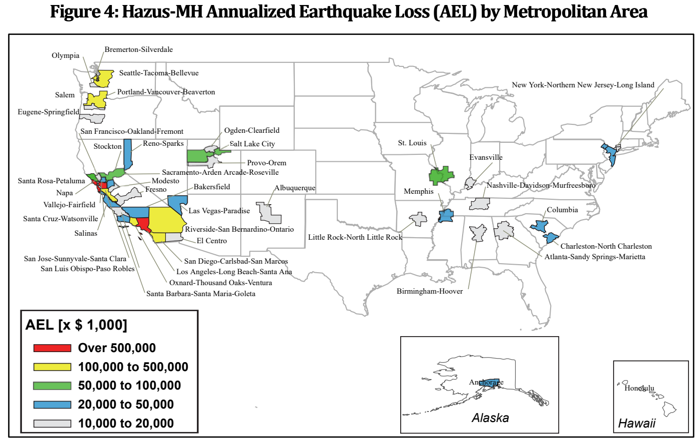
Figure 3 depicts the resulting state ALRs from this study, which helps to illustrate a national perspective of those areas more vulnerable to potential earthquake impacts. The states shown in dark red (Alaska, Washington, Oregon, California, Nevada and Utah) have the highest expected ALRs among all states and therefore have a higher likelihood of experiencing earthquake losses in any given year. Florida, North Dakota, Minnesota, Iowa, Wisconsin and Michigan have the lowest ALRs and are therefore least likely to experience earthquake losses when compared with the rest of the nation.

Figure 4 shows the annualized earthquake losses (AEL) by metropolitan area. Table 3 shows the top 7 metropolitan areas vulnerable to earthquake losses, as ranked using AEL. Of these 7 vulnerable areas, 5 are located in California.

Table 3: Top 7 Metropolitan Areas Vulnerable to Earthquake Losses

Order	Metropolitan Area	AEL ($ Million)
1	Los Angeles-Long Beach-Santa Ana, CA	1,312.3
2	San Francisco-Oakland-Fremont, CA	781.0
3	Riverside-San Bernardino-Ontario, CA	396.5
4	San Jose-Sunnyvale-Santa Clara, CA	276.7
5	Seattle-Tacoma-Bellevue, WA	243.9
6	San Diego-Carlsbad-San Marcos, CA	155.2
7	Portland-Vancouver-Beaverton, OR-WA	137.1

Figure 4: Hazus-MH Annualized Earthquake Loss (AEL) by Metropolitan Area



Source: FEMA, April 2008[22]

[22] FEMA Publication 366: Hazus-MH Estimated Annualized Earthquake Losses for the United States, April 2008.

Table 4: Earthquakes with 2011 damage estimates in excess of $100 million. Year, location, and current year (2011) damage estimates highlighted in blue.

Original Source[24]	Date	Year	City/place name	State	FIPS	Deaths	Event-year property damage	Inflation-only adjustment	Normalized damages with 1% mitigation	Proportional fatalities	Prop. fatalities 1% mitigation
ACC	4/18/1906	1906	San Francisco	CA	6901	3000	524,000,000	8,941,736,986	$104,905,367,626	24062	8896
EM-DAT	6/22/1915	1915	El Centro	CA	6025	6	1,000,000	14,598,047	$131,076,352	33	13
EM-DAT	10/11/1918	1918	Mona Passage	PR	72000	116	29,000,000	261,566,935	$1,943,953,812	331	138
NGDC-s	4/21/1918	1918	San Jacinto/Riverside County	CA	6065	0	200,000	1,803,910	$193,990,095		0
EM-DAT	6/29/1925	1925	Santa Barbara	CA	6083	13	8,000,000	74,247,020	$1,371,950,746	98	44
ACC	3/11/1933	1933	Long Beach	CA	6902	116	39,250,000	495,767,829	$7,565,220,534	737	358
NGDC-s	10/31/1935	1935	Helena	MT	30049	2	6,000,000	70,378,531	$512,380,253	6	3
NGDC-s	10/19/1935	1935	Helena	MT	30049	3	11,250,000	132,000,000	$960,000,000	9	5
EM-DAT	5/19/1940	1940	El Centro/Imperial Valley	CA	6025	9	6,000,000	69,000,000	$392,000,000	12	6
ACC	4/13/1949	1949	Puget Sound/Olympia	WA	53067	8	52,500,000	359,951,841	$3,403,585,667	41	24
NGDC-s	11/18/1949	1949	Terminal Island	CA	6902	0	9,000,000	61,706,030	$414,893,442		0
NGDC-s	8/15/1951	1951	Terminal Island	CA	6902	0	3,000,000	18,982,899	$109,913,608		0
ACC	8/22/1952	1952	Kern County/Bakersfield	CA	6029	2	20,000,000	124,417,934	$662,071,491	6	4
ACC	7/21/1952	1952	Kern County/Bakersfield	CA	6029	14	55,000,000	342,149,318	$1,820,696,601	44	26
EM-DAT	8/18/1959	1959	Hebgen Lake	MT	30031	28	26,000,000	140,472,170	$706,863,603	85	54
NGDC-s	3/28/1964	1964	Prince William Sound/Anchorage	AK	2099	131	540,000,000	2,735,575,437	$11,213,495,628	332	220
ACC	4/29/1965	1965	Seattle	WA	53999	7	20,250,000	100,744,986	$299,194,941	13	9
NGDC-s	10/2/1969	1969	Santa Rosa	CA	6097	1	8,000,000	36,000,000	$120,000,000	2	2
ACC	2/9/1971	1971	San Fernando	CA	6902	65	539,500,000	2,092,109,007	$5,083,948,997	114	81
NGDC-s	10/15/1979	1979	Imperial Valley	CA	6025	0	30,000,000	67,881,448	$129,806,214		0
ACC	10/1/1987	1987	Whittier/Los Angeles	CA	6902	8	354,000,000	542,215,449	$795,888,336	10	9
hybrid	10/18/1989	1989	Loma Prieta/San Francisco	CA	6901	62	5,750,000,000	8,206,000,000	$10,485,000,000	71	60
ACC	6/28/1992	1992	Landers/Yucca Valley	CA	6071	3	100,000,000	129,782,948	$202,144,394	4	3
ACC	4/25/1992	1992	Ferndale/Fortuna/Petrolia	CA	6023	0	66,000,000	85,656,746	$106,971,740		0
ACC	1/17/1994	1994	Northridge/Los Angeles	CA	6902	60	47,350,000,000	58,814,639,537	$78,235,199,499	69	62
ACC	2/28/2001	2001	Seattle/Tacoma/Olympia	WA	53999	1	2,000,000,000	2,189,728,415	$2,378,245,427	1	1
ACC	12/22/2003	2003	Paso Robles/San Simeon	CA	6079	2	300,000,000	316,390,574	$328,283,332	2	2

[24] Original source cited by Vranes and Pielke (2009), *op. cit.*, from which this table was taken.

Flood

A flood occurs within the U.S. resulting in direct economic losses greater than $100 Million.

Data Summary

Table 1 shows the minimum, average, and maximum values for frequencies and consequences of national level floods. Note that the low and high likelihoods do not correspond to the low and high consequences. In addition, low and high consequences are not necessarily correlated with each other between different consequence categories.

Description	Metric	Low	Best	High
Fatalities	Number of Fatalities[1]	0	3	25
Injuries and Illnesses	Number of Injuries or Illnesses[1]	0	95	4,520
Direct Economic Loss	U.S. Dollars[1]	$104 Million	$740 Million	$16 Billion
Social Displacement	Displaced from Homes ≥ 2 Days[2]	150	29,000	200,000
Psychological Distress	Qualitative Bins	See text		
Environmental Impact	Qualitative Bins[3]	Moderate[4]		
Frequency of Events	Number per Year[5]	0.5	4	10

Table 1

Event Background

Floods are one of the most common hazards in the United States. Their effects can be local, impacting a neighborhood or community, or large, affecting entire river basins and multiple states.[6] For the purpose of the SNRA, a national-level flood is defined as a flood producing direct economic loss in excess of $100 million dollars. Economic loss reported here is a combination of property and crop damage. A 13 year time period, from Jan-1-1993 to Dec-31-2005, was used to estimate the interarrival rates/frequencies and consequences for floods exceeding the $100 million threshold. A full list of aggregated flood events used for this report is located in Table 2. Table 1 reports the maximum, average, and minimum frequency with which such floods occurred in the United States, and the maximum, average and minimum consequences for fatalities, injuries, and direct economic losses associated with floods in the set.

This flood risk summary is based on aggregating flood losses reported by NOAA's National Climactic Data Center (NCDC).[7] Modern flood reporting by NOAA relies on many individual reports that assess damages in a specific area of responsibility. A large scale flood, for example, can result in dozens or hundreds of damage entries that assess damages for specific geographic regions. The reason for this is that damage estimates are recorded by individuals with specific areas of responsibility. As flooding passes down the Mississippi, for example, the affected areas can pass from region to region. To capture the transient and distributed nature of flood events, individual flood loss estimates were aggregated based on proximity and time. Flood damage reports that occur within 100 miles of one another and within plus or minus one calendar day are aggregated into composite flood events. The composite flood events above the $100 million threshold are used for reporting of national level event statistics in Tables 1 and 2 of this report. All hurricanes were removed from flood events to avoid over reporting flooding captured in the hurricane risk summary sheet.

Low, average and high consequence estimates were developed in the following manner. For fatalities, injuries and economic loss, the low estimate is the smallest consequence for events that exceed $100 million. For event frequency, the low estimate is the lowest number of events recorded in a year. The average frequency is the expected number of events in a given year. Similarly, the average for fatalities, injuries/illness, and economic damage are the expected value for each given the occurrence of a national level flood. The maximum frequency is the maximum number of national-level floods recorded in a single year. The maximum for fatalities, injuries/illness, and economic damage is the greatest value produced by a single storm in each consequence category.

It is important to note that the frequency estimates reported here differ from probabilities. The frequency of a national-level flood can be greater than one, while a probability cannot. Additionally, while the average estimates for consequences and frequency are correlated and approximate the average annual loss when multiplied together, the maximum and minimum historical values for consequence and frequency are uncorrelated and do not have meaning when multiplied together.

Economic flood damages were inflated to a 2011 dollar value using average changes in the Consumer Price Index. The historical maximum for fatalities was the Great October Flood of 1998 in West Texas with an estimated 25 deaths. Several floods within the time period exceeded $100 million in economic damages without any reported loss of life or injury. In total, 37 floods exceeding the $100 million threshold are aggregated in the findings of this report. For economic loss, $104 million[8] (5/8/1993: Heavy rain in parts of Oklahoma, Arkansas, and Texas) is the smallest historic loss that meets the $100 million threshold. Twenty three historic events exceeding the economic threshold did not record any fatalities. The greatest gap between flood events occurs between 1998 and 2000. This two year time lapse between national level events results in an interarrival frequency of 0.5, or $1/t_{max}$.

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

To estimate social displacement for the SNRA, U.S. flood event data from EM-DAT was used to approximate the number of people forced to leave home for two days or greater. EM-DAT, an Emergency Events Database maintained by the World Health Organization Collaborating Centre for Research on the Epidemiology of Disasters with support from USAID,[9] provides estimates of the "total number affected" by disaster events. Data on "total number affected" for U.S. flood events from 1970-2011 listed in EM-DAT as causing $100M or greater in damages are listed in Table 3. This data covers a longer historic time period than the flood data used for the economic analysis and the EM-DAT events listed may not match the events listed in Table 2 exactly due to differences in damage reporting between the two databases.[10] The low, high, and average of the "total affected" data in Table 3 are used as the social displacement estimates for floods in the SNRA.

The "total affected" measure includes the number of people needing immediate assistance, which can include displacements and evacuations; the number of people needing immediate assistance for shelter; and the number of people injured. Because EM-DAT includes injuries in the "total affected" measure, there is potential for double-counting between the SNRA injury and displacement estimates for this event. However, displacement due to floods is typically significantly greater than the number of injuries, so using EM-DAT's "total affected" measure was judged to provide an estimate of social displacement of sufficient precision for the SNRA. Note that the low estimate may be biased low due to incomplete reporting of displacement and evacuations in EM-DAT.

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[1] Low, best, and high estimates for fatalities, injuries and illnesses, and direct economic loss are the historical minimum, average, and maximum for each consequence type in the event set. Extremal events for one consequence type may but generally do not correspond to those for other consequence types.
[2] Low, average, and high reported "total affected" for floods causing greater than $100M in economic damage as recorded in the EM-DAT database during the time period 1970-2011. See Social Displacement section in this summary sheet for details.
[3] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories. Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'best' estimate.
[4] Floods were given a best estimate of 'Moderate'. The experts assessed that flooding of agricultural areas is a typical impact. The severity of the impact depends upon whether there is release of contaminants from urban areas.
[5] Historical lowest, average, and maximum number of events per year (calculated from interarrival times).
[6] FEMA.gov: Flood, March 2011. http://www.fema.gov/hazard/flood/.
[7] NOAA NCDC Storm Events Database, available by ftp from http://www.ncdc.noaa.gov/stormevents/ftp.jsp (current URL: database downloaded by SNRA project team from NCDC for analysis September 2011, URL updated 3/16/2013).
[8] 5/8/1993: Heavy rain in parts of Oklahoma, Arkansas, and Texas.
[9] EM-DAT: The OFDA/CRED International Disaster Database – www.emdat.be, Université Catholique de Louvain, Brussels (Belgium) [official citation]. EM-DAT is maintained by the Centre for Research on the Epidemiology of Disasters (CRED) at the School of Public Health of the Université Catholique de Louvain located in Brussels, Belgium (http://www.emdat.be/frequently-asked-questions), and is supported by the Office of U.S. Foreign Disaster Assistance (OFDA) of USAID (http://transition.usaid.gov/our_work/humanitarian_assistance/disaster_assistance/). See Criteria and Definition, http://www.emdat.be/criteria-and-definition, EMDAT Data Entry Procedures, at http://www.emdat.be/source-entry , and EMDAT Glossary, at http://www.emdat.be/glossary/ for details of criteria, thresholds, and methodology for the EM-DAT database.
[10] The historical flood incidents in Table 4 were paired with corresponding historical incidents in Table 3 for the purpose of determining a unique set of records with all consequence numbers, where available, for the SNRA core data set (Appendix K). However, this identification occurred after 2011, and Table K2 was not included in the SNRA data or documentation reviewed by FEMA and the interagency, or in classified (full) versions of the SNRA Technical Report.

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[11] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental consequences as "moderate." Flooding of agricultural areas is a typical impact of large scale flooding. The severity of the impact depends upon whether there is release of contaminants from urban areas.

Potential Mitigating Factors

Flood risk is typically based on history, combined with a number of factors such as rainfall, river-flow and tidal-surge data, topography, flood control measures, and changes due to building and development.

Assumptions

The SNRA project team used the following assumptions to estimate health and safety consequences for this event:

- Historical flood events from 1993-2005 are representative of current flood risk.[12]
- Aggregations of individual reports for flood deaths/injuries represent the actual deaths/injuries from historic flood events to sufficient precision for purposes of the SNRA. These fatality and injury reports are potentially biased low compared to published reports due to underreporting in the NOAA database.

The SNRA project team used the following assumptions to estimate economic consequences for this event:

- Property and flood loss dominate the direct economic losses, such that business interruptions, medical costs, and loss of spending due to fatalities can be neglected.

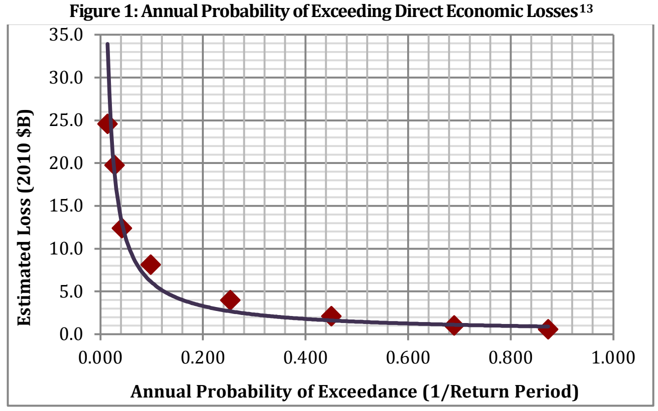
The SNRA project team used the following assumptions to estimate social displacement for this event:

- Numbers displaced by floods sufficiently dominate injuries that EM-DAT's total-affected measure may be considered an approximate measure of social displacement.

Expected Wind Damage Versus Return Period

Results reported in Tables 1 and 2 capture actual flood events. An additional perspective into flood damage is a loss exceedance probability shown in Figure 1. The 13-year range used for consequences in Tables 1 and 2 does not provide record of all possible consequences. Low frequency events have the capacity to eclipse the greatest damage reports from historic events. Figure 1 provides a loss exceedance probability for flood damages in a given year. It is important to note that this loss is an annualized number for the entire country, not specific flood events.

Figure 1: Annual Probability of Exceeding Direct Economic Losses[13]



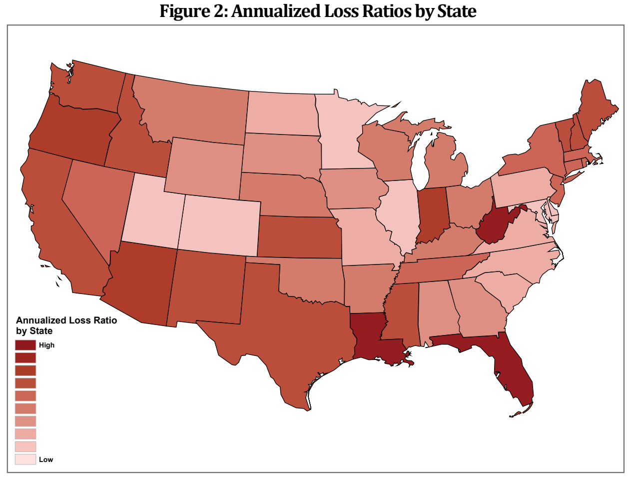
Additional Relevant Information

In 2010, FEMA used default analyses to estimate average annualized losses for flood for the entire nation by state. The estimated average annualized loss (AAL) addresses risk by estimating the probability of the loss occurring in the study area (largely a function of building construction type and quality). By annualizing estimated losses, the AAL factors in historic patterns of frequent, smaller events with infrequent but larger events to provide a balanced presentation of risk. The AAL analysis yielded an estimate of the national AAL of approximately $55 billion per year.

The annualized loss ratio (ALR) represents the AAL as a fraction of the replacement value of the local inventory. The ALR gauges the relationship between AAL and replacement value. This ratio can be used as a measure of vulnerability in the areas and, because it is normalized by replacement value, it can be directly compared across different geographic units such as metropolitan areas or counties.

Figure 2 depicts the resulting state ALRs from this study, which helps to illustrate from a national perspective those areas that are more vulnerable to potential flood impacts. The states shown in dark red (Florida, Louisiana and West Virginia) have the highest expected ALRs among all states and therefore have a higher likelihood of experiencing flood losses in any given year.

Figure 2: Annualized Loss Ratios by State



Source: FEMA, June 2011[14]

[11] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + \frac{1}{2} D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: floods were given a C_{EF} of 1.0.

The numerical estimates calculated from this formula are reported in Appendix G. The semi-quantitative risk matrix is discussed in the Findings (Psychological Distress Risk).

[12] Flood event records for 2006 – present are also available from NOAA, but in a different format than the records used for this summary sheet. These records will be included in future analysis.

[13] Modeling done by FEMA HAZUS-MH contract support for the SNRA project team.

[14] FEMA: HAZUS Average Annualized Flood Loss for the Contiguous United States, DRAFT June 2011.

Table 2: Flood Events

Description:	Report Date	Fatalities	Injuries	Econ Loss
Heavy rain in parts of OK, AR, and TX.	5/8/1993	5	0	$103,635,700
Extensive flooding due to 4 to 8 inches of rain in South Central Kansas.	5/8/1993	0	0	$157,000,000
Flooding in OK.	5/8/1993	0	0	$157,000,000
Great Flood of 93.	8/31/1993	0	0	$15,700,000,000
Steady rains in and around Springfield MO.	9/24/1993	1	0	$119,013,850
Flooding in SC and TN.	3/27/1993	3	0	$238,068,000
Heavy rains resulted in flash floods in PA and NY.	8/18/1994	3	6	$111,766,500
Texas flooding.	10/16/1994	15	0	$399,146,400
Flooding in Kern, Los Angeles and San Diego CA.	1/10/1995	0	0	$166,135,000
Flooding from Kern to Tulare CA.	3/1/1995	0	0	$168,072,000
Salinas River flooding in Monterey County CA.	3/10/1995	0	0	$447,000,000
Rain combined with snow melt from unprecedented warm temperatures caused flooding from VA to NY.	1/18/1996	22	1	$475,800,480
Melting snow and rain caused northern Oregon river flooding.	2/6/1996	7	0	$576,000,000
Record breaking rainfall fell over parts of north central and northeast Illinois.	7/17/1996	0	0	$111,888,000
Heavy thunderstorms in PA.	7/19/1996	2	1	$326,160,000
Damages in CA from rain combined with snow melt in the Sierra Nevada.	1/1/1997	3	52	$1,635,600,000
Melting snow and heavy rain in Southern Oregon.	1/1/1997	0	0	$126,900,000
Flooding from excessive rain in KY, OH, and WV.	3/1/1997	10	3	$153,368,520
Record 24 hour rainfall in Jefferson County, KY.	3/1/1997	2	0	$296,100,000
Sheyenne River flooding in ND.	4/8/1997	0	0	$5,428,500,000
Severe flash floods in MN and WI. Milwaukee County, WI was extensively damaged.	6/20/1997	0	6	$141,751,530
Heavy rains resulting in flash floods in multiple counties of CO.	7/28/1997	5	40	$289,162,800
Large hail, strong winds and torrential rain hammered portions of Lakewood and South Denver CO.	8/11/1997	0	0	$180,480,000
A slow moving Nor'easter battered eastern VA.	2/4/1998	0	0	$104,250,000
Powerful Pacific storm fed by an unusually warm El Nino struck southern and central CA.	2/23/1998	5	3	$152,316,200
A slow moving weather system dumped large amounts of rain on AL.	3/8/1998	4	0	$165,389,150
An intense gulf storm dumped up to 14 inches of rain in Houston, Dale, and Geneva counties in AL and southwest Georgia.	3/8/1998	1	1	$543,490,000
Nearly six inches of rain in Calhoun, Franklin, Gadsden, Gulf, Holmes, Jackson, Walton, and Jackson counties of FL.	3/10/1998	0	0	$510,130,000
Agricultural damage due to a large Southern Sierra Nevada snow melt.	6/1/1998	0	0	$139,556,000
Sustained flooding through parts of East Central OH.	6/26/1998	10	0	$281,502,800
A series of slow moving thunderstorms moved through WI.	8/5/1998	2	5	$114,410,900
The Great October Flood in west Texas.	10/17/1998	25	4520	$559,266,500
Flooding from Devils Lake in ND.	8/5/1998	0	0	$136,000,000
Heavy rainfall in Jefferson and Franklin county MO.	5/7/2000	2	0	$132,660,000
Heavy thunderstorms in MN produced record rainfall amounts.	6/19/2000	0	0	$147,840,000
Thunderstorms with near torrential downpours in NJ.	8/12/2000	0	0	$237,996,000
Prior to the formation of tropical storm Leslie, a low pressure system produced massive rainfall in South West FL.	10/3/2000	0	0	$1,254,000,000
Flooding from rapid snow melt and rain.	4/1/2001	3	1	$256,000,000
Severe flash flooding in WV and VA.	7/8/2001	1	0	$280,748,800
High water in Columbia AR.	10/11/2001	0	0	$153,606,400
Flash floods in KY, VA, and WV.	5/2/2002	4	0	$141,233,400
Heavy rainfall caused the Roseau River to overflow the dikes of Roseau.	6/10/2002	0	0	$252,000,000
Heavy rains caused flooding in several counties of MS.	4/6/2003	2	0	$325,683,090
Flooding TN, GA and AL in with the most severe damage in Jefferson County AL.	5/5/2003	3	6	$1,474,800,000
Thunderstorm generated flash floods throughout OH.	7/21/2003	5	0	$288,261,570
A stationary front caused widespread flooding over Southeast Michigan.	5/23/2004	0	0	$120,000,000
Scattered to widespread heavy rains across south-central and southeast WI.	6/1/2004	0	0	$301,860,000
A stalled storm system dumped rain throughout many portions of UT.	1/10/2005	1	6	$348,000,000
Widespread flooding in several CA counties due to heavy rainfall.	12/30/2005	0	0	$476,298,320

Table 3: Social displacement and damage estimates from EM-DAT

Start (DD/MM/YY)	End (DD/MM/YY)	Location	EM-DAT Total Affected	EM-DAT Est. Damage (US$ Million)
09/06/1972	09/06/1972	Rapid City (South Dakota) ...	3,000	120
22/07/1977	22/07/1977	Johnstown (Pennsylvania)	2,700	200
19/02/1980	19/02/1980	South California	106,000	350
06/01/1993	20/01/1993	California, Arizona, Neva ...	6,000	100
28/02/1993	28/02/1993	N/A	5,200	190
24/06/1993	23/08/1993	Oklahoma, Minnesota, Wis ...	31,000	12,000
17/10/1994	23/10/1994	Houston, Galveston (Texas ...	14,070	700
07/05/1995	13/05/1995	Louisiana (New Orleans)	20,000	3,000
28/11/1995	10/12/1995	Washington, Oregon	15,000	100
15/01/1996	21/01/1996	Nevada, Arizona, New Mexi ...	200,000	700
07/02/1996	13/02/1996	Washington, Oregon, Idaho ...	24,900	500
27/12/1996	03/01/1997	Washington, Oregon, Nevad ...	18,100	1,500
01/01/1997	07/02/1997	Nevada, Idaho, California ...	125,000	1,500
17/04/1997	07/05/1997	Grand Forks, Fargo	50,400	5,000
25/07/1997	01/08/1997	Fort Collins (Northern Co ...	424	100
07/03/1998	13/03/1998	S Alabama, N and C Georgi ...	18,000	270
13/06/1998	17/06/1998	Iowa, Indiana, , Illinois ...	1,000	201
24/06/1998	01/07/1998	Kansas, IA, MO, Illinois, ...	14,000	469
23/05/2000	23/05/2000	Franklin, Jefferson, Gasc ...	300	100
12/08/2000	14/08/2000	Morris (Sussex county, Ne ...	175	166
30/06/2002	23/07/2002	New Braunfels, Bandera, U ...	144,000	1,000
05/07/2003	21/07/2003	Carroll, Adams, Cass, How ...	1,200	106
07/01/2005	11/01/2005	La Conchita, Ventura coun ...	508	200

Start (DD/MM/YY)	End (DD/MM/YY)	Location	EM-DAT Total Affected	EM-DAT Est. Damage (US$ Million)
17/02/2005	23/02/2005	Los Angeles, region (Cali ...	150	250
31/12/2005	18/01/2006	Napa, Sonoma, Mendocino, ...	3,600	245
04/04/2006	17/04/2006	Amador, Calaveras, Fresno ...	600	259
25/06/2006	01/07/2006	Maryland, Pennsylvania, N ...	65,000	1,000
16/08/2007	27/08/2007	Illinois, Colorado, Mich ...	2,840	700
24/03/2009	20/04/2009	North Dakota, Minnesota	5,060	166
20/09/2009	21/09/2009	Douglas, Floyd, Carroll, ...	3,000	500

*Note: EM-DAT data from June 2008 Midwest floods is not included because “total affected” estimate (11 million) is a large outlier which could not be independently validated against news reports.

Human Pandemic Outbreak

A severe outbreak of pandemic influenza with a 25% gross clinical attack rate spreads across the U.S. populace.[1]

Data Summary

In the following table, note that the low and high likelihoods do not correspond to the low and high consequences. In addition, low and high consequences are not necessarily correlated with each other between different consequence categories.

Description	Metric	Low	Best	High
Fatalities	Number of Fatalities	140,000	250,000	440,000
Injuries and Illnesses	Number of Injuries or Illnesses	62 Million	77 Million	110 Million
Direct Economic Loss	U.S. Dollars	$84 Billion	$170 Billion	$260 Billion
Social Displacement	Displaced from Homes ≥ 2 Days	0[2]		
Psychological Distress	Qualitative Bins	See text		
Environmental Impact	Qualitative Bins[3]	Low[4]		
Frequency of Events	Number per Year	0.017	0.033	0.1

Event Background

There have been eight naturally caused influenza pandemics (including pandemics subsequently deduced to have been caused by influenza virus) since 1729.[5] Thus the historic frequency is once every 10 to 60 years. New influenza viruses that affect humans can emerge and spread rapidly. Influenza pandemics can occur at any time due in part to the following factors: the quality and scope of epidemiological and laboratory resources to identify and diagnose viruses with pandemic potential – both in the United States and globally; the complex re-assorting of new influenza viruses between animal and humans; potential lack of antibody resistance to new influenza virus strains in the population at large; potential resistance of new influenza virus strains to available antiviral medications; time needed to identify, develop, produce, and distribute an effective pandemic influenza vaccine; and countermeasure resources in the United States and globally to mitigate the transmission of a pandemic virus.

[1] Because of the prominence of the Pandemic national-level event among the SNRA natural hazards, the explanatory text of this risk summary sheet was extensively edited from the 2011 version in 2013. Likelihood and consequence estimates are unchanged from the 2011 data. Reversion to a form more closely resembling the original delivered to FEMA in 2011 would be preferable, but the current text was retained for consistency with the final (July 2013) version of the classified Technical Report.

[2] Social displacement was assumed to be zero for the Human Pandemic Outbreak national-level event.

[3] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.

[4] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The experts provided a best estimate of 'Moderate' for a pandemic scenario with severe social impacts and a second best estimate of 'Low' for a less severe pandemic scenario (see Environmental Impacts). The SNRA used 'Low' as the best estimate and 'Moderate' as the second best estimate for the Pandemic national-level event, because the final numbers on other consequence scales defined a scenario with social impacts corresponding to the less severe pandemic scenario, rather than the more severe scenario.

[5] Different authors have different lists of which influenza years they consider to have been pandemics, but most modern writers' lists of likely influenza pandemics in the past three centuries include from about 8 to 12 events in total (when the 2009 H1N1 pandemic is included). Serological studies - blood tests to characterize antigens to surface proteins of influenza viruses a person may have been exposed to in his/her lifetime - have been successfully used to determine the serotypes (combinations of particular H and N surface proteins) of influenza outbreaks back to around 1900. However, making a determination of which historical outbreaks before that point were pandemics by the modern virological definition from past writers' observations indicative of a new influenza serotype (e.g. cross-continent spread, patterns of residual immunity from previous outbreaks) involves a great deal of inference and human judgment. Potter CW, A history of influenza. *Journal of Applied Microbiology* 2001 (91) 572-579; Taubenberger et al (2009, April), Pandemic influenza – including a risk assessment of H5N1, *Revue Scientifique et Technique (Rev. Sci. Tech.)* 28(1) 187-202, at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2720801/ (accessed March 2013); Patterson, Karl D. (1986), Pandemic Influenza, 1700-1900: A study in historical epidemiology, Rowan & Littlefield, publishers; Dowdle, W. R. (1999), Influenza A virus recycling revisited. *Bulletin of the World Health Organization* 77(10) 820-828; at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2557748/ (accessed April 2013); Morens et al (2010, November), Historical thoughts on influenza viral ecosystems, or behold a pale horse, dead dogs, failing fowl, and sick swine. *Influenza and Other Respiratory Viruses* 4(6) 327-337, at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3180823/ (accessed May 2013).

Assumptions

Fatalities and Illnesses

The SNRA project team used the following assumptions to estimate health and safety consequences caused by a pandemic event:

- The scenario is based on a U.S. population of approximately 307 million.
- Likelihood, fatality, and illness best estimates and ranges were provided to the SNRA project team by the U.S. Centers for Disease Control and Prevention. These were derived from expert judgment by CDC subject matter experts, informed by modeling and assumptions similar to those used in U.S. Government pandemic planning scenarios.[6]
- These experts stress that it is impossible to predict the timing or severity of the next pandemic.
- All of the estimates are given absent any intervention (i.e., before interventions are applied or attempted).
- The modeled National-level Event is based on assuming a 25% attack rate,[7] and death rates associated with a scenario modeled on a 1968-scale pandemic were it to occur in today's population. Medical technologies to improve survival probabilities in the elderly and health-compromised populations most at risk of dying from influenza have advanced in past decades. However, the larger fraction of these high-risk subpopulations in today's U.S. population – due in large part to these same advances – means that total fatalities from an influenza pandemic of similar virulence could be much higher today than in 1968.[8]

Comparisons to other estimates of health and safety impacts: Large uncertainties dominate any estimate of the human consequences of the next influenza pandemic.

- Severity of virus: Although useful indications of the potential range of impacts may be inferred from records of the historical variability of the influenza virus (see last section), patterns deduced from the historical record have been insufficient in themselves for constructing predictive models for the severity of the next pandemics.[9] Many planning scenarios frequently model experts' best judgment of a 'most representative' scenario, such as the 1968-scale pandemic model used for the SNRA and many other planning scenarios in this country; others model a 1918-scale pandemic as a maximal scenario for planning purposes.[10] Current U.S. Government guidance is to plan to both a 'moderate' 1957/1968-style pandemic and a 'severe' 1918-style pandemic to ensure preparedness for a range of impacts.[11]
- Mitigation measures: In addition to the inherent characteristics of the virus, the actual consequences of a future pandemic will also depend upon the availability, speed of deployment, and effectiveness of medical and non-medical measures to mitigate disease spread and lethality. Despite extensive study in the literature,[12] the extent to which the effects of the next pandemic

[6] E.g. Homeland Security Council (2005, November), National Strategy for Pandemic Influenza; U.S. Department of Health and Human Services (2005, November), HHS Pandemic Influenza Plan; Homeland Security Council (2005), National Planning Scenarios (Scenario 3, Pandemic Influenza).

[7] The attack rate is the percentage of population that becomes clinically ill due to influenza. Clinical illness is defined as a case of influenza that causes some measurable economic impact, such as one-half day of work lost or a visit to a physician's office.

[8] Meltzer MI, Cox NJ, Fukuda K. (1999). The economic impact of pandemic influenza in the United States: priorities for intervention. *Emerging Infectious Diseases* 5(5) 659-671.

Although the SNRA project team is not aware of any longitudinal study looking at the proportion of high-risk populations defined in comparable terms, the scale of this increase is apparent in studies of the U.S. populations covering shorter time periods. One illustration of this is the increase of the overall percentage of the U.S. population at high risk from complications of influenza from 15.5% to 20% in the five year period 1973-1978 displayed in Table 12 of the Office of Technology Assessment's 1981 study of influenza response options. Office of Technology Assessment, U.S. Congress (1981, December), Cost Effectiveness of Influenza Vaccination. NTIS order #PB82-178492, also at http://ota.fas.org/reports/8112.pdf.

[9] Dowdle, W. R. (1999), Influenza A virus recycling revisited. *Bulletin of the World Health Organization* 77(10) 820-828; at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2557748/ (accessed April 2013).

For a recent approach from CDC scientists which could be adapted to a quantitative risk assessment of pandemic influenza from historical data in a manner similar to other events in the SNRA, see Reed et al (2013, January), Novel framework for assessing epidemiologic effects of influenza epidemics and pandemics, *Emerging Infectious Diseases* 19(1) 85-91 and its technical appendix. This approach is being studied for a future iteration of the SNRA.

[10] National Infrastructure Simulation & Analysis Center (NISAC), for the Office of Infrastructure Protection, U.S. Department of Homeland Security (2007, October 10), National Population, Economic, and Infrastructure Impacts of Pandemic Influenza with Strategic Recommendations; also the 'high' scenario of the 2005 HHS Pandemic Influenza Plan (p. 18), and the 'high' and conservative fatalities planning factors of the UK Pandemic Influenza Strategy 2011 (pp. 16-17, 20-25) (overall, the UK strategy stresses a range of scenarios similar to HHS recommendations). Department of Health, United Kingdom (2011, November 10), UK Influenza Pandemic Preparedness Strategy 2011, at https://www.gov.uk/government/publications/responding-to-a-uk-flu-pandemic (accessed June 2013); U.S. Department of Health and Human Services (2005, November), HHS Pandemic Influenza Plan, at http://www.flu.gov/planning-preparedness/federal/hhspandemicinfluenzaplan.pdf (accessed April 2013).

[11] HHS Pandemic Influenza Plan, *op cit*; U.S. Centers for Disease Control and Prevention, CDC Resources for Pandemic Flu [web portal], http://www.cdc.gov/flu/pandemic-resources/ (accessed June 2013).

[12] Longini et al (2004, April 1). Containing pandemic influenza with antiviral agents. *American Journal of Epidemiology* 159(7) 623-633; Miller et al (2008, August 1). Prioritization of influenza pandemic vaccination to minimize years of life lost. *Journal of Infectious Diseases* 198(3) 305-311; Perlroth et al (2010, January 15). Health outcomes and costs of community mitigation strategies for an influenza pandemic in the United States. *Emerging Infectious Diseases* 50(2) 165-174; Meltzer et al (1999), *op cit.*; NISAC (2007), *op cit.*; Office of Technology Assessment (1981), *op cit.*; CDC (2011, May 10). Ten Great Public Health Achievements – United States, 2001-2010. *Mortality and Morbidity Weekly Report (MMWR)* 60(19) 619-623; CDC (2011, September 30), Notice to Readers: Revised Estimates of the Public Health Impact of 2009 Pandemic Influenza. *MMWR* 60(38) 1321; Atkins et al (2011, September). Estimating effect of antiviral drug use during pandemic (H1N1) 2009 outbreak, United States. *Emerging Infectious Diseases* 17(9) 1591-1598.

will be mitigated in practice is dominated by open questions (see Potential Mitigating Factors).

Economic Loss

The SNRA project team used the following assumptions to estimate economic consequences caused by a pandemic event:

- All of the estimates are given absent any intervention (i.e., before interventions are applied or attempted).
- The economic impact for the 1968 scenario was taken from Meltzer et al.,[13] and updated from 1995 values to 2010 dollar estimates, using the Consumer Price Index conversion factor (CPI - 1.431 conversion factor).[14] The dollar values provided include estimates for lost productivity due to time off work to either convalesce or to care for a family member who is ill.
- Approximately 83% of the estimated impact for this scenario is associated with the value of lost productivity due to premature death.
- Beyond the inclusion of value of time lost from work, these estimates do not include any valuation for lost economic activity, such as business closing or notable reduction in economic activity.

Comparisons to other estimates of economic impact: In comparison to the 1968 scenario estimate, a 2006 study of the potential economic impact of an influenza pandemic gave an estimate of impact for a "mild" pandemic of 0.8% of global GDP, equivalent in the U.S. to approximately $117.6 billion.[15] This is within the range given in the "Data Summary" for the 1968 scenario.

A Congressional Budget Office (CBO)[16] study of a 1918-type outbreak scenario, assuming 2 million deaths, estimated that such a pandemic would cause the U.S. GDP ($14.7 trillion) to decrease by 4.25% - equivalent to $625 billion. This is above the range included in the Table, but it represents a comparatively less likely worst case scenario. The CBO's "mild" pandemic scenario, equivalent to the 1968 and 1957 pandemics, assumed 100,000 might die, and cause an impact of about 1% of GDP ($147 billion). A detailed Canadian study[17] estimated that a 1918-type pandemic would reduce the Canadian economy by a maximum of 1.1% GDP - equivalent in the U.S. to US$161.7 billion.

Social Displacement

Social displacement was assumed to be zero for the Human Pandemic Outbreak national-level event.[18]

Note that hospitalization is not counted as social displacement for the purposes of the SNRA since it would result in double counting with illnesses. Social distancing, quarantine, large scale telework, and children and family staying home or college students returning home as a result of school closures are also not counted as social displacement because they result in more people staying home rather than leaving home.

Psychological Distress

Psychological consequences for the SNRA focus on significant distress and prolonged distress, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[19] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- The experts provided a best estimate of 'Moderate' for a pandemic scenario with severe social impacts and a second best estimate of 'Low' for a less severe pandemic scenario.
- The SNRA reports the 'Low' environmental impact judgment as the best estimate for the purposes of the SNRA because the social impacts of the final SNRA Pandemic best estimate scenario, as defined by the best estimates on other consequence axes, correspond to the less severe pandemic scenario. The SNRA reports 'Moderate' as the second best judgment because it describes the environmental impacts of a more severe pandemic scenario.
- Experts identified the consequences of a larger pandemic scenario as "Moderate" due to the potential for resources to be pulled from environmental protection activities, thereby allowing impacts to cascade and cause environmental consequences. If the pandemic were large enough, environmental protection could be deemphasized in order to divert resources towards higher priority response efforts and consequences could be increased as service providers are afflicted with the pandemic (e.g., waste disposal efforts could be halted if workers require treatment).

Potential Mitigating Factors

Numerous medical and non-medical measures for mitigating the human consequences of an influenza pandemic, including social distancing, school closing, antiviral medications, antibiotics for secondary bacterial infections, and targeted vaccines, are known and would be expected to be deployed, at least in part. These measures' efficacy for those individuals who directly receive them is clearly indicated by the evidence in the literature. However, there is no consensus in the literature on what proportional or percentage reductions in total national fatalities and illnesses could be expected under the constraints and conditions of an actual pandemic.[20] Estimates of percentage reductions (mitigation effectiveness) in the literature range from 1.6%[21] to 96%[22] for fatalities and 6%[23] to 99%[24] for illnesses respectively.

The appropriate factor for converting the currently unmitigated consequence numbers to mitigated equivalents is not known. However, recent CDC studies of the 2009-10 H1N1 pandemic indicate that any adjustment for mitigation under real-world societal and economic conditions would not substantially shift the numbers reported here.[25]

Additional Relevant Information

New influenza viruses that affect humans can emerge and spread rapidly. Influenza pandemics can occur at any time due in part to the following

[13] Meltzer MI, Cox NJ, Fukuda K. *Emerging Infectious Diseases* 1999;5:659-671.
[14] CPI conversion factors from Bureau Labor Statistics: at: http://www.bls.gov/data/.
[15] McKibinnin WJ and Sidorenko AA. Global macroeconomic consequences of pandemic influenza. Lowry Institute Analyses paper. Lowy Institute for International Policy. Feb. 2006.
[16] Congressional Budget Office (2006, July: updated/corrected from December 2005). A potential influenza pandemic: an update on possible macroeconomic effects and policy issues. At http://www.cbo.gov/publication/17785 (accessed April 2013).
[17] James S and Sargent T. The economic impact of an influenza pandemic. Economic Analysis and Forecasting Division, Department of Finance – Canada. (unpublished paper) May, 2006.
[18] For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. This measure does not capture the significant differences between temporary evacuations and permanent displacement due to property destruction. However, this distinction is less relevant for events with zero displacement on both measures.
[19] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + \frac{1}{2} D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.
The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: Human Pandemic Outbreak was given a C_{EF} of 1.0.
The numerical estimates calculated from this formula are reported in Appendix G. The semi-quantitative risk matrix is discussed in the Findings (Psychological Distress Risk).
[20] E.g. not everyone who is sick can afford going to the doctor or antiviral prescriptions; research and production times needed to mass produce vaccines targeted to the pandemic virus may delay their mass availability until after the pandemic's peak.
[21] CDC (2011, May 10). Ten Great Public Health Achievements – United States, 2001-2010. *Mortality and Morbidity Weekly Report (MMWR)* 60(19) 619-623, at http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6019a5.htm?s_cid=mm6019a5_w; CDC (2011, September 30), Notice to Readers: Revised Estimates of the Public Health Impact of 2009 Pandemic Influenza. *MMWR* 60(38) 1321, at http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6038a7.htm (accessed June 2013).
[22] Proportion of attack and mortality rates in the Anticipated scenario to rates in the Baseline scenario, figure 3-1, p. 17. National Infrastructure Simulation and Analysis Center (NISAC) (2007, October 10). National Population, Economic, and Infrastructure Impacts of Pandemic Influenza with Strategic Recommendations. Office of Infrastructure Protection, U.S. Department of Homeland Security.
[23] CDC (2011), Ten Great Public Health Achievements, *op cit;* CDC (2011), Revised Estimates, *op cit.*
[24] NISAC (2007), *op cit.*
[25] CDC (2011, May 10, September 30) *op cit.*; Atkins et al (2011, September). Estimating effect of antiviral drug use during pandemic (H1N1) 2009 outbreak, United States. *Emerging Infectious Diseases* 17(9) 1591-1598; at http://wwwnc.cdc.gov/eid/article/17/9/11-0295_article.htm (accessed June 2013).

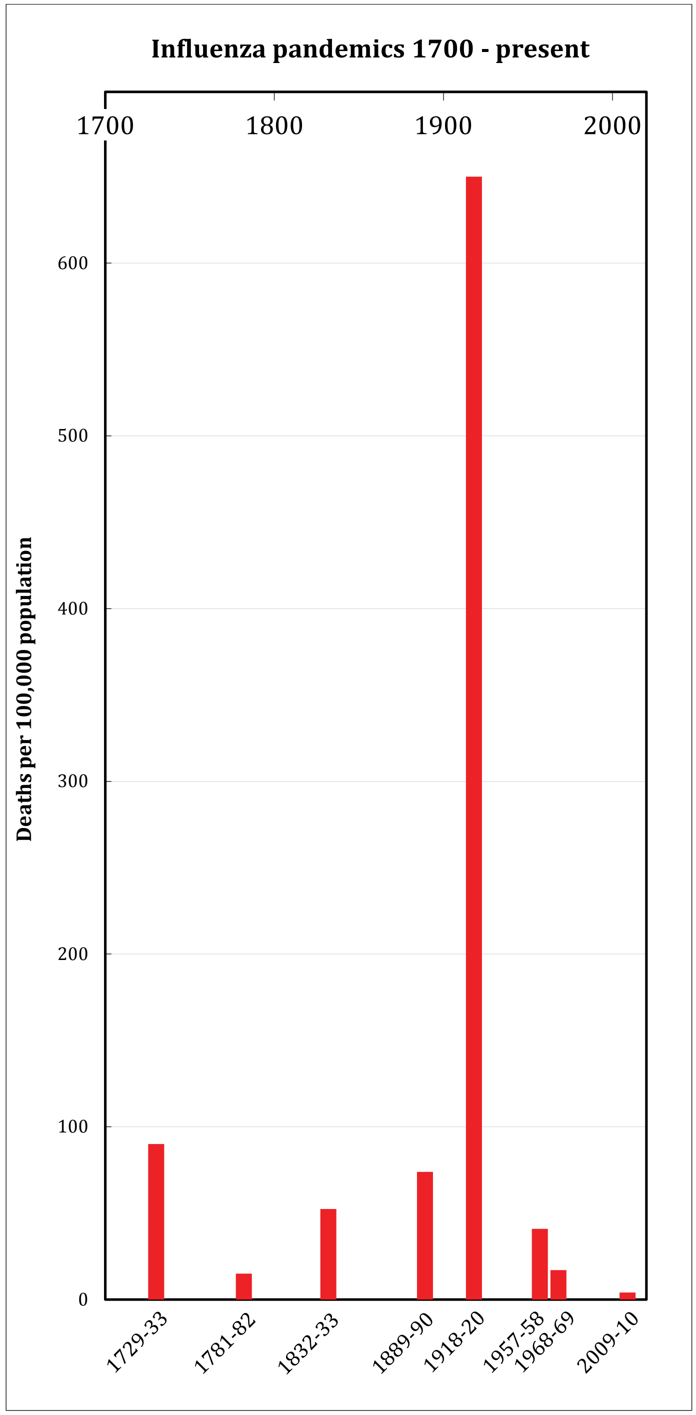
factors: the quality and scope of epidemiological and laboratory resources to identify and diagnose viruses with pandemic potential – both in the United States and globally; the complex re-assorting of new influenza viruses between animal and humans; the potential lack of antibody resistance to new influenza virus strains in the population at large; the potential resistance of new influenza virus strains to available antiviral medications; the time needed to identify, develop, produce, and distribute an effective pandemic influenza vaccine; and the availability of countermeasure resources in the United States and globally to mitigate the transmission of a pandemic virus.

The probability of impact due to a pandemic has two parts: the probability of a pandemic (any type) occurring, and then, once it has occurred, the severity of impact (essentially, the conditional probability that the "mild," "middle," or "worst case" scenario occurs).

- *Probability of a pandemic occurring*: From 1729 through 2009 there have been 8-12 influenza pandemics (including pandemics subsequently deduced to have been caused by influenza virus).[26] They have thus historically occurred with a frequency of once every 10 to 60 years.
- *Probability of severity* (probability of "mild," "middle," or "worst case" occurring once pandemic has started): The 1918 pandemic appears to have caused an exceptionally high case fatality rate. Such a pandemic could, in theory, re-occur but historically has only occurred once in approximately 8-12 pandemics. This historical frequency gives an approximately 10% chance that the next pandemic will be a 1918-type pandemic. Similarly, a "mild" pandemic, such as the 2009 pandemic, has only occurred once in 8-12 pandemics since 1700, and also has an approximate 10% probability of occurring. If one includes both the 1968 and 1957 pandemics as examples of "mild" impact pandemics, then the probability that such a scenario will occur rises to 30%. The probability of a "middle" scenario occurring is the residual after accounting for the probabilities of both "worst case" and "mild" scenarios (range for a "middle": 50% - 80%).

Visualizing the time series of influenza pandemics, 1700-present[27]

Quantitative study of mortality from historical influenza pandemics has focused almost entirely on the twentieth century. However, sufficient data on prior events exist for researchers to depict time series of historical pandemics over longer periods for mortality in selected populations. While differences in base population,[28] health, counting measures, and population age structures prevent precise comparisons, such estimates can be nonetheless arrayed together to get a rough picture of the historical variability of the influenza virus in terms of its effects on the human population (Figure 1).[29] The exceptional scale of the 1918-20 pandemic compared with other pandemics is immediately apparent.



[26] Potter CW, A history of influenza. *J Applied Micro*. 2001:91:572-579; Taubenberger et al (2009, April), Pandemic influenza – including a risk assessment of H5N1, *Revue Scientifique et Technique (Rev. Sci. Tech.)* 28(1) 187-202, at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2720801/ (accessed March 2013); Patterson, Karl D. (1986), Pandemic Influenza, 1700-1900: A study in historical epidemiology, Rowan & Littlefield, publishers; Dowdle, W. R. (1999), Influenza A virus recycling revisited. *Bulletin of the World Health Organization* 77(10) 820-828; at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2557748/(accessed April 2013). Different authors count different events as pandemic or not, but most events on different authors' lists overlap, as does the 8 to 12 total number when the 2009 H1N1 pandemic is included.

[27] This visualization and supporting text were added July 2013.

[28] 1729-1890 estimates are for England and Wales;1918-present are for the U.S. (sources below).

[29] The eight pandemics of natural origin are the list of Potter (2001), *op cit.* Note that these eight pandemics will differ from the pandemic lists of many of the sources from which the chart data come, especially those of older sources.

Note that uncertainties reported in the data sources below are suppressed in the Figure for clarity of presentation.

Pre-1918: Estimates for the population of England and Wales, Eichel, Otto R. (1922, December). The long-time cycles of pandemic influenza. *Journal of the American Statistical Association* 18(140) 446-454; available via JSTOR Early Journals Free Content at http://www.jstor.org/stable/2276917 (accessed June 2013). 1729-33 (90/100,000) is the sum of Eichel's lines for 1729 (30-45) and 1733 (45-60); 1781-82, for 1782 (15); 1832-33, for 1833 (45-60); 1889-90 (74/100,000), for 1889 (16) and 1890 (58). The midpoints of the dashed-line uncertainty ranges reported by Eichel were used as 'best estimates' (e.g. 37.5 + 52.5 = 90; 15; 52.5).

1918-20, 1957-58, 1968-69: Historical fatalities, National Institutes of Health, 2011. *Timeline of human flu pandemics* [electronic resource]. National Institute of Allergy and Infectious Diseases, National Institutes of Health, January 14, 2011; at http://www.niaid.nih.gov/topics/flu/research/pandemic/pages/timelinehumanpandemics.aspx (accessed March 2013). U.S. population, for population fatality rate: United States population including Armed Forces abroad, Table I: National Center for Health Statistics (1999). *Vital Statistics of the United States: 1999 Mortality Technical Appendix*. At http://www.cdc.gov/nchs/products/vsus/ta.htm (accessed April 2013).

2009-10: Fatalities (12,470 total), best estimate, Centers for Disease Control (2010, May 4). Updated CDC estimates of 2009 H1N1 influenza cases, hospitalizations and deaths in the United States, April 2009 – April 10, 2010 [electronic resource]; at http://www.cdc.gov/h1n1flu/pdf/CDC_2009_H1N1_Est_PDF_May_4_10_fulltext.pdf (accessed April 2013).

Hurricane

A tropical storm or hurricane impacts the U.S. resulting in direct economic losses of greater than $100 Million.

Data Summary

In the following table, note that the low and high likelihoods do not correspond to the low and high consequences. In addition, low and high consequences are not necessarily correlated with each other between different consequence categories.

Description	Metric	Low	Best	High
Fatalities	Number of Fatalities[1]	0	26	1,200
Injuries and Illnesses	Number of Injuries or Illnesses[1]	0	650	30,000
Direct Economic Loss	U.S. Dollars[1]	$100 Million	$5.7 Billion	$92 Billion
Social Displacement	Displaced from Homes ≥ 2 Days[2]	140	520,000	5 Million
Psychological Distress	Qualitative Bins	See text		
Environmental Impact	Qualitative Bins[3]	High[4]		
Frequency of Events	Number per Year[5]	0.33	1.9	7

Table 1

Event Background

For the purpose of the SNRA, a national-level hurricane is defined as a hurricane producing direct economic loss in excess of $100 million dollars. Economic damages reported here are a combination of coastal flooding and wind damage generated by hurricanes and tropical storms. A 40 year time period, from 1970 to 2010, was used to estimate the interarrival rates/ frequencies and consequences for hurricanes exceeding the $100 million threshold. While accurate hurricane damages have been recorded since before 1900, mitigation and evacuation strategies have significantly changed since the turn of the 20th century, substantially lowering hurricane consequences. To capture a representative subset for current hurricane consequences, only storms recorded after 1970 were used for this report. Table 1 reports the maximum, average, and minimum frequency with which such hurricanes occurred in the United States, and the maximum, average and minimum consequences for fatalities, injuries, and direct economic losses associated with hurricanes in the set. A list of all hurricanes with accompanying economic consequences and fatalities is shown in Table 2.

Low, average and high estimates were developed in the following manner from the normalized consequence estimates and historic record. For fatalities, injuries and direct economic loss, the low estimate is the smallest consequence for events that exceed $100 million. For event frequency, the low estimate is derived from the greatest time gap, t_{max}, between years with national level events. The average frequency is the expected number of events in a given year. Similarly, the average for fatalities, injuries/illness, and direct economic loss are the expected value for each measure given the occurrence of a national level hurricane. The maximum frequency is the maximum number of national level hurricanes recorded in a single year. The maximum for fatalities, injuries/illness, and direct economic loss is the greatest value produced by a single storm in each consequence category.

It is important to note that the frequency estimates reported here differ from probabilities. The frequency of a national-level hurricane can be greater than one, while a probability cannot. Additionally, while the average estimates for consequences and frequency are correlated and approximate the average annual loss when multiplied together, the maximum and minimum historical values for consequence and frequency are uncorrelated and do not have meaning when multiplied together.

Fatalities

Fatality estimates are based directly on the historic record (Blake, Landsea, & Gibney, August 2011). The historical maximum for fatalities was Katrina in 2005 with an estimated 1,200 deaths.[6] Several storms within the 40 year time period exceeded $100 million in economic damages without causing any loss of life. While several storms have zero recorded fatalities, fatality estimates were not always available for events with less than 25 fatalities. In the case where records were not available, fatality estimates were apportioned as percentages of yearly hurricane fatalities based on economic damages. The average of all national level hurricanes was then used to produce the historical average of 26 fatalities per storm. The table of national level hurricanes, Table 2, contains a total of 2016 fatalities from 78 distinct events.

Injuries and Illnesses

Injury/illness estimates were produced for each hurricane based on a linear model relating fatalities to injuries and illness. The model is derived from Hurricane Andrew in 1992 (CDC, 1993). A model was needed because accurate injury and illness estimates were not readily available for most hurricanes. Fatality, injury and illness statistics are available for regional hospitals and mobile clinics, but these reports do not provide comprehensive estimates for hurricane related injuries. Evacuees can travel hundreds of miles (Faul, Weller, & Jones, September 2011) before receiving medical attention creating a difficult task when accounting for the number of storm related injuries. The CDC, however, has published injury/illness and fatality estimates for 19 parishes during Hurricane Andrew (CDC, 1993) that the SNRA project team used to model a multiplier for estimating total injuries. There were approximately 25 injuries to every fatality within the study group. The multiplier was applied to the fatality estimates to obtain injury/illness estimates for hurricane consequences.

Economic Loss

To provide an accurate assessment for current year planning, historic economic damage estimates have been updated to a 2011 base year. Economic and health & safety consequences, derived directly from historic record, are updated based on changes in populations, building structures, and infrastructure. These damage estimates are published by ICAT and available via the internet.[7] A full description of methods used in economic loss normalization is documented by Pielke (Pielke Jr., Gratz, Landsea, Collins, Saunders, & Musulin, 2008). In total, 78 hurricanes exceeding the $100 million threshold are aggregated in the findings of this report. These estimates potentially contain indirect economic losses. There is not a clear disambiguation for economic loss estimates as there is no readily available record for each loss estimate. Due to this ambiguity, economic loss estimates have the potential to be biased high by as much as 20 percent.

For economic loss, $100 million (1993 Hurricane Emily) is the smallest normalized historic loss that meets the $100 million threshold. Twelve historic events exceeding the economic threshold did not result in any fatalities and, consequently, were not estimated to cause any injuries/illness resulting in a minimum for both fatalities and injuries/illness of zero. The greatest gap occurs between 1985 and 1988. This three year time lapse between national level events results in an interarrival frequency of 0.33, or $1/t_{max}$.

The average economic consequence is $5.7 billion per event. On average, 26 fatalities occur per event with an average of 650 injuries per event. The average time between national level events is approximately six months, resulting in 1.9 events expected per year. An estimate of the average annual loss for each consequence type (e.g., fatalities per year or economic loss per year) can be obtained by multiplying the average frequency by the average consequence in a category. The average annual fatality and economic losses for the set of 78 historic events analyzed are approximately 26 fatalities per year and approximately $5.7 billion per year.

[1] Low, best, and high estimates for fatalities, injuries and illnesses, and direct economic loss are the historical minimum, average, and maximum for each consequence type in the event set. Extremal events for one consequence type may but generally do not correspond to those for other consequence types.
[2] Low, average, and high reported "total affected" for hurricanes causing greater than $100M in economic damage as recorded in the EM-DAT database during the time period 1970-2011. See Social Displacement section in this summary sheet for details.
[3] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories. Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'best' estimate.
[4] Hurricanes were given a best estimate of 'High', with a second best estimate of 'Moderate'. The experts assessed that hurricanes can cause ecological impacts, beach erosion, nutrient loading, chemical contamination, salt water intrusion into fresh water bodies, and removal of plants leading to erosion. Large areas can experience impacts.
[5] Historical low, average, and maximum number of events per year (calculated from interarrival times).

[6] Note that fatality and economic damage estimates can differ across sources, including official U.S. Government sources, depending upon different definitions of what is counted. The fatality estimate of 1,200 for Hurricane Katrina was the latest official estimate of the National Hurricane Service for fatalities directly caused by the hurricane as of August 2011, as reported in the primary source used for fatality data by the SNRA (Blake and Landsea, p. 5). Counts of all fatalities including indirect fatalities can total 1,833, the current official estimate for all fatalities, or higher.
[7] ICAT damage estimates are available at http://www.icatdamageestimator.com. Accessed September 16, 2011.

Table 2: National Level Hurricane Events from 1970 to 2010

STORM NAME	CURRENT DAMAGE ($ 2011)	Year	Yearly Fatalities[8]	Event Fatalities (Estimated if < 25)
Hermine	$250,000,000	2010	13	12
Hanna	$170,000,000	2008	41	0
Fay	$590,000,000	2008	41	1
Dolly	$1,080,000,000	2008	41	2
Gustav	$4,220,000,000	2008	41	7
Ike	$19,600,000,000	2008	41	31
Ernesto	$550,000,000	2006	0	0
Cindy	$360,000,000	2005	1225	0
Dennis	$2,670,000,000	2005	1225	2
Rita	$11,330,000,000	2005	1225	8
Wilma	$26,210,000,000	2005	1225	16
Katrina	$92,050,000,000	2005	1225	1200
Charley	$120,000,000	2004	60	0
Gaston	$160,000,000	2004	60	0
Jeanne	$9,350,000,000	2004	60	8
Frances	$12,310,000,000	2004	60	11
Charley	$18,520,000,000	2004	60	16
Ivan	$18,480,000,000	2004	60	25
Claudette	$250,000,000	2003	24	1
Isabel	$4,820,000,000	2003	24	22
Isidore	$480,000,000	2002	9	2
Lili	$1,210,000,000	2002	9	6
Gabrielle	$390,000,000	2001	45	2
Allison	$8,330,000,000	2001	45	43
Dennis	$270,000,000	1999	62	2
Irene	$1,430,000,000	1999	62	9
Floyd	$7,700,000,000	1999	62	50
Earl	$150,000,000	1998	23	0
Frances	$970,000,000	1998	23	3
Bonnie	$1,440,000,000	1998	23	4
Georges	$4,100,000,000	1998	23	14
Danny	$200,000,000	1997	4	4
Josephine	$310,000,000	1996	36	1
Bertha	$610,000,000	1996	36	3
Fran	$7,260,000,000	1996	36	32
Jerry	$110,000,000	1995	29	0
Erin	$820,000,000	1995	29	3
Erin	$830,000,000	1995	29	3
Opal	$7,490,000,000	1995	29	23
Beryl	$180,000,000	1994	38	3
Gordon	$1,230,000,000	1994	38	16
Alberto	$1,290,000,000	1994	38	20
Emily	$100,000,000	1993	4	2
Andrew	$66,770,000,000	1992	26	26
Bob	$3,620,000,000	1991	16	16
Marco	$210,000,000	1990	13	13
Jerry	$210,000,000	1989	56	1
Chantal	$280,000,000	1989	56	1
Allison	$1,680,000,000	1989	56	4
Hugo	$18,320,000,000	1989	56	51
Gilbert	$200,000,000	1988	6	5
Bob	$120,000,000	1985	30	0
Danny	$160,000,000	1985	30	0
Gloria	$520,000,000	1985	30	1
Kate	$1,270,000,000	1985	30	2
Gloria	$2,490,000,000	1985	30	6
Elena	$4,340,000,000	1985	30	9
Juan	$4,560,000,000	1985	30	11
Diana	$370,000,000	1984	4	4
Alicia	$9,670,000,000	1983	22	22
Dennis	$140,000,000	1981	0	0
Allen	$2,060,000,000	1980	2	2
David	$980,000,000	1979	22	1
David	$1,570,000,000	1979	22	1
Claudette	$1,710,000,000	1979	22	3
Frederic	$12,640,000,000	1979	22	17
Amelia	$190,000,000	1978	36	36
Belle	$570,000,000	1976	9	9
Eloise	$6,230,000,000	1975	21	21
Subtrop 1 1974	$130,000,000	1974	1	0
Carmen	$1,140,000,000	1974	1	1
Delia	$300,000,000	1973	5	5
Agnes	$20,300,000,000	1972	122	122
Ginger	$190,000,000	1971	8	0
Edith	$310,000,000	1971	8	1
Fern	$480,000,000	1971	8	1
Doria	$2,400,000,000	1971	8	6
Celia	$6,850,000,000	1970	11	11

[8] Fatalities due to all hurricanes in same year.

Social Displacement

To estimate social displacement for the SNRA, U.S. hurricane event data from the international disaster database EM-DAT[9] was used to approximate the number of people forced to leave home for two days or greater. EM-DAT provides estimates of the "total number affected" by disaster events. The national-level hurricane events for which EM-DAT data on "total number affected" was available are listed in Table 3 below. (EM-DAT data was available for approximately one-third of the national-level hurricane events identified from the historic record.) The low, high, and average of the "total affected" data in Table 3 are used as the social displacement estimates for hurricanes in the SNRA.

The "total affected" measure includes the number of people needing immediate assistance, which can include displacements and evacuations; the number of people needing immediate assistance for shelter; and the number of people injured. Because EM-DAT includes injuries in the "total affected" measure, there is potential for double-counting between the SNRA injury and displacement estimates for this event. However, displacement due to hurricanes is typically significantly greater than the number of injuries, so using EM-DAT's "total affected" measure was judged to provide an estimate of social displacement of sufficient precision for the SNRA. Note that the low estimate may be biased low due to incomplete reporting of displacement and evacuations in EM-DAT.

Table 3: Social Displacement

Storm Name	Current Damage ($2011)	Category	Year	EMDAT Total Affected
Alberto	$1,290,000,000	TS	1994	20,022
Allison	$8,330,000,000	TS	2001	172,000
Andrew	$66,770,000,000	5	1992	250,055
Bob	$3,620,000,000	2	1991	1,200
Bonnie	$1,440,000,000	2	1998	17,000
Charley	$18,520,000,000	4	2004	30,000
Charley	$120,000,000	1	2004	545
Elena	$4,340,000,000	3	1985	1,000,000
Erin	$830,000,000	1	1995	6,000
Ernesto	$550,000,000	TS	2006	140
Fay	$590,000,000	TS	2008	400
Floyd	$7,700,000,000	2	1999	3,000,010
Fran	$7,260,000,000	3	1996	4,000
Frances	$12,310,000,000	2	2004	5,000,000
Georges	$4,100,000,000	2	1998	5,127
Gustav	$4,220,000,000	2	2008	2,100,000
Hugo	$18,320,000,000	4	1989	25,000
Ike	$19,600,000,000	2	2008	200,000
Isabel	$4,820,000,000	2	2003	225,000
Isidore	$480,000,000	TS	2002	13,200
Jeanne	$9,350,000,000	3	2004	40,000
Katrina	$92,050,000,000	3	2005	500,000
Opal	$7,490,000,000	3	1995	78,000
Rita	$11,330,000,000	3	2005	300,000
Wilma	$26,210,000,000	3	2005	30,000

*Note: EM-DAT estimate for TS Frances (1998) was not included because it only includes injuries, not displacement.

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[10] The numerical outputs of

[9] EM-DAT: The OFDA/CRED International Disaster Database – www.emdat.be, Université Catholique de Louvain, Brussels (Belgium) [official citation]. EM-DAT is maintained by the World Health Organization Collaborating Centre for Research on the Epidemiology of Disasters (CRED) at the School of Public Health of the Université Catholique de Louvain, Brussels, Belgium (http://www.emdat.be/frequently-asked-questions), and is supported by the Office of U.S. Foreign Disaster Assistance (OFDA) of USAID (http://transition.usaid.gov/our_work/humanitarian_assistance/disaster_assistance/). See Criteria and Definition, http://www.emdat.be/criteria-and-definition, EMDAT Data Entry Procedures, at http://www.emdat.be/source-entry , and EMDAT Glossary, at http://www.emdat.be/glossary/ for details of criteria, thresholds, and methodology for the EM-DAT database.

[10] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + \frac{1}{2} D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: hurricanes were given a C_{EF} of 1.0.

this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

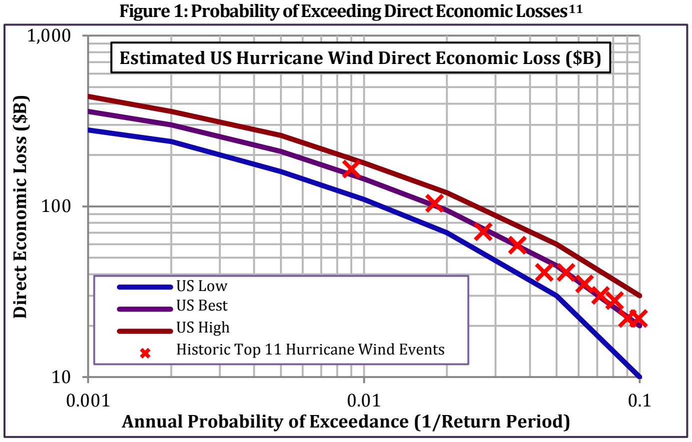
The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental consequences as "moderate." Hurricanes can cause ecological impacts, beach erosion, nutrient loading, chemical contamination, salt water intrusion into fresh water bodies, and removal of plants leading to erosion. Large areas can experience impacts.

Expected Wind Damage Versus Return Period

The results reported in Tables 1 and 2 capture both wind and coastal flooding. An additional perspective into hurricane damage is the effect of wind damage alone. Figure 1 provides a loss exceedance probability for wind related hurricane damages in addition to damages from the top 11 hurricane wind events.

Figure 1: Probability of Exceeding Direct Economic Losses[11]



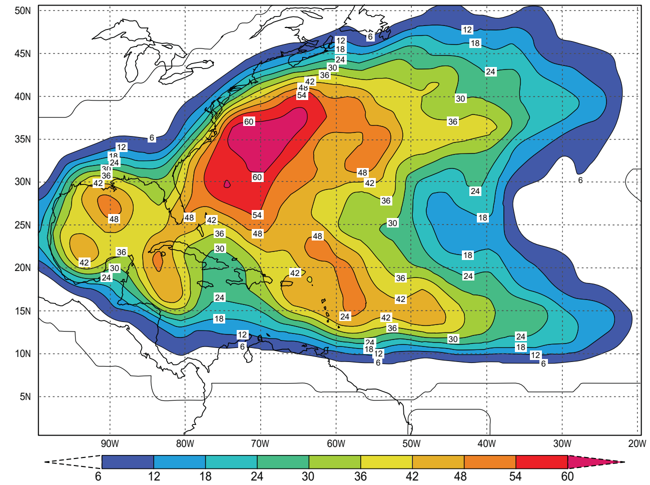
Additional Relevant Information

Figure 2 depicts the likelihood that a tropical storm or hurricane would affect the area sometime during the Atlantic hurricane season. This figure was created by the National Oceanic and Atmospheric Administration's Hurricane Research Division using data from 1944 to 1999 and counting hits when a storm or hurricane was within approximately 100 miles (165 kilometers) of each location.

As shown in Figure 2, the probability of potential impact varies across the U.S. coastline. Portions of the North Carolina Outer Banks have the same probability of occurrence (42 to 48 percent) as South Florida and southern Louisiana. Parts of the southeastern U.S. coastline as well as the Florida panhandle and portions of the Texas coastline have a lower probability of occurrence, in the 24 to 36 percent range. The northeastern U.S. coastline has the lowest probability, in the 12 to 24 percent range. The ranges provided in the "Data Summary" on Page 1 reflect the range of probability from a national perspective.

The probability of storm occurrences will vary significantly based on the return interval for different categories of magnitude. The probability of less intense storms (lower return periods) is higher than more intense storms (higher return periods).

Figure 2: Empirical Probability of a Named Hurricane or Tropical Storm

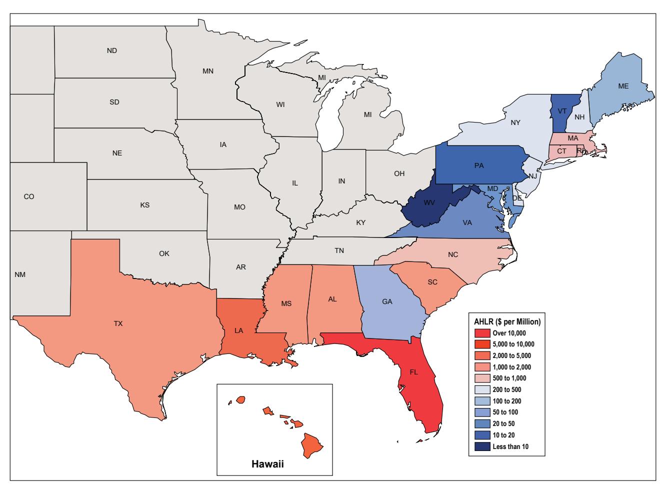


Source: National Oceanic and Atmospheric Administration[12]

In 2007, FEMA estimated average annualized losses for hurricane wind for the nation by state. The estimated average annualized loss (AAL) addresses the key idea of risk: the probability of the loss occurring in the study area (largely a function of building construction type and quality). By annualizing estimated losses, the AAL factors in historic patterns of frequent, smaller events with infrequent but larger events to provide a balanced presentation of the event risk. The AAL analysis, which only considered those 22 states and the District of Columbia that are susceptible to the hurricane wind hazard, yielded an estimate of the national AAL of $11.1 billion per year. This estimate does not include storm surge, lifeline infrastructure losses or indirect (long-term) economic losses, and is therefore a minimum estimate of the potential losses. Moreover, the estimate represents a long-term average and actual losses in any single year may be much larger or smaller. It is important to recognize that the nationwide losses are the result of averaging losses caused by hurricanes occurring in different parts of the nation in different years.

The annualized loss ratio (ALR) represents the AAL as a fraction of the replacement value of the local inventory. The ALR gauges the relationship between average AAL and replacement value. This ratio can be used as a measure of vulnerability in the areas and, because it is normalized by replacement value, it can be directly compared across different geographic units such as metropolitan areas or counties.

Figure 3: Hazus-MH Hurricane Wind Annualized Loss Ratios by State



Source: FEMA, September 2007[13]

Figure 3 shows the resulting state ALRs from this study,[14] which helps to illustrate from a national perspective those areas that are more vulnerable to potential hurricane wind impacts. Based on this data, Florida has the highest expected ALR among all states exposed to hurricane winds and therefore has the highest likelihood of experiencing losses due to hurricane

The numerical estimates calculated from this formula are reported in Appendix G. The semi-quantitative risk matrix is discussed in the Findings (Psychological Distress Risk).

[11] Graphical output of modeling done by HAZUS-MH contract support and provided to the SNRA project team.

[12] Available through NOAA, National Weather Service, Tropical Cyclone Climatology; at http://www.prh.noaa.gov/cphc/pages/FAQ/Climatology.php (accessed 3/16/2013).

[13] Estimated annualized hurricane wind losses for the United States calculated September 2007 using HAZUS-MH, and provided to the SNRA project team by FEMA.

[14] FEMA 610: HAZUS-MH Estimated Annualized Hurricane Wind Losses for the United States, draft September 2007 (pre-publication draft, no corresponding publication in FEMA Library).

wind in any given year. Other high potential loss states include Louisiana, Texas, Mississippi, Alabama and South Carolina. Table 4 ranks states according to hurricane wind AAL and ALR.

Table 4: Hazus-MH Annualized Hurricane Loss (AHL) and Annualized Hurricane Loss Ratios (AHLR) Ranking

Order	State	AHL ($ K)	Order	State	AHLR ($ Million)
1	Florida	5,610,000	1	Florida	5,660
2	Texas	1,450,000	2	Louisiana	3,560
3	Louisiana	889,000	3	Hawaii	2,520
4	New York	505,000	4	Mississippi	1,600
5	Massachusetts	430,000	5	Rhode Island	1,510
6	Hawaii	335,000	6	Texas	1,170
7	Alabama	303,000	7	South Carolina	1,160
8	North Carolina	262,000	8	Alabama	1,120
9	South Carolina	247,000	9	Massachusetts	875
10	Mississippi	210,000	10	Connecticut	728
11	New Jersey	194,000	11	North Carolina	622
12	Connecticut	187,000	12	New York	357
13	Georgia	125,000	13	New Hampshire	320
14	Rhode Island	113,000	14	Delaware	310
15	Virginia	72,500	15	New Jersey	307
16	Pennsylvania	34,100	16	Georgia	262
17	Maryland	31,000	17	Maine	224
18	New Hampshire	25,000	18	Virginia	174
19	Maine	17,800	19	Maryland	91
20	Delaware	17,300	20	District of Columbia	45
21	District of Columbia	2,160	21	Vermont	43
22	Vermont	1,560	22	Pennsylvania	42
23	West Virginia	792	23	West Virginia	7

Source: FEMA, September 2007[15]

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[15] Estimated Annualized Hurricane Loss (AHL) and Annualized Hurricane Loss Ratios (AHLR) calculated September 2007 using HAZUS-MH, provided to the SNRA project team by FEMA and rounded to three significant figures.

Space Weather

The Sun emits bursts of electromagnetic radiation and energetic particles causing utility outages and damage to infrastructure.

Data Summary[1]

Description	Metric	Low	Best	High
Fatalities	Number of Fatalities	N/A		
Injuries and Illnesses	Number of Injuries or Illnesses	N/A		
Direct Economic Loss	U.S. Dollars	N/A		
Indirect Economic Loss	U.S. Dollars	$4-10 Billion	N/A	$1-2 Trillion
Social Displacement	Displaced from Homes ≥ 2 Days	N/A		
Psychological Distress	Qualitative Bins	See Discussion		
Environmental Impact	Qualitative Bins[2]	None[3]		
Frequency of Events	Number per Year	N/A	One per 100 Years	N/A

Event Background

Space weather events presumably have occurred throughout human history, but were not noticed until human technology advanced to the point of developing systems that would be affected by geomagnetic and electrical disturbances. The connection to solar phenomena was made in 1859 when a solar flare was observed, followed by disruption of telegraph communications. Direct environmental and health effects are minimal as damage occurs mainly through the medium of disruption of technology.

Technologies that can be directly affected by extreme space weather are the electric power, spacecraft, aviation, and GPS-based positioning industries. Within the last 30 years, space weather events have disrupted all of these technologies. Severe storms could result in additional consequences for numerous systems that rely on the electrical grid. As stated in a NRC workshop report, "Impacts would be felt on interdependent infrastructures, with, for example, potable water distribution affected within several hours; perishable foods and medications lost in about 12-24 hours; and immediate or eventual loss of heating/air conditioning, sewage disposal, phone service, transportation, fuel resupply, and so on."[4] The potential effects of a more severe event have been studied but are still subject to considerable uncertainty.

The potential for loss of life is thought to be low. Any deaths would be caused by the loss of electricity and the resulting cascading effects on other critical infrastructures. For example, the loss of electricity could cause mass transit and passenger rail control systems to fail, potentially causing accidents with fatalities. Water shortages may be caused by the failure of electrical pumps to convey water. Power loss at purification plants could lead to acute exposure to toxicants or disease. By extension, firefighters would not have access to water to put out fires and hospitals would not have access to water to take care of at-risk patients. In summary, circumstances beyond a geomagnetic event are necessary to lead to injury, illness, or death. [5]

Assumptions

The analysis conducted in this summary assumes a G5 level or "Extreme" geomagnetic storm on the NOAA Space Weather Scale.

[1] Defensible quantitative estimates could not be determined for the Space Weather event. See discussion.
[2] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.
[3] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'Best' estimate.
[4] National Research Council, Severe Space Weather Events – Understanding Societal and Economic Impacts Workshop Report, 2008, p. 77.
[5] OECD/International Futures Programme, Geomagnetic Storms, January 2011, p.25.

Economic Impacts

The SNRA project team used the following assumptions to estimate economic consequences resulting from a space weather event:

- *Effects on Aviation*: A severe event might force the rerouting of hundreds of flights not just over the pole but also across Canada and the northern U.S. These adverse conditions could last for a week.[6] A National Weather Service (NWS) study estimated the cost of such diversions as approximately $100,000 per flight.[7] In addition, GPS-based air navigation could be disrupted. The Federal Aviation Administration's GPS-based Wide Area Augmentation System (WAAS) was disabled for 30 hours during the severe space weather events of October-November 2003.
- *Effects on Satellites*: Exposure of spacecraft to energetic particles during solar energetic particle events and radiation belt enhancements can cause temporary operational anomalies, damage critical electronics, degrade solar arrays, and blind optical systems such as imagers and star trackers.[8] In January 1994, Telesat's Anik E1 and E2 telecommunications satellites were affected by a space weather event; E2 required 6 months to repair at a cost of $50-70 million. The U.S. Department of Defense has estimated that solar disruptions to government satellites currently cost about $100 million per year.[9] A study by Odenwald and Green[10] estimated total costs due to satellite damage and loss of satellite services at $20-70 billion for a severe event.
- *Effects on GPS services*: Direct estimates of the potential cost of a loss or degradation of GPS services from a severe space weather event were not found. However, the total economic benefit of GPS services to users (i.e., not counting sales of GPS devices) has been estimated at $28-51 billion per year.[11] The percentage of such services that could be lost due to a severe space weather event is unknown.
- *Effects on Electricity Supply*: A very strong space weather event theoretically could cause widespread, lasting damage to our electric power supply system. A widely quoted study by J. Kappenman of Metatech Corp. estimates that power outages would quickly affect almost the entire U.S. east of the Mississippi River plus the Pacific Northwest. Recovery times could be long (months to years) due to the need to replace a significant percentage (approximately 20-55%) of the extremely high voltage transformers in the affected areas. In those areas, approximately 128 gigawatts of generating capacity might be offline for significant periods due to loss of these transformers.[12] At the 2008 NRC workshop on space weather impacts, Mr. Kappenman estimated potential economic losses as $1-2 trillion in the first year, with a potential total duration of 4-10 years.[13] The low estimate of $4-10 billion is the estimated cost of the August 2003 blackout in the Eastern U.S., which was smaller in extent than the estimate for a national-level space weather event and was only hours to days in duration.[14]

Social Displacement

A persistent, widespread power outage could lead to significant social effects. Significant areas might become uninhabitable, particularly in winter. Mr. Kappenman has testified to Congress that over 100 million people could be affected by power outages.[15] Widespread persistent loss of power supply could cause significant psychological impact through job loss and displacement from uninhabitable areas.

The uncertainties in the likelihood of occurrence of such a catastrophic scenario prevented inclusion of quantitative estimates of social displacement in the SNRA.

Psychological Distress

Because defensible estimates for the fatalities, injuries and illnesses, and social displacement upon which the SNRA measure of psychological distress is based could not be determined,[16] estimates for psychological

[6] Sten F. Odenwald and James L. Green, Bracing for a Solar Superstorm, *Scientific American*, July 2008.
[7] NOAA NWS, Intense Space Weather Storms October 19-November 07, 2003, April 2004, p. 17.
[8] National Research Council, Severe Space Weather Events – Understanding Societal and Economic Impacts Workshop Report, 2008, p. 1.
[9] Supra note 1.
[10] Supra note 1.
[11] Nam D. Pham, Ph.D., NDP Consulting, The Economic Benefits of Commercial GPS Use in the U.S. and the Costs of Potential Disruption, June 2011, accessed at http://www.saveourgps.org/pdf/GPS-Report-June-22-2011.pdf.
[12] Kappenman, John, Metatech Corp., Geomagnetic Storms and Their Impacts on the U.S. Power Grid, Jan. 2010, Chapter 4. Prepared for Oak Ridge National Laboratory.
[13] NRC, supra note 3, p. 79.
[14] Electricity Consumers Resource Council, 2004. The economic impacts of the August 2003 blackout. At http://www.elcon.org/Documents/EconomicImpactsOfAugust2003Blackout.pdf.
[15] Testimony of John Kappenman, October 30, 2003, to the Subcommittee on Environment, Technology, and Standards, Committee on Science, U.S. House of Representatives (108th Congress). Hearing title: What is space weather and who should forecast it? GPO Serial No. 108-31, DOCID: f:90161.wais.
[16] Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input. The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

distress are not reported for the space weather event in this iteration of the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agents, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental consequences as "de minimus" or none. Experts indicated environmental/ecological effects would likely depend on duration of outages. For one day to a few days, the damage would be relatively minimal/de minimus (this is in the scope of typical power outages due to snowstorms, rain, and other natural disasters). If the outage persisted for weeks, then there is the potential for backup systems to fail. If backup systems (such as diesel fuel delivery) failed, then the lack of power to treatment plants and chemical plants could have a massive impact. A space weather event would most likely affect a large geographic area in addition to having the potential for a longer duration.

Potential Mitigating Factors

The consequences of a geomagnetic storm depend largely on the severity of the storm, geographic latitude, ground conductivity, capacity of electrical power transmission networks and length and direction of extra high voltage (EHV) lines contained in these networks. In general, northern latitudes with igneous rock and other high-conductivity ground materials are more vulnerable to the effects of geomagnetic storms. Further, high-capacity electrical transmission systems act as antennae for geomagnetic storms, exacerbating potential consequences. Extra high voltage (EHV) lines that travel east to west over long distances are of particular concern.

Additional Relevant Information

The NOAA Space Weather Prediction Center provides the following estimates for frequency of geomagnetic storms during an average 11–year solar cycle:

GME Event	Average Frequency of Events (Number of Days per Cycle) when Physical Measure (Kp value) was met
G-5 Extreme (Kp=9)	4 Events per Cycle (4 Days per Cycle)
G-4 Severe (Kp=8)	100 Events per Cycle (60 Days per Cycle)
G-3 Strong (Kp=7)	200 Events per Cycle (130 Days per Cycle)
G-2 Moderate (Kp=6)	600 Events per Cycle (360 Days per Cycle)
G-1 Minor (Kp=5)	1700 Events per Cycle (900 Days per Cycle)

The Metatech study estimated that a geomagnetic storm of approximately -5,000 nanoTeslas (nT)/min. intensity, may be expected approximately once every 100 years.[17] For comparison, the 1859 "Carrington Event" was measured at -1760 nT/min, which is three times as intense as the geomagnetic storm responsible for the Quebec power outage in 1989 (-640 nT/min).[18]

The Significant Distress Index is calculated using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + ½\ D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: Space Weather was given a C_{EF} of 1.0.

[17] Kappenman, supra note 7, p. 3-13.

[18] OECD/International Futures Programme, Geomagnetic Storms, January 2011, p.9.

Tsunami

A large tsunami with a wave of approximately 50 feet impacts the Pacific Coast of the United States.

Data Summary

In the following table, note that the low and high likelihoods do not correspond to the low and high consequences. In addition, low and high consequences are not necessarily correlated with each other between different consequence categories.

Description	Metric	Low	Best	High
Fatalities	Number of Fatalities	1	300	1000
Injuries and Illnesses	Number of Injuries or Illnesses	1	300	1000
Direct Economic Loss[1]	U.S. Dollars	$705 Million	$1.53 Billion	$3.32 Billion
Social Displacement	Displaced from Homes for ≥ 2 Days	8,600	14,700	N/A[2]
Psychological Distress	Qualitative Bins	See text		
Environmental Impact	Qualitative Bins[3]	Moderate[4]		
Frequency of Events	Number per Year	0.26%[5]	0.57%[6]	0.92%[7]

Event Background

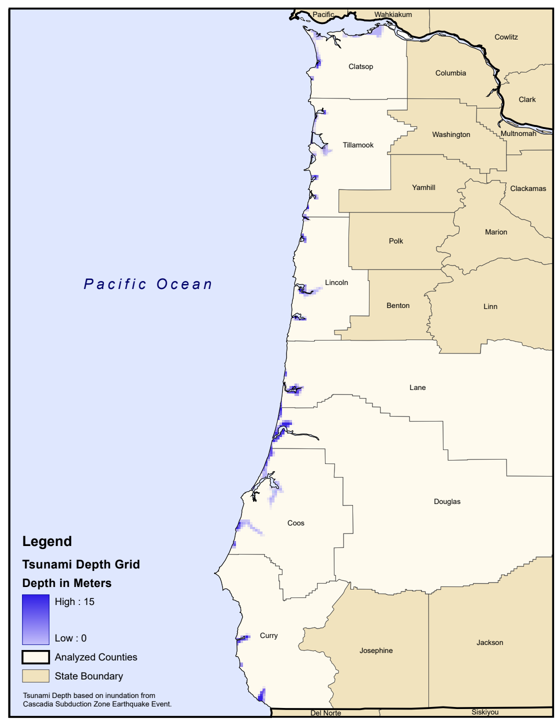
A tsunami event could present a significant risk to the west coast of the United States. The Pacific Northwest is an area of increased risk due to the Cascadian Subduction Zone, which is where the Juan de Fuca Plate meets and is forced under the North American Plate.[8] These subduction zones are associated with volcanism, earthquakes, and orogenic uplift, commonly referred to as mountain building. Earthquakes produced in these areas have the potential to be incredibly powerful, with nine of the ten largest quakes over the last 100 years occurring in these areas, including the 2004 Indian Ocean earthquake and the 2011 Tohoku, Japan, earthquake, both of which caused massive tsunamis. This is the same risk posed to the Pacific Northwest as a result of the Cascadian Subduction Zone.

A report for Seaside, Oregon, involved running more than 25 models including both near field (local) and far field (distant) generated tsunamis with estimated return periods.[9] A modeled 100-year tsunami event showed similar impacts to the 1964 Alaska earthquake, which represented a distant event. The local event looked at Cascadian-type events, which tended to follow a 500-year return period event, although the historical evidence shows that these are rarer than every 500 years. The models generated from this project showed tsunami depths ranging from 22 to 38 meters (72 to 124 feet), although the highest of these depths occurred at the shoreline, with the depths of the land areas seeing highs around 14 to 16 meters (45 to 52 feet). A study was performed to develop a method for Probabilistic Tsunami Hazard Analysis based on traditional Probabilistic Seismic Hazard Analysis.[10] While the study did not focus on the Pacific Northwest, this area was included in the discussion, and the findings showed a maximum expected height from a 975-year return period event would be in the range of 10 to 15 meters.

The Seaside area of the Oregon Coast was chosen to model the risk of such an event because it is typical of many coastal communities in the section of the Pacific Coast from Cape Mendocino to the Strait of Juan de Fuca, and because State agencies and local stakeholders expressed considerable interest in mapping the tsunami threat to this area.[11] Looking at possible events with catastrophic consequences, the Cascadian Subduction Zone is one that has a likelihood of occurring and would result in major damages. Oregon has detailed modeling and analysis of tsunamis that would be generated by an earthquake along this zone, including an inundation boundary that extends the entire length of the coastline.

To perform this scenario analysis, ground digital elevation models (DEM) were used for the entire study area as well as the mapped tsunami inundation line from the State of Oregon GIS Clearinghouse.[12,13] The inundation line was converted to a 3D feature with the DEM as the elevation source. This line was copied and placed parallel to the west, offset by approximately 1,000 meters. This outer line was generalized to remove the inlets and river areas that were represented in the original inundation line feature. The lines were used to create a tin that represented a constant ground surface from the actual inundation line, extending west beyond the coast. This tin was converted into a grid, which allowed for a raster calculation to be performed where the ground surface DEM was subtracted from the inundation grid. The output from the calculation produced the depth grid. Potential losses in the seven coastal counties in Oregon were estimated using HAZUS-MH to model the scenario defined by these modeling inputs.[14] Figure 1 shows the scenario area and the inundation zones.

Figure 1. Tsunami Scenario Location Map[15]



Assumptions

Based on previously conducted research, it is reasonable to assume that modeling a tsunami with the maximum height of 15 meters (approximately 50 feet) is appropriate for analyzing a potential Cascadian event generated tsunami along the Oregon Coast.[16,17] Additionally, the depth damage

[1] The economic damage numbers reported here include property damage and business interruption costs. The SNRA measure of direct economic damage additionally includes medical costs, and one year's lost demand due to fatalities ($42,500 per fatality): the SNRA project team made the assumption that these contributions would be negligible in comparison to the property damage and business interruption costs, in particular the property damage estimates calculated by HAZUS.

[2] Since variations of scenario parameters in HAZUS did not produce social displacement estimates substantially higher than the best estimate of 14,700, the SNRA does not report a separate high estimate.

[3] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.

[4] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'Best' estimate.

[5] One-year frequency corresponding to 12% probability within the next 50 years of a 9.0 magnitude earthquake causing a tsunami inundating coastal communities across the U.S. Pacific Northwest and Northern California. 12% was taken as the midpoint of the 10-15% range estimate cited by geologists (see Additional Relevant Information).

[6] One-year frequency corresponding to a 25% probability of a tsunami within 50 years. The SNRA project team averaged the low and high probability estimates reported in the literature to obtain this best estimate.

[7] One-year frequency corresponding to a 37% probability within the next 50 years of an 8.2 magnitude earthquake causing a tsunami impacting a portion of the U.S. Pacific Northwest and/or Northern California (see Additional Relevant Information).

[8] Local Tsunami Hazards in the Pacific Northwest from Cascadia Subduction Zone Earthquakes, http://pubs.usgs.gov/pp/pp1661b/pp1661b.pdf.

[9] Wong, F.L., Venturato, A.J., and Geist, E.L., 2006, Seaside, Oregon, tsunami pilot study—Modernization of FEMA flood hazard maps: GIS Data: USGS Data Series 236: http://pubs.usgs.gov/ds/2006/236/.

[10] Thio, H. K., Ichinose, G. A.; Somerville, P. G.; Polet, J, 2006. Probabilistic Tsunami Hazard Analysis. Presentation, American Geophysical Union Fall Meeting, December 2006; abstract at http://adsabs.harvard.edu/abs/2006AGUFM.S31C..08T. See also Thio et al 2007, Probabilistic tsunami hazard analysis for ports and harbors, Proceedings of the American Society of Civil Engineers, Ports 2007, pp 1-10, abstract http://ascelibrary.org/doi/abs/10.1061/40834%28238%29103; and Thio, H. K., Probabilistic Tsunami Hazard Analysis, presentation, National Tsunami Hazard Mitigation Program 2012 Tsunami Hazard/Risk Analysis Workshop, July 2012, full deck http://nthmp.tsunami.gov/2012tsuhazworkshop/presentations/Thio_presentation.pdf (accessed March 2013).

[11] Wong, *op cit*.

[12] Oregon GIS Data Clearinghouse, http://spatialdata.oregonexplorer.info/GPT9/catalog/main/home.page.

[13] The inundation line matched well with the near field event boundary from the USGS project, and it was determined that this was an acceptable line upon which to base scenario depths.

[14] HAZUS-MH: multihazard loss estimation software. Federal Emergency Management Agency (FEMA), U.S. Department of Homeland Security (1997-2011): http://www.fema.gov/hazus. See FEMA 433 (2004, August), Using HAZUS-MH for Risk Assessment, http://www.fema.gov/pdf/plan/prevent/hazus/fema433.pdf .

[15] Source: GIS Analysis using Hazus-MH and Oregon GIS Data Clearinghouse data. See Discussion.

[16] Thio et al 2006, *op cit*.

functions were adjusted to reflect the velocity losses associated with the tsunami phenomenon. The damage function used assumes a linearly increasing damage from 0 to 100 percent for flood depth, with wave action ranging from 0 feet to 4 feet and 100 percent damage at 4 feet and beyond.

Fatalities and Injuries

The HAZUS-MH flood model used to model the Tsunami scenario does not provide direct estimates of fatalities and injuries. The SNRA project team used the following assumptions to estimate health and safety consequences caused by a tsunami event:

- In terms of fatalities, minimal impact is assumed except:
  - In areas that do not receive the warning in time (may include possible malfunction of warning equipment)
  - In communities not trained in evacuation
  - In flat areas where no evacuation routes exist
  - For persons who do not obey orders or who happen to be in vulnerable areas with no warning systems
- Based on these exceptions, it is reasonable to assume the possible range of fatalities to be between 1 and 1,000 and injuries to be between 1 and 1,000. The timing of a tsunami (impact during day versus night) could potentially impact the ability of the population to receive warnings; therefore, a tsunami at 2 a.m. when people are sleeping could potentially cause more deaths and injuries than a daytime tsunami.
- The population information used for estimating the health and safety consequences is 2000 U.S. Census data.
- Given the effort Oregon has put into training, warning systems, evacuation route planning, as well as other mitigation techniques, professional engineering judgment based on experience suggests that it would be reasonable to expect that approximately 1% of the exposed population would be injured or killed as a result of this event. The result was then split evenly with 50% counted as injured and 50% counted as being killed by the event.
- If a similar scenario were to occur along other areas of the U.S. coastline, higher casualty rates may be more likely because the West Coast (as well as Alaska and Hawaii) is better prepared for tsunami impacts than the East Coast and Gulf Coast (in terms of evacuation plans, drills, and warning systems), and the exceptions listed above would be more likely to be the case in non-West Coast areas.

Economic Loss

The SNRA project team used the following assumptions to estimate economic consequences caused by a tsunami event:

- More than 1,700 buildings were estimated as being destroyed in the modeled event. Building losses would likely exceed $1.5 billion. The event would also cause business disruption, which is estimated to be nearly $13 million. The area incurring the most severe consequences would be Clatsup County, accounting for nearly half of the destroyed buildings and economic losses which would occur.
- If a similar scenario were to occur along other areas of the U.S. coastline, higher economic losses may be expected resulting from the proximity of more development to the coast, lack of warning, and panic.

Social Displacement

The SNRA project team used the following assumptions to estimate social consequences caused by a tsunami event:

- Displacement estimates assume those affected would require accommodations in temporary public shelters. The results estimate that approximately 14,737 persons would seek temporary refuge in public shelters, which was used as the best estimate.
- Range estimates for social displacement were calculated by running the same scenario using inundation level as a variation parameter, decreasing the inundation by 2 feet to estimate the lower bound and increasing the inundation by 2 feet to estimate the higher bound. The lower bound of 8,600 was used as the low estimate.
- Since increasing inundation level did not substantially vary the displacement numbers, the SNRA does not report a high estimate for the tsunami event.[18]

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. To reflect empirical findings that the scope and severity of an event is more important than the type of event, the SNRA psychological distress metric is constructed from the fatalities, injuries, and displacement associated with an event as primary inputs, weighted by a secondary factor elicited from subject matter experts for differing psychological impact based on the type of event.[19]

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental consequences as "Moderate." Experts indicated that this is the best estimate, but that consequences could be higher or lower depending on the precise location, barrier channels, and ecosystem impacts.

Potential Mitigating Factors

The consequences caused by a tsunami can be mitigated through several preparedness strategies. Warning and monitoring systems can assist in alerting population areas that may be impacted by a tsunami. Periodically testing these systems will ensure that they are functioning when a tsunami event occurs. Identifying evacuation routes and training communities in how to use them during an event will improve the ability for the population to egress vulnerable areas. Finally, the importance of evacuating during a potential event should be communicated to individuals living or working in vulnerable areas.

Additional Relevant Information

In 1700, a major earthquake occurred along this zone, rupturing a 620-mile section of the fault line. The estimated magnitude was between 8.7 and 9.2 and caused a tsunami that impacted the Oregon coastline and was recorded in Japan. More recently, geologists have studied this fault and concluded there is a 37 percent chance of an 8.2 or larger event in the next 50 years and a 10 to 15 percent chance for a rupture along the entire fault from a 9.0 or larger event.[20,21,22] A tsunami generated from this magnitude event could reach heights of 20 to 30 meters (65 to 100 feet) along the Pacific Northwest coast and have catastrophic results.[23] All oceanic regions of the world can experience tsunamis, but in the Pacific Ocean there is a much more frequent occurrence of large, destructive tsunamis because of the many large earthquakes along the margins of the Pacific Ocean.

It is reasonable to expect that a tsunami impacting the U.S. could potentially experience similar consequences to this scenario, regardless of coastal location. The range of potential loss could be broad depending upon many factors including but not limited to the population density of low-lying coastal areas, presence of agricultural assets such as crops and livestock, and location of nearby drinking water supplies. Long-term impacts could also be experienced and would depend on the level of contamination caused in the area.

[17] Wong, op cit.

[18] Because the inundation boundary line would not likely extend further due to topography as well as other contributing factors, the number or displaced persons is not expected to change from the original scenario calculation even when inundation was assumed to increase by two feet of water.

[19] A Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\, Fat + Inj + \frac{1}{2} D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics. The familiarity factor, intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences, was assessed as 1.0 for Tsunami on a scale of 1.0 for familiar events to 1.3 for unfamiliar events.
The specificity of the tsunami event to a single geographic scenario precluded comparative judgments of risk on the psychological or other consequence metrics with other events. This limitation will be addressed in a future iteration of the SNRA.

[20] Odds are 1-in-3 that a huge quake will hit Northwest in next 50 years. Oregon State University press release, 24 May 2010, announcing preliminary results later published as reference [22]; at http://oregonstate.edu/ua/ncs/node/13426 (accessed 3/17/2013).

[21] Risk of giant quake off American west coast goes up. *Nature News*, 31 May 2010, citing results later published as reference [22]; at www.nature.com/news/2010/100531/full/news.2010.270.html.

[22] Goldfinger et al, 2012. Turbidite event history – Methods and implications for Holocene paleoseismicity of the Cascadia Subduction Zone. USGS p 1661-F, 7/17/2012: http://pubs.usgs.gov/pp/pp1661f/ (accessed 3/17/13).

[23] Recent findings concluded the Cascadia subduction zone was more hazardous than previously suggested. The feared next major earthquake has some geologists predicting a 10% to 14% probability that the Cascadia Subduction Zone will produce an event of magnitude 9 or higher in the next 50 years; however, the most recent studies suggest that this risk could be as high as 37% for earthquakes of magnitude 8 or higher. Geologists have also determined the Pacific Northwest is not prepared for such a colossal earthquake. The tsunami produced may reach heights of approximately 30 meters (100 ft).

Volcanic Eruption

A large volcano in the Pacific Northwest erupts, impacting the surrounding areas with lava flows and ash, and areas east with smoke and ash.

Data Summary

In the following table, note that the low and high likelihoods do not correspond to the low and high consequences. In addition, low and high consequences are not necessarily correlated with each other between different consequence categories.

Description	Metric	Low	Best	High
Fatalities	Number of Fatalities	340[1]	515[2]	780[3]
Injuries and Illnesses	Number of Injuries or Illnesses	2,000	17,000	150,000
Direct Economic Loss[4]	U.S. Dollars	$4.3 Billion[5]	$8.3 Billion[6]	$16.2 Billion[7]
Social Displacement	Number of Displaced from Homes for ≥ 2 Days	1,300	130,000	2.1 Million
Psychological Distress	Qualitative Bins	See text		
Environmental Impact	Qualitative Bins[8]	High[9]		
Frequency of Events	Number per Unit of Time	1/1000 yrs	1/500 yrs	1/100 yrs

Event Background

This volcanic hazard scenario focuses on community exposure to lahar (large, swift, and saturated debris flows produced by volcanoes) hazards and ashfall associated with Mount Rainier, Washington. Mount Rainier lahar flow affects four counties in the state of Washington: King County, Lewis County, Pierce County, and Thurston County. A majority of the hazard areas are located in Pierce County. Mount Rainier is part of the Cascade Volcano range aligned in a north-south direction that roughly parallels the Pacific Ocean. Mount Rainier is the second highest peak in the conterminous U.S. at 14,410 feet (4,393 meters) and the largest single-peak glacial system in the U.S. Due to the proximity of over 1.5 million people living within the shadow of Mount Rainier, it is considered the most dangerous volcano in the Cascade Range.[10] The most populous city near Mount Rainier is Tacoma. Tacoma is approximately less than one mile from the lahar hazard area boundary.

The lahar hazard areas and debris flow paths used in this scenario are based on the behavior of the Electron Mudflow, a lahar that traveled along the Puyallup River approximately 500 years ago and was due to a slope failure on the west flank of Mount Rainier (Figure 1).[11]

The SNRA project team leveraged data from a 2009 study calculating community vulnerability to possible lahar hazards originating at Mount Rainier.[12]

Ash normally accompanies an eruption of a volcano and is composed of fine particles of fragmented volcanic rock (less than 2 mm diameter).[13] Ashfall is the accumulation of volcanic ash and a typical result of volcanic activity. Ashfall radius is dependent on wind direction, wind strength, and size of ash particles. The negative effects are dependent on the amount of ash accumulation. Ashfall with a thickness of 1/3 inch may cause disruption of ground and air transportation and cause damage to electronics and machinery, while four inches of ash could be sufficient to collapse building roofs. Ash can possibly produce acid rain when mixed with precipitation creating a form of diluted sulfuric acid.[14]

Figure 1 – Reference Map[15]

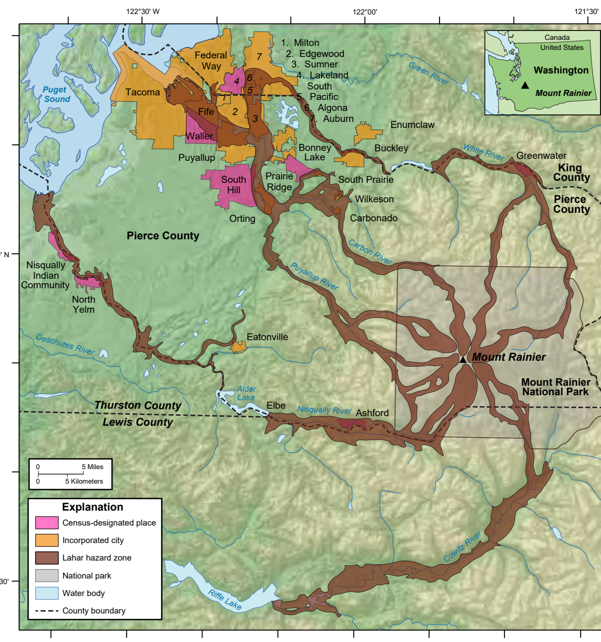


Figure 1. Map showing counties, incorporated cities, and census-designated places within a lahar-hazard zone on and near Mount Rainier, Washington (Hoblitt and others, 1998; Schilling and others, 2008).

Volcanoes commonly repeat past behaviors, therefore historic ashfall and gas patterns were evaluated for Mount Rainier.[16] For this scenario, historic ashfall and gas patterns from Mount St. Helens were used. These patterns caused ash and gas to rise more than 15 miles vertically in 15 minutes. Clouds of ash can extend thousands of miles.[17] Mount St. Helens' heaviest ash deposition occurred in a 60 mile long swath immediately downwind of the volcano and thick ash deposits extended about 195 miles. During the 9 hours of vigorous eruptive activity, about 540 million tons of ash fell over an area of more than 22,000 square miles.[18] If similar ashfall were to occur as a result of Mount Rainier volcanic activity, the ash would reach westerly to Fort Lewis and easterly past the Snoqualmie National Forest.

Some possible negative consequences of ash include, but are not limited to:[19]

- Respiratory effects such as nasal irritation, throat irritation, and airway irritation
- Eye symptoms such as eye irritation, abrasions, discharge, or acute conjunctivitis
- Skin irritation
- Indirect health effects such as reduction of visibility on roadways, increased demand on power leading to electricity loss, and effects on water supply creating possible contamination
- Disruption of ground and air transportation
- Major air routes pass downwind of the Cascade Volcanoes resulting in possible disturbance to flights and flight patterns
- Damage to electronics and machinery possibly affecting economic dynamics
- Crop damage causing agricultural loss

[1] The 'Low' estimation was calculated by overlaying the Case I Debris Flow GIS boundary on 2000 U.S. Census designated census blocks to determine the affected population. 2010 U.S. Census data was not available during the time of analysis (July 2011).
[2] The 'Best' estimation is the geometric mean of 'Low' and 'High' possible fatalities.
[3] Community Exposure to Lahar Hazards from Mount Rainier, Washington; Nathan J. Wood and Christopher E. Soulard, USGS Scientific Investigations Report 2009-5211, September 16, 2009.
[4] The economic damage numbers reported here includes property damage and business interruption costs, but not lost demand due to fatalities and medical costs due to injuries. The SNRA project team determined that the property damage and business interruption costs dominated the direct economic damages of the scenario used for the volcanic eruption event to the extent that the multipliers for the other two components would have a negligible effect on the reported totals.
[5] The 'Low' estimation was calculated by overlaying the Case I Debris Flow GIS boundary was overlaid on 2000 U.S. Census designated census blocks to determine the affected population. 2010 U.S. Census data was not available during the time of analysis (July 2011).
[6] The 'Best' estimation is the geometric mean of 'low' and 'high' possible economic consequences.
[7] The 'High' estimate for economic consequences was calculated using previously collected data that was developed by overlaying and calculating the union of lahar-hazard zone, community boundaries, and block-level population counts compiled for the 2000 U.S. Census (2010 U.S. Census data was not available during the time of analysis). The economic loss amounts used are based on the total loss of annual sales generated by 3,890 businesses within lahar hazard areas.
[8] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.
[9] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'Best' estimate.
[10] Mount Rainier National Park: Geologic Resource Evaluation Report; U.S. Department of the Interior, National Park Service; Natural Resource Report NPS/NRPC/GRD/NRR—2005/007, September 2005.
[11] Community Exposure to Lahar Hazards from Mount Rainier, Washington; Nathan J. Wood and Christopher E. Soulard, USGS Scientific Investigations Report 2009-5211, September 16, 2009.
[12] All lahar hazard zone area boundaries used in calculations for this scenario are from the USGS 2009 study.

[13] Pierce County Hazard Identification and Risk Assessment: Volcanic; Pierce County Department of Emergency Management; 2010.
[14] The Health Hazards of Volcanic Ash: Guide for the Public. International Volcanic Health Hazard Network (IVHHN), 2003-2011; at http://www.ivhhn.org/index.php?option=com content&view =article&id=55&Itemid=61 (accessed March 2013).
[15] Ibid.
[16] Hazard Identification and Vulnerability Analysis (HIVA) of Walla Walla, Washington – Volcanic Ash Fall; Walla Walla County Emergency Management Department, October 2003.
[17] Volcanic Ash Fall – A "Hard Rain" of Abrasive Particles: USGS Fact Sheet 027-00; USGS, 2000.
[18] Eruptions of Mount St. Helens: Past, Present, and Future, U.S. Geological Survey Special Interest Publication: Ash Eruption and Fallout; Cascades Volcano Observatory (Robert I. Tilling, Lyn Topinka, and Donald A. Swanson); 1990.
[19] The Health Hazards of Volcanic Ash: Guide for the Public.

- Interruption of telephone, cell, and radio communications

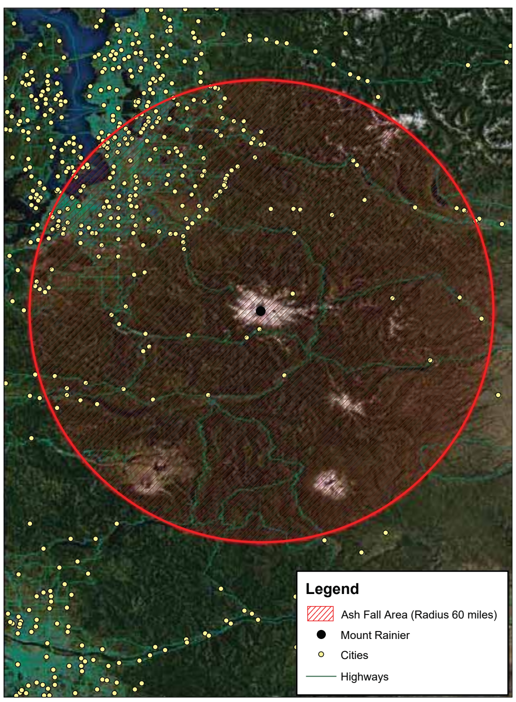
Assumptions

Fatalities and Injuries

The SNRA project team used the following assumptions to estimate health and safety consequences resulting from a volcano event:

- The total population within lahar hazard areas was calculated using a GIS shapefile representing Inundation Zones for Case I Debris Flows.[20] Inundation Zones for Case I Debris Flows are areas that could be affected by cohesive debris flow that originates as enormous avalanches of weak chemically altered rock from the volcano. The Case I Debris Flow GIS boundary shapefile was used in this scenario because the layer covers a larger potentially hazardous area, and therefore includes all possibly vulnerable populations.
- One percent of the total population in lahar hazard areas was used as the amount of possible deaths in the health and safety consequences calculations because the total population is not at risk during Case I Debris Flow activity due to national, regional, state, and local monitoring systems, evaluation routes, and mitigation measures.[21] Further, one percent of the population was used to calculate possible deaths as a result of volcanic activity based on previous data from the 1980 Mount St. Helens eruption. 57 deaths occurred as a result of volcanic activity.[22] The Skamania County 1980 population was 8,289; therefore, 0.6% of the County's population was lost due to volcanic activity. This percentage was increased to 1% for this scenario in the event that a greater percentage of the population was at risk during eruption.
- The methodology used consists of overlaying and calculating the union of lahar-hazard zone, community boundaries, and block-level population counts compiled for the 2000 U.S. Census.[23]
- Possible tourist populations were not considered in any calculations.

Figure 2 – Ashfall Radius



- To calculate injuries and illness amounts, a possible ashfall area with a radius of 60 miles from Mount Rainier (46.852947, -121.760424) was created and is depicted in Figure 2.[24]
- The radius buffer was overlaid on 2000 U.S. Census block data to determine the total population in the ashfall area. The ashfall area was distributed over an eight-county area: Cowlitz County, King County, Kittas County, Lewis County, Pierce County, Skamania County, Thurston County, and Yakima County. The population of the ashfall area was estimated to be approximately 1.5 million. For the 'High' estimate of injuries/illnesses, ten percent of the total population was determined to be vulnerable to injury or illness as a result of ashfall.[25]
- Wind direction and speed were not taken into account during this analysis.
- Existing data did not include specific amounts for injuries and illness due to ashfall: therefore calculations for this scenario were performed using GIS technology.
- Ten percent of the population was used to calculate possible injury or illness as a result of volcanic activity based on previous data from the 1980 Mount St. Helens eruption. For this scenario it was estimated that 250 homes were damaged as a result of volcanic activity based on USGS calculations (USGS reports that more than 200 homes were destroyed).[26] The average household is comprised of an estimated 2.6 persons based on the U.S. Census. This resulted in an estimate that 650 people would be directly affected by the volcanic activity, or 7.3% of the county population. This percentage was increased to 10% for this scenario to include possible persons on transportation routes, working in the surrounding National Park, etc. Due to data limitations, only one radius layer was developed to calculate the "Best" estimation.
- For the 'Low' estimate of injuries/illnesses, the population in the State of Washington U.S. Census tracts immediately surrounding Mt. Rainier was used. Approximately 20,000 people live in the following Census tracts: Census Tract 30.01, Yakima County; Census Tract 701, Pierce County; Census Tract 9720, Lewis County; Census Tract 5238, Kittitas County; and Census Tract 315.02, King County. Ten percent of this population was determined to be vulnerable to injury or illness as a result of ashfall, as discussed above.[27]
- The 'Best' estimate of injuries/illnesses was calculated as the geometric mean of the 'Low' and High' estimates.

Economic Loss

The SNRA project team used the following assumptions to estimate the economic consequences resulting from a volcano event:

- The General Building Stock Dollar Exposure (Replacement Amount) designated by occupancy in census blocks was used to calculate the total dollar exposure of the combined amounts for commercial, industrial, agricultural, religion, government, and educational industries.
- Major transportation routes would be affected by possible volcanic activity. Interstate 5 and State Routes 161 and 167 are within Case I Debris Flow hazard areas, along with 195 major roadway segments. The obstruction of major roadways may have a negative impact on the economy due to supply and delivery delays, restrictions, and cancelations.
- A disruption in port activities resulting from volcanic activity could hinder job security and revenue, thus resulting in an economic loss for the state of Washington. More than 43,000 jobs in Pierce County and more than 113,000 jobs in Washington State are related to the Port activities. Port-related jobs generate $637 million in annual wages in Pierce County and more than $90 million annually in state and local taxes in Washington.[28] The Port of Tacoma is approximately 1 mile from the Case 1 Debris Flow hazard areas and vulnerable to possible volcanic activity.

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

- The number of homes destroyed in the output ranges of the HAZUS model gave low, best, and high estimates of numbers of persons displaced of 1,300, 130,000, and 2.1 million respectively.

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[29] The numerical outputs of

[20] Digital Data for Volcano Hazards from Mount Rainier, Washington Revised 1998: Data to accompany U.S. Geological Survey Open-File Report 98-428; USGS; 2007.
[21] Danger Lurks Deep: The Human Impact of Volcanoes; Joanne Feldman and Robert I. Tilling, Division of Emergency Medicine at the Stanford University School of Medicine in Palo Alto, Calif., GeoTime November 2007.
[22] USGS Cascades Volcano Observatory, Vancouver, Washington Mount St. Helens, Washington "On This Day in 1980" October 6, 1980 http://vulcan.wr.usgs.gov/Volcanoes/MSH/May18/OnThisDay1980/Days/1980October06.html.
[23] "Community Exposure to Lahar Hazards from Mount Rainier, Washington" by Wood and Soulard.
[24] A 60 mile radius was selected based on data from the actual Mt. St. Helens ashfall extents.
[25] Volcanic hazards: a sourcebook on the effects of eruptions: Academic Press; Blong, R.J., 1984, Australia, p. 424.
[26] USGS Cascades Volcano Observatory, Vancouver, Washington Mount St. Helens, Washington.
[27] U.S. Census data obtained from http://factfinder2.census.gov. Accessed on September 18, 2001.
[28] The Economic Impact of the Port of Tacoma; Port of Tacoma as prepared by Martin Associates; May 24, 2005.
[29] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\,Fat + Inj + ½\,D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the

this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., as chemical or biological agents, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental consequences as "High." A volcanic eruption can cause disruption of aquatic life, eco-systems, etc. over a potentially large area. In addition, there are potential long-term climate change effects if airborne plume is extreme.

Potential Mitigating Factors

The consequences of a volcanic eruption will depend on the severity of the eruption, the sophistication of the monitoring and warning systems, and the level of preparedness (familiarity with evacuation routes, mitigation measures implemented, etc.) of the surrounding population areas that can be potentially affected by fallout from the eruption.

Additional Relevant Information

The average time interval between eruptions of Mount Rainier is estimated at 100 to 1,000 years.[30] For all consequence calculations, the Inundation Zone for Case I Debris Flows used has a frequency of one event per 500 to 1,000 years.[31] These frequencies are based on the last 5,600 years. The annual probability of such a flow originating somewhere on Mount Rainier is thus about 0.1 to 0.2 percent. The debris flow reached the Puget Sound lowland about 600 years ago along the Puyallup River and is considered to be a characteristic Case I flow for purposes of identifying probable inundation areas.[32] The accounts of the most recent Mount Rainier volcanic event range from 1820 to 1870. According to the USGS, there is no immediate indication of renewed activity at Mount Rainier; however, due to the large population surrounding Mount Rainier hazard mitigation actions should be explored.

number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: Volcanic Eruption was given a C_{EF} of 1.0.

The numerical estimates calculated from this formula are reported in Appendix G. The semi-quantitative risk matrix is discussed in the Findings (Psychological Distress Risk).

[30] Volcano Hazards from Mount Rainier, Washington, Revised 1998: Open File 98-428; USGS; 1998.

[31] Ibid.

[32] Volcano Hazards from Mount Rainier, Washington, Revised 1998: Open File 98-428; USGS; 1998.

Wildfire

A wildfire occurs within the U.S. resulting in direct economic losses greater than $100 Million.

Data Summary

In the following table, note that the low and high likelihoods do not correspond to the low and high consequences. In addition, low and high consequences are not necessarily correlated with each other between different consequence categories.

Description	Metric	Low	Best	High
Fatalities	Number of Fatalities	0	5	25
Injuries and Illnesses	Number of Injuries or Illnesses	0	63	187
Direct Economic Loss	U.S. Dollars	$104 Million	$900 Million	$2.8 Billion
Social Displacement	Displaced from Homes ≥ 2 Days	770	110,000	640,000
Psychological Distress	Qualitative Bins	See text		
Environmental Impact	Qualitative Bins[1]	High[2]		
Frequency of Events	Number per Year	0.2	0.8	3

Event Background

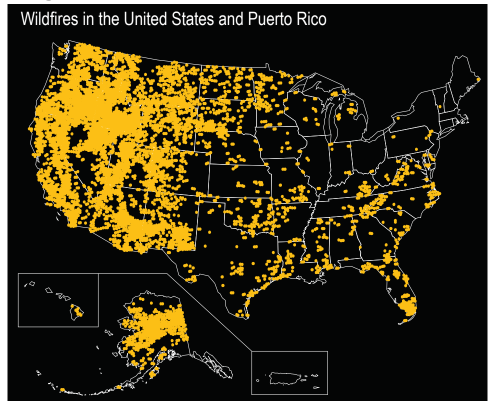
Since 1970, wildfires have destroyed more than 10,000 homes and 20,000 other structures across the nation. Fire suppression has cost government agencies in excess of $20 billion and the insurance industry $6 billion in restitution.[3] Severe wildfire events have the potential to create great economic losses—from hundreds of millions of dollars to the three California wildfires in 1991, 1993, and 2003, each of which caused damages greater than $2 billion.[4]

Wildfires are a frequent event in the United States: some 1,570,000 wildfires were reported for the 20 year period 1990-2009, consuming a total of 94,000,000 acres[5] and 110 human lives.[6] Only a small proportion of these are large enough to overwhelm local fire-fighting capabilities.[7] Although the vast majority of large wildfires occur in sparsely populated regions of the United States—a disproportionate share of the very largest wildfires by acres burned occur in Alaska[8]—it is at the "wildland/urban interface," where the wilderness meets new urban and suburban areas of high population densities, that the wildfires of greatest destructiveness in terms of human life and economic damage occur.[9] Overall, although wildfire frequency has decreased in the last 200 years, the severity of wildfires has increased, and the overall risk to life and property of wildfires in the U.S. is increasing.[10] In particular, the frequency and economic costs of the very largest wildfires considered here show a sharp increase around 1990.[11]

For even the most catastrophic wildfires in the United States, the numbers of dead and injured tend to be relatively small. No wildfire causing human deaths on a catastrophic scale in the United States has occurred since 1918, when a brush fire engulfed 38 towns across Minnesota, killing 450 people.[12] Since then, the largest death tolls have not numbered more than 30 from a single incident—for the majority of massive wildfires in recent decades, potentially affected populations receive sufficient advanced warning that no human deaths occur.

The health risk of wildfires is largely dependent on the population in the impacted area as well as the speed and intensity with which the fire moves through those areas.[13] Wildfires can increase eye and respiratory illnesses related to fire-induced air pollution. Wildfires can also result in direct and indirect deaths caused by direct contact with the wildfire or wildfire product (e.g., smoke or superheated air) or from indirect contact with a wildfire product (e.g., smoke that caused poor visibility resulting in a car crash).[14]

Figure 1. Wildfires Greater than 250 Acres, 1980-2003[15]



Assumptions

The estimates provided above are based on historical examples of major wildfires in the United States. The dataset that was considered comprises all wildfires with reported total economic damage of $100 million or greater (in 2011 dollars) which occurred from 1990 to 2009.[16]

Fatalities and Injuries

The SNRA project team used the following assumptions to estimate health and safety consequences caused by a wildfire event:

- In order to produce the summary figures in the "Data Summary," all "Low," "Best," and "High," estimates for human deaths and injuries are calculated from the dataset of catastrophic wildfires selected according to the economic cutoff of $100M minimum (see Table 1). The set chosen by this economic measure captured the range of the scenarios most catastrophic in numbers of dead and injured for all historical wildfires in the United States since 1990. To compute "Low", "Best", and "High" estimates for fatalities and injuries the historical low, average, and high values of the 1990-2009 dataset were used.
- The best-estimate frequency is the average frequency of occurrence of this set of wildfires in the selected twenty-year period. The low frequency is the inverse of the longest time interval between wildfires in this set (in days, measured from fire begin day); the high frequency is the greatest number of fires which occurred in one year (four, in 2006).

Economic Loss

The SNRA project team used the following assumptions to estimate economic consequences caused by a wildfire event:

- Since total monetary losses appeared more representative of the geographic spread of wildfires and the relative difficulty of fighting them than the number of dead and injured, the former were used to select a set of national-level events having the capability to overwhelm local emergency response efforts.
- All "Low," "Best," and "High," estimates are calculated from historical data of property damage and crop damage, comprising all U.S. wildfires between 1990 and 2009 meeting a cutoff of $100 million dollars total cost adjusted to 2011 dollars (Table 1).[17] As the frequency and severity in economic consequences caused by large wildfires were seen to have sharply increased after 1990, the dataset was restricted to this date range to be more representative of present-day conditions.
- Estimates of total losses for wildfires can vary greatly between sources. One of the reasons for this is that different types of economic cost—the cost of suppressing the fire, private property damage, crop damage, costs incurred for environmental remediation, and the indirect business-interruption costs due

[1] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.
[2] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'Best' estimate.
[3] Zane et al. for National Center for Environmental Health. 2007. Wildfire-related deaths—Texas, March 12-20, 2006. http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5630a1.htm.
[4]See Table 1.
[5] As compiled from National Interagency Fire Center, Total Wildland Fires and Acres (1960-2009), http://www.nifc.gov/fireInfo/fireInfo_stats_totalFires.html.
[6] As compiled from the SHELDUS database http://webra.cas.sc.edu/hvriapps/sheldus_setup/sheldus_login.aspx.
[7] Brush, Grass, and Forest Fires. Ahrens, Marty, 2010, National Fire Protection Association, pp 11, 15: http://www.nfpa.org/assets/files//PDF/OS.BrushGrassForest.pdf; analysis of SHELDUS database.
[8] National Interagency Fire Center, 1997-2009 Large Fires (100,000+ acres), http://www.nifc.gov/fireInfo/fireInfo_stats_lgFires.html.
[9] Fires in the wildland/urban interface, U.S. Fire Administration 2002, at http://www.usfa.dhs.gov/downloads/pdf/tfrs/v2i16.pdf; quoting Ainsworth et al, Natural History of Fire and Flood Cycles, University of California-Santa Barbara 1955, and 'History of fire', National Park Service.
[10] Wildfire hazards – a national threat. Fact sheet 2006-3015, U.S. Geological Survey, Department of the Interior, 2006; available at http://pubs.usgs.gov/fs/2006/3015/2006-3015.pdf.
[11] Analysis of SHELDUS database.
[12] National Interagency Fire Center, Historically significant wildland fires: http://www.nifc.gov/fireInfo/fireInfo_stats_histSigFires.html.

[13] U.S. Climate Change Science Program. 2008. Analyses of the effects of global change on human health and welfare and human systems: A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Gamble J.L. ed, Ebi et al authors, U.S. EPA.
[14] Zane et al. for National Center for Environmental Health. 2007. Wildfire-related deaths—Texas, March 12-20, 2006. http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5630a1.htm.
[15] Wildfire Hazards – A National Threat. U.S. Geological Survey fact sheet 2006-3015, Feb 2006, available at http://pubs.usgs.gov/fs/2006/3015/2006-3015.pdf .
[16] As compiled from the SHELDUS database, http://webra.cas.sc.edu/hvriapps/sheldus_setup/ sheldus_login.aspx. SHELDUS breaks down wildfire events into separate counties, and sometimes breaks down single wildfires in the same location into separate fires with overlapping date ranges, dividing casualty and damages between them to avoid double counting. Where this was obviously done (fires reported by counties in the same state having the same time range, or reported in the same city with overlapping or continuously adjacent time ranges) the separately reported portions of a single fire event were consolidated into single events.
All wildfires (after consolidation) above the $100 million threshold in 2011 dollars (a CPI multiplier of 1.0464 was used to convert the December 2009 values given in SHELDUS to May 2011) from 1970 follow after these endnotes. As noted in the "Assumptions" section, only the data points from 1990 on were used for analysis.
[17] Available at http://webra.cas.sc.edu/hvriapps/sheldus_setup/sheldus_login.aspx.

to lost economic productivity, economic activity, and tax revenue—are accounted for or missing from cost tallies for different major wildfires, even within the same source. In general, for the type of wildfire considered here, which has a direct impact on human populations, the total damages enumerable as property and crop damage are substantially larger than the pure costs of suppressing the fire, and also tend to be substantially larger than the second-order indirect costs of lost economic activity and demand due to business interruption, injuries and fatalities, and loss of tax revenue base.[18] Hence the total reported property and crop damages used here for calculating economic loss estimates are believed to capture the dominant portion of the total economic losses from this type of wildfire.[19]

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

To estimate social displacement for the SNRA, U.S. wildfire event data from the international disaster database EM-DAT[20] was used to approximate the number of people forced to leave home for two days or greater. EM-DAT's public interface reports estimates for "total number affected" by disaster events: these data are listed in Table 1 for the seven wildfire events in the main historical data set for which it was available.[21] The low, high, and average of the "total affected" data in Table 1 are used as the social displacement estimates for wildfires in the SNRA.

The "total affected" measure includes the number of people needing immediate assistance, which can include displacements and evacuations; the number of people needing immediate assistance for shelter; and the number of people injured. Because EM-DAT includes injuries in the "total affected" measure, there is potential for double-counting between the SNRA injury and displacement estimates for this event. However, displacement due to wildfires is typically significantly greater than the number of injuries, so using EM-DAT's "total affected" measure was judged to provide an estimate of social displacement of sufficient precision for the SNRA.

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[22] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- The EPA experts identified the best estimate for environmental consequences as "High." Experts made this estimate given the assumption that the wildfire threatens an "urban U.S. setting," as the fire could envelop oil, chemical, or other hazardous storage tanks and cause widespread release of such materials. However, many wildfires would have low longer-term effects on eco-systems and, in fact, provide longer-term benefits including re-seeding of certain plants and assisting the growth of forested areas. Thus, this scenario could quite conceivably be scored as "Low" or "De Minimus (None)" if the wildfire does not occur in an urban U.S. setting.[23]

Potential Mitigating Factors

The primary drivers of increased consequences associated with wildfires appear to be the high proportion of new home construction in high-risk regions adjacent to or intermixed with wildlands,[24] long-term changes in forest management practices,[25] and early effects of climate change.[26] These three trends most converge in California, where the data show that two-thirds of the most catastrophic (by cost) wildfires of the last twenty years have occurred.[27]

Additional Relevant Information

The frequency of catastrophic fires, such as those listed in Table 1, depends upon the threshold used to select which fires will be on the list. The economic cutoff of $100M resulted in a set of major wildfires which have occurred with an average historical frequency of slightly less than once per year in the 1990-2009 time period (0.8 per year to be precise). Wildfires causing 500 million dollars or greater in damages occur about one every other year (0.45/year); the most catastrophic wildfires, causing $2 billion or more in damages, occur about one every four years (0.25/year).

Table 1. U.S. wildfires causing ≥ $100 million in direct economic damages, 1970-2009[28]

Begin	End	Location	State	Name (if any)	Fatal-ities	Injur-ies	Total damage (2011 dollars)	EM-DAT Tot.Aff
9/25/70	9/29/70	LA/San Diego	CA	Laguna Fire	9	770	$1,288,741,000	
8/8/77	8/8/77	Monterey	CA		0	0	$1,182,055,000	
10/20/91	10/20/91	Oakland	CA	Oakland Hills Fire	25	150	$2,803,063,000	
10/26/93	10/31/93	Sacramento	CA		0	89	$514,587,000	
10/27/93	11/4/93	Los Angeles	CA	Old Topanga Fire	6	187	$2,221,587,000	
5/31/98	7/30/98	Central Florida	FL		0	150	$261,731,000	
7/1/98	7/10/98	Central Florida	FL		0	65	$523,462,000	40,124
8/2/98	8/30/98	Chelan	WA		0	0	$123,978,000	
5/4/00	5/31/00	Los Alamos	NM	Cerro Grande	0	0	$1,966,720,000	25,400
9/29/00	9/30/00	Tehama	CA		0	0	$717,197,000	
6/17/03	7/15/03	Pima	AZ	Rodeo-Chediski Fire	0	0	$161,404,000	1,269
10/25/03	11/5/03	San Diego	CA	Cedar Fire	22	157	$2,572,317,000	27,104
3/12/06	3/18/06	Carson	TX		12	8	$107,289,000	
4/11/06	4/13/06	Wheeler	TX		0	2	$103,553,000	
6/24/07	6/30/07	Alpine	CA	Alpine Fire	0	3	$544,127,000	768
10/21/07	10/31/07	San Diego County	CA		10	132	$748,175,000	640,064
11/15/08	11/19/08	Sacramento	CA		0	0	$156,960,000	55,000

[18] Western Forestry Leadership Coalition 2010. The true cost of wildfire in the western U.S. At http://www.wflccenter.org/news_pdf/324_pdf.pdf. The SHELDUS database attempts to provide some consistency between reports by relying on two U.S. Government sources (the National Climactic Data Center and the U.S. Fire Administration (http://webra.cas.sc.edu/hvri/products/sheldusmetadata.aspx#6), and by including property and crop damage estimates only.

[19] Note that the damages to crops and private property considered here to be direct damages – since they represent the property and crops directly damaged or consumed by the wildfire – are usually referred to as 'indirect' costs in studies of the economic damages of wildfires. This is because 'direct' costs are by convention limited to the cost of fire suppression, and all damage caused by the wildfire is considered as 'indirect' or 'additional' costs (see for instance the reference above).

[20] EM-DAT: The OFDA/CRED International Disaster Database – www.emdat.be, Université Catholique de Louvain, Brussels. EM-DAT is maintained by the Centre for Research on the Epidemiology of Disasters (CRED) at the School of Public Health of the Université Catholique de Louvain located in Brussels, Belgium (http://www.emdat.be/frequently-asked-questions), and is supported by the Office of U.S. Foreign Disaster Assistance (OFDA) of USAID (http://transition.usaid.gov/our_work/humanitarian_assistance/disaster_assistance/). See Criteria and Definition, http://www.emdat.be/criteria-and-definition, EMDAT Data Entry Procedures, at http://www.emdat.be/source-entry, and EMDAT Glossary, at http://www.emdat.be/glossary/ for details of criteria, thresholds, and methodology for the EM-DAT database.

[21] In addition to these, the Old Topanga fire had an EM-DAT Total Affected count of 130. This was excluded from the SNRA data set as being either a clear undercount (a fire causing $2 B of damages would be expected to destroy hundreds or thousands of homes) or a count of injuries rather than homeless.

[22] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\,Fat + Inj + \frac{1}{2}D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: wildfires were given a C_{EF} of 1.0.

The numerical estimates calculated from this formula are reported in Appendix G. The semi-quantitative risk matrix is discussed in the Findings (Psychological Distress Risk).

[23] The best and second best estimates were switched by the SNRA project team in October 2011, subsequent to the reporting of the SNRA results to FEMA, in response to stakeholder feedback focusing on the longer-term environmental effects associated with the experts' "Low" judgment.

[24] Fires in the wildland/urban interface, U.S. Fire Administration 2002, at http://www.usfa.dhs.gov/downloads/pdf/tfrs/v2i16.pdf; quoting Wildland Fire Preparedness/Education Partnership, Firewise Colorado, February 2001.

[25] Fires in the wildland/urban interface, U.S. Fire Administration 2002, http://www.usfa.dhs.gov/downloads/pdf/tfrs/v2i16.pdf; Westerling et al 2006, Warming and earlier spring increase western U.S. forest wildfire activity, *Science* 313(5789) pp 940-943, http://www.sciencemag.org/content/313/5789/940.full.pdf.

[26] National Academy of Sciences, America's Climate Choices, 2011, p 19, at http://dels.nas.edu/Report/Americas-Climate-Choices/12781; Global Climate Change Impacts in the United States, U.S. Global Change Research Group, p 82, at http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf; Ryan et al, The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States, U.S. Department of Agriculture Synthesis and Assessment Product 4.3 (2008), sections 3.1-3.2, at http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf; Westerling et al 2006, Warming and earlier spring increase western U.S. forest wildfire activity, *Science* 313(5789) pp 940-943, at http://www.sciencemag.org/content/313/5789/940.full.pdf.

[27] For wildfires above $100 M reported total cost.

[28] Dataset used for analysis excluded the two fire events before 1990.

Biological Food Contamination

Accidental conditions where introduction of a biological agent (e.g., Salmonella, *E.coli*, botulinum toxin) into the food supply results in 100 hospitalizations or greater and a multi-state response. This event does not include food contamination caused by malicious acts.

Data Summary

In the following table, note that the low and high likelihoods do not correspond to the low and high consequences. In addition, low and high consequences are not necessarily correlated with each other between different consequence categories.

Metric	Low	Best	High
Fatalities[1]	0	11	42
Injuries and Illnesses[2]	200	17,000	45,000
Direct Economic Loss (USD)	N/A[3]		
Social Displacement[4,5]	0	400	950
Psychological Distress	See text		
Environmental Impact[6]	Moderate[7]		
Frequency of Events (per Year)[8]	0.2	0.64	1.2

Event Background

The risk data estimated for this summary sheet are applicable to a contamination event (or a series of interconnected events) where a biological agent is accidentally or unintentionally introduced into the U.S. food supply resulting in national level public health consequences and product recalls. This event may include contamination of domestic food products, international food imports, or food products or ingredients that are utilized as a component of a supply chain. Such an incident may span multiple months as the investigation on the disease agent or contaminant is identified through laboratory analysis and traced to the product origin. This assessment only addresses outbreaks that result directly in harm to human health, and does not assess the consequences of crop or animal diseases, such as Foot and Mouth Disease in cattle, which could have catastrophic effects on the Nation. Nor does it address intentional contamination of the food supply by a terrorist; that risk is captured in a different National Level Event.

Data from the CDC's Foodborne Outbreak Online Database (FOOD)[9] were used to identify events that rose to a level of national significance. Data in FOOD come from CDC's national Foodborne Disease Outbreak Surveillance System database. Most foodborne outbreaks are investigated by the state, local, territorial, and tribal health departments where the outbreak occurs. Outbreak information is then reported to CDC by the public health agency that conducted the investigation. CDC is only directly involved in outbreak investigations that involve more than one state, or are particularly large, or when the state or local health department requests assistance. Because of this only multistate outbreaks that resulted in reported hospitalizations of more than 100 persons were considered to be National Level Events. There have been seven such events between 1998 and 2008, the years included in FOOD.

The best-estimate frequency is the average frequency of occurrence of this set of events in the selected eleven year period. The low frequency is the inverse of the longest time interval between outbreaks in this set (5 years); the high frequency is the greatest number of outbreaks which occurred in one year (two, in 2006).

Assumptions

Fatalities and Illnesses

The SNRA project team used the following assumptions to estimate health and safety consequences resulting from an accidental biological food contamination event:

- Outbreaks included in FOOD report a number of illnesses and fatalities. These reported numbers are known to be low because they do not account for underreporting or underdiagnosis. Consequently, the reported numbers were adjusted using the latest multipliers provided by the CDC.[10]
- Fatalities were increased by a factor of two, while illnesses were increased with the following multipliers:

Table 1: Multipliers Used to Adjust Reported Illnesses

Pathogen	Multipliers	
	Underreporting	Underdiagnosis
STEC O157 (*E. Coli*)	1.0	26.1
Salmonella spp., nontyphoidal	1.0	29.3
Listeria Monocytogenes	1.0	2.1

- The "Low," "Best," and "High" values of illnesses and fatalities are populated with the minimum, mean, and maximum of these adjusted values.

Table 2: Reported and Adjusted Values for SNRA Events

Outbreak	Reported Illnesses	Adjusted Illnesses	Reported Fatalities	Adjusted Fatalities
1998 *Lysteria*-Hot Dog	101	212	21	42
2004 *Salmonella*-Roma Tomato	429	12,570	0	0
2006 *E. Coli*-Spinach	238	6,212	5	10
2006 *Salmonella*-Peanut Butter	715	20,950	9	18
2007 *Salmonella*-Pot Pie	401	11,749	3	6
2008 *Salmonella*-Jalapeno/Serrano Peppers	1,535	44,976	2	4
2008 *Salmonella*-Peanut Butter	716	20,979	9	18

Economic Loss

The SNRA project team used the following assumptions to estimate economic consequences resulting from an accidental biological food contamination event:

- For each of the seven outbreaks, the costs of lost productivity due to illness as well as medical costs were calculated using the USDA Economic Research Service's Foodborne Illness Cost Calculator,[11] with the Value of Statistical Life reset to $0.

Table 3: Economic Impact (Adjusted to 2010 USD)

Outbreak	Lost Productivity & Medical Costs	Business Interruption Costs	Total
1998 *Lysteria*-Hot Dog	N/A		
2004 *Salmonella*-Roma Tomato	$4.2 Million		
2006 *E. Coli*-Spinach	$6.0 Million	$61.4 Million[12]	$67.4 Million
2006 *Salmonella*-Peanut Butter	$4.7 Million		
2007 *Salmonella*-Pot Pie	$ 3.6 Million		
2008 *Salmonella* Jalapeno/Serrano Peppers	$11.0 Million		
2008 *Salmonella*-Peanut Butter	$5.7 Million		

Business interruption costs could be determined for only one event. However, its magnitude indicated that the unknown business interruption

[1] Low, average, and high adjusted fatalities of the set of multistate outbreaks with 100 or more reported hospitalizations between 1998 and 2008 from the CDC FOOD database. Reported fatalities were multiplied by a factor of 2 to compensate for underreporting (see text).
[2] Low, average, and high adjusted illnesses from the set of events described in note 1. Reported illnesses were multiplied by the CDC's recommended multipliers (see Table 2 below) to compensate for underdiagnosis and underreporting.
[3] The SNRA project team judged that the single data point calculated (see text) was insufficient to determine a representative range of economic consequence estimates for this event.
[4] The SNRA measure of Social Displacement is the number of people displaced from their homes for two or more days.
[5] Low and best estimates of 0 and 400 respectively reflect expert judgment. The high estimate of 950 is a judgment based on a historic incident where contamination of the water by *E. coli* in the Ontario community of Kashechewan forced the evacuation of the town (see discussion for references).
[6] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.
[7] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'Best' estimate.
[8] Frequency estimates correspond to the inverse of the number of years of the longest interval between accident events (low), the mean frequency of the accident events (best), and the greatest number of accidents within one year (high) of the set described in note 1 above.
[9] Centers for Disease Control and Prevention (CDC). Foodborne Outbreak Online Database. Atlanta, Georgia: U.S. Department of Health and Human Services, Center for Disease Control and Prevention. Available from URL: http://wwwn.cdc.gov/foodborneoutbreaks. Accessed 08/17/2011.
[10] Scallan E, Hoekstra RM, Angulo FJ, Tauxe RV, Widdowson M-A, Roy SL, et al. Foodborne illness acquired in the United States—major pathogens. *Emerging Infectious Diseases*. Volume 17 Number 1 January 2011. Available from URL: http://www.cdc.gov/EID/content/17/1/7.htm. Accessed on 08/22/2011.
[11] United States Department of Agriculture, Economic Research Service. Foodborne Illness Cost Calculator. Available from URL: http://www.ers.usda.gov/Data/FoodBorneIllness. Accessed on 08/19/2011.
[12] United States Department of Agriculture, Economic Research Service. Consumers' Response to the 2006 Foodborne Illness Outbreak Linked to Spinach. Available from URL: http://www.ers.usda.gov/AmberWaves/March10/Features/OutbreakSpinach.htm. Accessed on 08/19/2011.

cost estimates for other events were likely to dominate total direct costs. As a representative range of total costs could not be determined for additional data points, the SNRA project team elected not to report economic consequences for the Biological Food Contamination event.

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

- Social displacement estimates for the accidental Biological Food Contamination event were provided by staff researchers and subject matter experts at the National Consortium for the Study of Terrorism and Responses to Terrorism (START).[13]
- The low and best estimates of 0 and 400 respectively reflect expert judgment. The high estimate of 950 is a judgment based on a historic incident where contamination of the water by *E. coli* in the Ontario community of Kashechewan forced the evacuation of the town.[14]

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[15] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., as chemical or biological agents, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental consequences as "Moderate." Moderate impacts would most likely result from either waste disposal (e.g., disposing of the contaminated food supply) or dissemination of an infectious agent through some type of accidental application (e.g., pesticide application on crops). In either event, the result could be the introduction of a non-native pathogen into native species, thus causing extinction and permanent change to the ecosystem if disseminated over a wide geographic area. If the agent infects only humans, the environmental/ecological risk would be "Low." There may also be increased environmental/ecological risk if the food production cycle were disrupted. Changing the mechanisms of food production could increase the environmental/ecological risk.

Potential Mitigating Factors

The consequences caused by an accidental introduction of an infectious agent into the food supply can be mitigated through several preparedness strategies. Effective investigative capability, early warning systems and emergency information dissemination are necessary to rapidly detect contamination, locate its source and notify the public of the event and necessary safety measures. Monitoring and warning systems should be regularly tested to ensure that they are functioning properly when an event occurs. Further, a properly prepared and deployed response team could potentially aid in containing the spread of the contamination.

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[13] START is a Department of Homeland Security University Center of Excellence that focuses on social and behavioral aspects of terrorism, natural disasters, and technological accidents, and the social, behavioral, cultural and economic factors influencing responses to and recovery from catastrophes.

[14] Contamination of the water by *E. coli* in the Ontario community of Kashechewan forced the evacuation of the town. Source: Virchez, Jorge, and Ronald Brisbois. 2007. "A Historical and Situtional Summary of Relations between Canada and the First Nations: The case of the Community of Kashechewan in Northern Ontario." *Associacion Mexicana de Estudios sobre Canada*, AC. 87-100. Note that contamination of the food supply is likely to cause minimal displacement.

[15] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\,Fat + Inj + ½\,D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: accidental Biological Food Contamination was given a C_{EF} of 1.0.

The numerical estimates calculated from this formula are reported in Appendix G. The semi-quantitative risk matrix is discussed in the Findings (Psychological Distress Risk).

Chemical Substance Release

Accidental conditions where release of a large volume of a chemical acutely toxic to human beings (a toxic inhalation hazard, or TIH) from a chemical plant, storage facility, or transportation mode results in either one or more offsite fatalities, or one or more fatalities (either on- or offsite) with offsite evacuations/shelter-in-place. This event does not include releases caused by malicious acts.

Data Summary[1]

In the following table, note that the low and high likelihoods do not correspond to the low and high consequences. In addition, low and high consequences are not necessarily correlated with each other between different consequence categories.

Description	Metric	Low	Best	High
Fatalities	Number of Fatalities[2]	1	5	25
Injuries and Illnesses	Number of Injuries or Illnesses[2]	0	57	790
Direct Economic Loss	U.S. Dollars[2]	$43,000	$14 Million	$330 Million
Social Displacement	Displaced from Homes ≥ 2 Days[2]	0	260	5,400
Psychological Distress	Qualitative Bins	See text		
Environmental Impact	Qualitative Bins[3]	Moderate[4]		
Frequency of Events	Number per Year[5]	0.61	1.6	5

Event Background

The dominant risk to human beings from accidental chemical releases is from an accidental release of a highly toxic gas, or toxic inhalation hazard (TIH), in a densely populated area.[6] The 1984 accidental release of toxic methyl isocyanate gas from the Union Carbide chemical plant in the city of Bhopal, India, which killed about 4,000 people immediately and 20,000 in subsequent years, is the primary historical example of the human damage such a release may cause.[7]

Across the United States, accidental releases of chemicals hazardous to human beings occur with a frequency of several times a day.[8] Of these, the largest number of historical (and recurring) accidents causing human death and injury – sometimes in the dozens or hundreds – are caused by fires and explosions from highly flammable chemicals such as propane, liquefied petroleum gas, and ammonium nitrate. However, as these fire and explosion hazards are of a different character and potential magnitude than the hazard posed by a highly toxic gas such as chlorine, hydrogen fluoride (HF), or the Bhopal chemical methyl isocyanate which could potentially kill thousands of people if released in a high population area,[9] they have not been included within the scope of this chemical substance release event analysis for the purpose of the SNRA.

Highly toxic gases may be released while transported by road, rail, or pipeline, or from a fixed facility where they are manufactured, stored, or used for further chemical processing, agricultural chemical production, meat packing, or water treatment. Of the most toxic industrial chemicals, chlorine in particular is used and transported in a total quantity much greater than all the other most toxic industrial chemicals combined: after anhydrous ammonia (which is less toxic),[10] it is the second most commonly used and transported chemical in this country.[11] Chlorine is also normally stored, used, and transported in the United States in volumes large enough to kill thousands of people if released in a densely populated area.[12] Further, like other hazardous chemicals it is routinely transported through the nation's most densely populated areas, in particular Chicago, the central hub of North America's railroad network (one out of every 25 of the nation's major rail accidents—derailments, fires, explosions—occur in Cook County, Illinois alone).[13] An insurance model of a single accidental chlorine railcar breach in the Chicago railyards projected 10,200 fatalities, with several square miles of the city's business district shut down and cordoned off for a week for investigation and recovery efforts.[14] Similarly, FEMA's current National Planning Scenario for a catastrophic release of chlorine from a fixed plant near a medium sized city projects 17,000 dead.[15]

However, these consequence models do not attempt to estimate the likelihood of such an event to occur, which was a particular requirement of the SNRA project. Compared to other types of events (for instance, nuclear plant accidents), few studies linking frequency to consequence estimates have been done for catastrophic chemical accidents. Although the overall national risk to human health and life from catastrophic accidents has been quantitatively modeled in a number of studies of the transportation portion of the chemical sector as a whole, these results could not be used for the SNRA because comparable national-scale estimates could not be found for fixed facilities. Unlike the transportation sector, it does not appear that a national risk assessment attempting to answer these questions for the fixed-facility sector has been attempted since 1974.[16]

[1] The data reported in this table represent historical U.S. accident data. This data is not representative of either the likelihood or the consequences of a catastrophic, mass-casualty chemical accident of a magnitude which has not yet occurred in the United States. The SNRA project team used historic data because a defensible estimate for the likelihood of a catastrophic accident could not be determined. For additional discussion, see Event Background section below.

[2] Low, best, and high estimates for fatalities, injuries and illnesses, direct economic loss, and number of displaced from homes for at least two days come from the low, average, and high values of the set of events meeting one of the following two threshold criteria: 1) at least one "public" fatality, defined as one fatality other or in addition to an employee fatality, caused by the hazardous material; 2) at least one fatality of any kind caused by the hazardous material, plus a reported evacuation or shelter-in-place order; this set came from the set of all reported toxic inhalation hazard (TIH) incidents reported 1994-2010 to either the EPA's RMP (Risk Management Program) accident database for fixed industrial producers and consumers of listed toxic chemicals above given threshold limits, or to the Department of Transportation's Pipeline and Hazardous Substances Administration (PHMSA)'s database of road, rail, water, and air transportation accidents. For further details see Assumptions sections below.

[3] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.

[4] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'best' estimate.

[5] Frequency estimates correspond to the inverse of the number of years of the longest interval between accident events (low), the mean frequency of the accident events (best), and the greatest number of accidents within one year (high) of the set described in note 2 above.

[6] See note 11.

[7] [Pastel/Bhopal]. Bibliographic information for all cited references may be found at the end of this section.

[8] [Belke], appendix A. A scrolling newsfeed on the homepage of the Chemical Safety Board at http://www.csb.gov/ lists all the reported chemical accidents which occurred in the United States in the past week. A similar newsfeed with global coverage may be found on the homepage of the Mary Kay O'Connor Process Safety Center, http://process-safety.tamu.edu/.

[9] [Argonne-2000] pp 128, 132; [PHMSA].

[10] [Argonne-2000] pp 128, 132; [PHMSA].

[11] Chlorine gas, like the Bhopal chemical methyl isocyanate and many other industrial chemicals used in the U.S., is a highly toxic gas capable of killing large numbers of people at relatively low concentrations, but is used and transported in much greater quantities than any other. Anhydrous ammonia and flammable chemicals such as propane are used and shipped in comparable total quantities in storage tanks, pipelines, trucks, and railcars comparable to chlorine, under much less stringent safety standards, and are involved in a much higher proportion of fatal accidents. However, they are most frequently shipped in much smaller containers than chlorine, and by toxicity (ammonia) or blast range (propane and other flammables) they have the capability to cause many fewer deaths than chlorine even if transported in similar quantities (which is why their required storage and shipment safety standards are much lower) ([Wharton] pp 69, 129, [DoT-1992] p 7-9, [Argonne-2000] pp 4-5, 19, 67-69, 126-128, 148-150).

[12] Unlike most other chemicals which are most frequently shipped by road and pipelines, the primary hazard chlorine is shipped almost exclusively (85%) by rail, usually in standard 90 ton (18,000 gallon) tanks ([Branscomb] pp 11-12) which are of comparable size to the largest storage tanks (60,000 – 120,000 gallon) used in fixed facilities often cited in catastrophic-release scenarios (as in [FEMA-2006]). Eleven ruptures of chlorine railcars resulting in the loss of most or all contents have occurred in the 42 year period 1965-2007 which included 2.2 million rail shipments of chlorine (for comparison, the 2007 annual rate was 30,000 shipments). [ACC]

[13] 7% of the nation's rail network mileage lies within the highest population density counties, 3000 people per square mile or more ([Vanderbilt] pp 3-5]); 8% of severe rail accidents occur in these counties (the 23 most densely populated) (all derailments, fires, and explosions, 2006-2010, [FRA] database sorted by county, correlated with Census county population data). Half of these (4% of the total) occur in Cook County, IL alone. The population density of Cook County is 5800 people per square mile; the population of Aiken County, South Carolina where the 2005 Graniteville crash resulted in 9 fatalities and 631 injuries was 144 per square mile ([DoT-PHMSA] pp 33, 104). Other references calculating similar proportions include ([DoT-1992] pp 5-15-19, [DoE] pp 68-72).

DoT's most recent review noted

> DOT is aware that there are [toxic inhalation hazard] rail movements along corridors with population densities several times higher than these [four of the major hazmat rail releases of the past decade]. This coupled with the relatively favorable circumstances surrounding the four incidents leads DOT to believe that the mean of the casualties resulting from the releases analyzed is likely not the true mean of the distribution of the population of preventable releases, but rather lies in the lower end of the distribution. DOT believes that absent issuance of the proposed standards a future incident could potentially result in a larger number of casualties than experienced in recent years. ([DoT-PHMSA] p 33)

[14] [RMS] pp 54-59. This estimate of 10,200 dead (and additionally 32,400 injured) models a 90-ton chlorine railcar breach in a switchyard in Chicago, where the areas of greatest rail line and node density are surrounded by densely populated neighborhoods. Although hundreds of thousands of people may be within the zone of a modeled chlorine cloud (see also [FEMA-2006]), most scenarios (including both of these) realistically assume that nearly everyone is indoors at home or at work, or is able to go indoors before they are overcome: such shelter-in-place measures are known from experience to reduce the number of human casualties by ten times or more. Under circumstances where large numbers of people may be gathered for an outdoor event the fatality rate may be much higher: a similarly modeled scenario of a chlorine railcar breach within Washington DC, but set at a time when thousands of people are thronged on the National Mall for a festival or other event, estimated 100,000 fatalities. [Branscomb] p 5 footnote 9.

[15] [FEMA-2006]. This scenario modeled a deliberate release, but the consequences are similar to a catastrophic accidental release: once a large volume of gas escapes to the air, its subsequent behavior no longer depends on the cause of the breach.

[16] Accident data and worst-case scenarios reported by fixed facilities in the United States from 1995-2005 have been most extensively analyzed by [Belke], [Wharton], [Kleindorfer], and other reports from its authors available at this reference's parent site link (http://opim.wharton.upenn.edu/risk/papers.php). They do not attempt to quantitatively estimate the likelihood of the type of low-frequency

This 1974 national risk assessment for catastrophic chemical accidents[17] (performed by UCLA's School of Engineering, also referenced below by its lead author as Simmons et al 1974) was commissioned by the Atomic Energy Commission as one of a set of studies attempting to quantify the risk on a national scale of a number of different hazards (dam failure, airplane accidents, hurricanes, tornadoes, asteroids) for the purpose of comparison with the risk to the nation of civilian nuclear power.[18] However, only the risk of transporting chlorine by rail was treated in a fully quantitative manner: semi-quantitative analyses were used to assess that this risk dominated the national risk of catastrophic accidents from all TIH in the fixed and transportation sectors combined to such an extent, that the chlorine rail accident likelihood and consequence estimates could be taken as a reasonable approximation to the risk of catastrophic mass-casualty accidents from the chemical industry as a whole. Although its quantitative approach was further developed in subsequent and more sophisticated studies of the transportation sector taken in isolation, and similar methods have been applied to individual chemical process plants, no public industry-wide quantitative risk assessment has been attempted in this country since.[19]

For the fixed sector, the only recent national-scale likelihood estimate for a catastrophic chemical accident comes from a 1996 regulatory impact analysis by the EPA. After including its estimated risk reduction consequent to the proposed regulation (which was enacted) fully going into effect, and incorporating its given ranges in uncertainty in its estimates of consequent risk reduction and in its basic assumptions, the EPA study's calculations give a 0.002% (1 in 50,000) to 0.4% (1 in 250) annual likelihood of a Bhopal-scale accident causing on the order of 4,000 fatalities to occur in the United States, with 0.4% being the best as well as high estimate.[20]

For the transportation sector, the National Transportation Risk Assessment done for the Department of Transportation (DoT) by Argonne National Laboratory in 2000 modeled the nation's road and rail network, routing for each of the top six toxic inhalation hazard (TIH) chemicals, accident rates and rupture probabilities for different models of train car, variation of population density along transport routes, and expected distributions of atmospheric conditions relevant to gaseous chemical dispersion to model expected ten-year frequency estimates for accidents along a range from zero to thousands of fatal exposures. The authors estimated the annual likelihood of a catastrophic chemical accident causing thousands of fatalities to be 0.0001% (one in 100,000 years).[21]

Given the frequency of major chemical accidents in the United States, whether during transport (at least five in the last decade[22]) or at fixed facilities,[23] and the routine production, use, and carriage of large volumes of hazardous chemicals in or through large population centers as mentioned earlier, other researchers have assessed the likelihood of a catastrophic release to be much greater than the estimate reported in the DoT study mentioned above. For example, a later (non-quantitative) DoT study of rail hazardous material transport qualitatively compared the frequency of accidents with the frequent proximity of transport to large population centers in this manner, and concluded it was only a matter of time before the two probabilities should overlap with catastrophic results.[24] The recent accidental rupture of the nuclear plant in Fukushima, Japan may also bring to mind the unquantified but possibly substantial risk of an external event such as an earthquake causing similar damage to a chemical plant or storage tank here, with catastrophic results: several very large concentrations of chlorine are stored on earthquake fault lines in California in highly populated counties.[25] (Note that complex, cascading events such as an earthquake triggering a chemical release are not

high-consequence accidents within the scope of SNRA. They have, however, concluded that the extensively documented historical frequency of high-frequency but lower-consequence accidents has too low a correlation with the likelihood of high-consequence events for extrapolation from historical data to generate meaningful frequency estimates for high-consequence accidents [Elliot].

One partial list of major historical accidents involving chlorine (as well as the flammable liquefied petroleum gas and the explosive ammonium nitrate not considered here) may be found at [UK-HSE]: although worldwide in scope, it is dominated by accidents from fixed facilities which have occurred in the United States. Another list of major chemical accidents may be obtained from the UN Environmental Program's APPELL database [APPELL] by query limited to the United States and sorted by chemical involved. Other good historical sources of comprehensive chemical accident lists include [NICS], [Lees], and for pre-1974 accidents [EPA-1974].

Because of its reliance on recent historical data, this risk summary sheet for chemical accidents is essentially an update of [EPA-1974]. Along with [Simmons] which was completed in the same year (1974) these appear to have been the last and only attempts to produce a national-scale risk assessment for chemical accidents in the United States. See also [Fullwood] pp 428ff.

17 [Simmons].

18 These results were presented in the Nuclear Regulatory Commission's landmark 1975 Reactor Safety Study [WASH-1400], also known as the Rasmussen Report, which developed many of the techniques of probabilistic risk assessment relied upon for risk assessments today. In its quantitative approach, communication of uncertainty estimates, all-hazards scope, and deliberate comparison of different national-level risks by common metrics, chapter 6 of this report reads very similar to the SNRA.

19 [Simmons] Being also almost 40 years old, it is unclear to what extent industry trends and practices in the years since, the last decade in particular, have rendered its inputs and assumptions out to date (although its growth projections for the chlorine industry, its prediction that this trend and population increases along rail routes would roughly cancel the risk reduction of expected safety improvements with time, and its prediction that accident trends would hence remain constant through 1990 proved accurate). As the first attempt of its kind, it relied on many simplifying assumptions to reduce the problem space and make tractable the large computational problem with its variables of rail traffic modeled across multiple segments, population distribution, weather patterns, railcar accident and rupture rates. Every subsequent quantitative study of hazardous material transportation hazards of a national scope located by the SNRA project team ([DoT-1988], [DoT-1992], [Argonne-2000], [DoE]), although each increasing in sophistication over the one before it, has followed this model. It reported two fatality-vs-frequency curves, one with and one without modeled evacuation: both curves are presented in figures 6-1 and 6-12 of [WASH-1400], but only the lower-fatality evacuation model is represented on the graph here.

20 [EPA-1996] Chapter 6, pp 6-8 – 6-30. Noting that the Bhopal plant was American-owned and similar to American-owned plants in the U.S., the authors' first estimate comes from the product of the historical frequency of such events worldwide (1 in 50 years of 'the modern industrial era' since the second world war) with the proportional exposure of the United States to chemical risks (50%, as 50% of the world's annual output of chemicals and refined petroleum came from the U.S.), resulting in 1/50 x 1/2 = 0.01 or 1% in the absence of further regulation (page 6-9). This was used as their best estimate because it required the fewest number of assumptions. On an alternate assumption that the U.S. share of fatal hazardous-materials disasters decreases with the number of fatalities (the world's largest mass-casualty accidents rarely occur in the U.S.) the authors estimated the likelihood might be only 15% of this number (0.15%) (pp 6-10 – 6-11). In footnote 9 they note that if the curves on a plot of the U.S.'s share of fatal accidents (y axis) vs. the log of fatalities per accident (x axis, i.e. the numbers on the x-axis represent $10^1 = 10$, $10^2 = 100$, $10^3 =1000$, $10^4 = 10,000$) could be relied upon in the high-casualty region where the curves are projected beyond the last data point, then a 1-2% proportion might be more appropriate than the 15% they cited in the main text (15% represents the high curve for the last data point). Although the authors state that they were not confident that the curve could be projected out this far, for the purposes of reporting their total range of certainty it is used here.

For the estimate of risk reduction consequent to the RMP rule coming into effect, the authors gave the best estimate of risk reduction from both the RMP rule and new OSHA regulations due to come into effect in the same timeframe to be 60% (pp 6-18 – 6-23: because the consequence estimate is essentially a point estimate for a single event, the overall risk reduction in costs from 'Large Magnitude Toxic Events' is here taken to be a reduction in frequency rather than consequences). This factor was used as their best estimate. Two alternate estimates of risk reduction in the authors' sensitivity analysis (pp 6-23 to 6-28) give what the SNRA project team calculated to be 80% and 83% total reductions in risk from the RMP and OSHA rules combined: after reduction to the one significant figure used throughout the authors' analysis in this section, these collapse to a single factor of 80%. Given the chemical industry's changes in a number of practices subsequent to these rules coming into effect, largely because of these rules (see Mitigating Factors), this range of 60-80% of risk reduction since 1996 seems reasonable. Since these are risk reductions, the overall residual risk multiplier after they are taken into account is either (100% - 60%) = 40% or (100% - 80%) = 20%.

Hence after incorporating both sources of uncertainty, the net range of annual likelihood comes to (0.01% to 1%) x (20% to 40%) = 0.002% to 0.4%. The SNRA project team took 0.4% to be the authors' best estimate because each of the factors going into it (1% base and 60% reduction) were the ones the authors selected to calculate their actual cost estimates.

Comparable likelihood estimates for a fixed-site industrial accident (but for the hazardous materials sector generally, including petroleum refining, flammables, and explosives) causing thousands of fatalities have been obtained by a fuller analysis of historical accidents for France [Rocard] and, by a full probabilistic-risk-analysis (but for only particular large concentrations of industry) for the UK (the Canvey Island studies, see for instance [Lees], [Fullwood]). Equipment failure rates which may be used for probabilistic safety analysis of chemical process plants are given in [Lees] and [FEMA-1989].

The International Atomic Energy Agency has published a procedure for conducting a regional or national quantitative risk assessment of fixed chemical sites using generic process plant and storage tank failure rates and specific chemical information [IAEA]. By allocating the number of loading and unloading operations to process plants in proportion to their reported quantities, total national amounts shipped of each chemical, and the distribution between rail and road shipments for each chemical as provided by studies such as [Argonne-2000], sufficient data exist in the public domain from Census block population and geographic population center data, RMP data available through [RTK], and chemical shipment statistics collated by the Department of Transportation and transportation studies such as those cited here to conduct such a national-scale quantitative risk assessment for catastrophic mass-casualty accidents caused by fixed facilities in the United States.

21 [Argonne-2000] pp 11-12, chapter 5. The summary figure 5.11 and table 5.22 may be found on pp 154, 156. These tabulate estimated fatal exposures for each chemical, as well as for all six TIH chemicals combined, at the 15 minute LC-50 threshold, representing the concentration at which an expected 50% of a normally distributed human population would be dead after fifteen minutes of continuous exposure. To account for the likelihood that most of the population within this area would be partially protected by being indoors (being inside even an ordinary building offers substantial partial protection, which can be enhanced to 90% protection or greater by sealing doors and windows with tape, rolled towels, or anything which will block off routes for air exchange), the authors note that these exposure numbers should be divided by 7 to give estimates for actual fatalities, pp 122-123. Although their reported numbers represent totals from all accidents in a ten-year period, the right hand high-exposure end of the curve may be taken as the approximate predicted frequency of a single event having that many fatal exposures in a ten year period: because of their sharply decreasing probability, an exceptionally high casualty toll in a given ten year period is more likely to be dominated by a single catastrophic event. The six TIH chemicals were estimated by the authors to represent about 90% of the risk from TIH chemicals as a whole, p 8. It is interesting to note how chlorine dominates the high-fatality end of the combined-chemical curve (figure 5.11).

This study is similar to previous studies commissioned by DoT ([DoT-1988], [DoT-1992]).

22 [DoT-PHMSA] Tables 3, 4, pp 62, 71.

23 Such as the Magnablend ammonia and allied chemicals plant in Waxahachie, Texas which caught fire in spectacular fashion in October 2011 during the drafting of this sheet. Such accidents are hardly exceptional, however: see note 8.

24 See note 8.

25 [Tierney], [Eguchi]. There is some evidence to suggest that the Fukushima accident may not have been an outlier event, or one characteristic only of nuclear facilities: the frequency of accidental chemical releases in Japan markedly spikes in earthquake years: [Wharton] figure 1.A-2, p 42. It is interesting that these three spikes are depicted on the graph as dotted lines as though to indicate that they should be considered outlier events.

As part of the overall industrywide risk-reduction trend discussed in Mitigating Factors below, many of the largest chemical hazards in quake zones have switched or plan to soon switch to alternate or less hazardous chemical production processes. One of the highest profile examples has been Clorox, which maintained a number of bleach production plants in the hills above Los Angeles storing very large quantities of liquefied chlorine gas on-site. The company announced in 2009 that it would be converting all its bleach plants to processes using concentrated bleach as the starting material rather than pure chlorine. [SHG], [CAP-2006], [CAP-2008], [PIRG].

The question of earthquake-caused accidents at fixed facilities storing or using hazardous chemicals has been extensively studied – [Tierney] and [Eguchi] cited above are but two of a large field – but it appears no attempt has been made to quantify the risk of such an event occurring on a national scale.

This summary sheet also does not consider catastrophic chemical release due to a terrorist attack, as that is considered elsewhere. However, it is interesting to note that well before 9/11, 10% of the thousands of chemical accidents occurring in the U.S. every year were attributed to deliberate or intentional human action [EPA-1999].

considered in the SNRA because of the difficulty of quantifying their interdependencies; this is a limitation of the assessment.)[26]

A notable historical counterexample to these expectations of large casualty numbers from an urban chemical accident is the 1979 multiple-railcar multiple-chemical derailment, release, and fire in the Canadian city of Mississauga, a suburb of Toronto. The train accident caused several cars to burst, including a full 90 ton tank of liquefied chlorine gas (the same volume as that of the Chicago train scenario mentioned above), and several tanks of an assortment of flammable and toxic chemicals. Evacuations soon began, and continued for several days while different chemicals came into contact, reacted with each other, and caused new fires, explosions, and clouds of toxic gases, making it an exceptionally difficult disaster for the fire crews to contain. 210,000 people were evacuated from the city – three-quarters of the city's population of 280,000 – and were not permitted to return for a period of three to six days. The entire city was essentially shut down for a week. Extensive federal and provincial resources were mobilized to assist the city's emergency crews, reroute traffic around the city, and coordinate the temporary resettlement and aid to the evacuated population. However, the winds happened to be blowing in the right direction to blow much of the toxic chlorine gas out over Lake Ontario and away from the city center, most of the rest burned up in reactions with the other chemicals, and the remainder, diluted by the water firefighters hosed at the ruptured tank, was frozen into a chlorine-water ice slush in the bottom of the tank by the subfreezing night temperatures of the Canadian winter. This was the worst-case imaginable scenario, a major release of highly toxic gas in a densely populated urban area similar to cities in the United States, causing massive disruption and economic loss to an entire city: yet there were no human fatalities.[27]

Since a distribution of frequency and consequence estimates representing these low-probability, high-consequence mass-casualty events could not be derived for the fixed chemical sector with rigor comparable to the studies producing such estimates for the transportation sector, the SNRA project team elected to rely on recent historical data of more frequent accidents which have occurred in the United States. These came from two publicly available databases of comparable quality and uniformity, the Risk Management Program (RMP) database of accidents reported to the EPA by fixed facilities under the Clean Air Act, and the Pipeline and Hazardous Materials Safety Administration (PHMSA) of the Department of Transportation's database of reported road, rail, air, and water accidents involving hazardous chemicals. Both were restricted to the seventeen year range 1994-2010 covered by the RMP database.[28]

The predicted fatality versus likelihood curves from the 1974 UCLA chlorine risk assessment (Simmons et al 1974), the EPA's 1996 Regulatory Impact Analysis (RIA) for the Risk Management Program for fixed facilities (one data point, plus uncertainties in frequency and consequence[29]), and data for one-year cumulative-year totals for all TIH generated by Argonne National Labs for the 2000 Argonne NTRA are plotted in Figure 1, along with historical fatality curves for 1994-2010 for fatalities directly caused by hazardous materials for all TIH fatal accidents reported to the PHMSA and RMP databases. Note that with the exception of the EPA estimate and the historical data, these lines represent only the best estimates without uncertainty,[30] and they are not strictly comparable. In particular, the Simmons and EPA estimates and the historical data represent the annual frequency or estimated probability that an accident of that magnitude or greater will occur; the Argonne numbers represent the estimated probability that the fatalities from all accidents in a given year will total to that number or greater. As the frequency of high-fatality accidents decreases with greater fatality numbers, a large number for a given year will be more and more likely to represent the effect of one rare large accident dominating the results, and so this curve will approach the estimated frequency of a single accident having that number of fatalities or greater.[31]

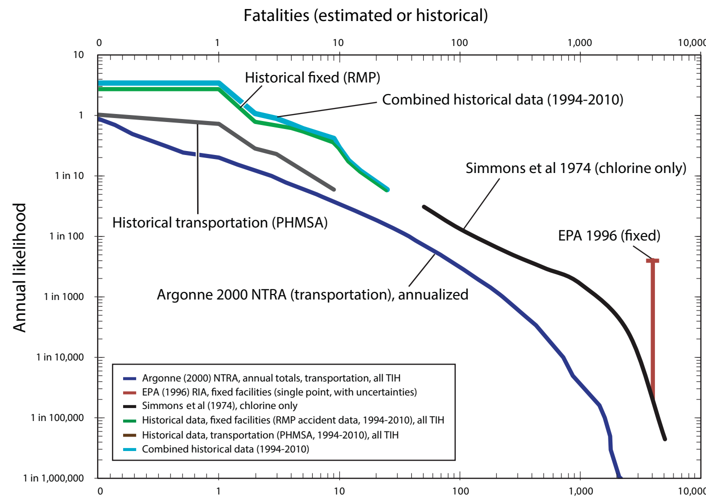

Figure 1

Note: The fatality scale from 0 to 1 is direct, and logarithmic above 1; the likelihood scale is logarithmic along its entire range. Fatalities are per event for historical data, the EPA's 1996 RIA (Regulatory Impact Analysis), Simmons et al (UCLA) 1974; annual yearly totals of all accidents for Argonne's 2000 NTRA (National Transportation Risk Assessment). Uncertainties are depicted only for the EPA point estimate, other curves are best estimate lines. The estimated uncertainty in likelihood and consequence in Argonne 2000 is a factor of 3, in Simmons et al 1974 a factor of 10 for likelihood and 2 for consequence.

The Argonne data represent 1 year totals, and total rail and road fatalities for all TIH (toxic inhalation hazard) chemicals, rather than the 10 year totals for six selected TIH chemicals as reported in the published NTRA: the line above represents actual estimated fatalities (LD-50 exposures divided by 7, see summary sheet text for reference). Historical RMP and PHMSA accident data represent all TIH accidents reported 1994-2010. Simmons et al (1974) calculated fatality estimates from chlorine transportation by rail alone, but estimated that this modality dominated the risk to the general population from fixed and transported chlorine combined: the curve here comes from the lower-fatality estimates of their evacuation model presented in figure 16 (p 53), which corresponds to the lower curve in the Rasmussen Report (WASH-1400) (see references).

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In order to restrict the set of historic events to those which presented the most significant challenge to national preparedness, the SNRA project team selected those events which either 1) caused at least one fatality outside the plant or accident location, or to a member of the public or a public responder; or 2) caused at least one fatality of any kind (public, public responder, or employee), and which also resulted in an evacuation or a shelter-in-place order. These criteria excluded accidents causing fatalities only among workers, if no evacuation or shelter orders were issued. In choosing these criteria, the SNRA project team attempted to select those events which had a serious impact to public health outside the plant or industry where it occurred. These criteria, while imperfect, reflect the difference in public perception between the voluntary acceptance of the risk of occupational hazards by those who choose to work in the chemical

[26] [Simmons] also explicitly ruled out treatment of earthquake hazards to chemical plants or storage tanks for similar reasons (p 39).

[27] [Mississauga], [City-Mississauga]. The identity of the slush as a semi-frozen mixture of chlorine and water was the assessment of hazardous materials experts on the scene at the time of the accident [City-Mississauga]; chemical interactions between the chlorine and water may have made the composition of the plugging slush more complicated.

For discussion of mass evacuations from chemical accidents in general, see [Cutter-1989], [Cutter-1991], [Sorensen].

[28] The EPA's Risk Management Program was established in 1999 to implement new reporting requirements from amendments to the Clean Air Act introduced after the Bhopal disaster. It requires fixed facilities producing, consuming, or storing more than a threshold quantity of a listed hazardous chemical in any single container or set of interconnected containers to report all accidents in the prior five-year period resulting in any loss of life, injury, environmental damage, evacuation or shelter-in-place orders, any economic damage outside the facility, or significant (judged by the reporting company) economic damage to the facility itself. It has been extensively studied and described by [Belke], [Wharton], [Kleindorfer], and in other papers available at the latter publication's parent site (http://opim.wharton.upenn.edu/risk/papers.php.) The EPA provided the SNRA project team with a disk containing the RMP accident databases through July 2011 for direct analysis. This database is also conveniently available on the Web through the Right to Know Network's site [RTK].

The PHMSA transportation database is available online [PHMSA-database].

[29] The likelihood (vertical) uncertainty is the range cited above, and represents the product of the uncertainty about the base likelihood of a Bhopal-style accident to occur in the U.S. (to what extent historical frequency data should be modified by an estimate of different conditions in the U.S. than in India) and the uncertainty about how much the net risk of high-consequence chemical accidents would decrease subsequent to the RMP's coming into effect in years following 1996. The consequence (horizontal) uncertainty is the range represented by the estimate of "on the order of 4,000 fatalities", which for the purposes of graphing was taken to mean the range 3,500 – 4,499, the significant-figure uncertainty represented by the use of a single significant figure (this is the range which would be rounded up or down to 4,000).

[30] The uncertainty in the Argonne numbers (frequency and consequence) are a factor of 3 ([Argonne-2000] p 5). The uncertainty estimates given by the UCLA Simmons et al (1974) report are a factor of 10 in frequency and a factor of 2 in consequence ([Simmons] pp 3, 41, 43).

[31] The Argonne report reported ten-year totals rather than single-year totals: these also (when divided by ten) will approximate the annual estimated probability of a single catastrophic high-fatality accident for fatality levels taken above a sufficiently high selected threshold to reduce to a minimum the likelihood that a high ten-year total could represent two or more medium-sized accidents, rather than be dominated by one very large, very rare accident. In order to allow for this approximation to be valid for a larger range of consequence data, Dan Brown of the original Argonne team kindly calculated single-year totals for the SNRA project team from the original study data and computer program. To extend the scope of the results to the class of chemical hazards the SNRA project team was considering, Dr Brown also extended the calculations to include estimates for all TIH chemicals transported by road and rail, rather than the top six TIH chemicals reported in the original study (which the authors estimated represented 90% of the total TIH hazard, [Argonne-2000] p 8). These data, divided by the factor of seven which the study authors themselves applied (to account for expected mitigating factors such as sheltering-in-place, pp 122-123) to convert their estimates of LC-50 fatal exposures to estimates of actual fatalities, are the data plotted in the graph above. Loading and unloading accidents may be reflected in the historical data, but were excluded from the risk assessment of the Argonne study ([Argonne-2000] pp 9-10).

industry, and the involuntary risk to the general public from chemical accidents.[32]

Assumptions

Frequency, fatality, injury and illness, direct economic loss, and social displacement estimates were determined from the set of all reported toxic inhalation hazard (TIH) incidents from 1994-2010 in two historical accident databases, the EPA RMP database for fixed facilities and the PHMSA database for transportation accidents. The EPA's RMP (Risk Management Program) maintains a database of accident reports from fixed industrial producers and consumers of listed toxic chemicals above given threshold limits. The Department of Transportation's Pipeline and Hazardous Substances Administration (PHMSA)'s database records road, rail, water, and air transportation accidents.

Low, best, and high estimates for fatalities, injuries and illnesses, direct economic loss, and number of displaced from homes for at least two days come from the low, average, and high values of historical incidents in this set meeting threshold criteria for the Chemical Substance Release event. Frequency estimates correspond to the inverse of the number of years of the longest interval between accident events (low), the mean frequency of the accident events (best), and the greatest number of accidents occurring within one year (high) from this set.

Environmental impact estimates were elicited from EPA subject matter experts.

Fatalities and Illnesses/Injuries

The SNRA project team used the following assumptions to estimate health and safety consequences caused by an accidental toxic inhalation hazard (TIH) chemical release event:

- The scope of this national-level event was limited to chemical accidents having the potential to cause a large number of human casualties in the brief timescale characterizing what is commonly considered to be an 'event'. As the class of chemicals having the potential to kill a large number of people in a very short period of time is comprised almost entirely of toxic inhalation hazards which are gaseous under normal conditions, only accidents involving toxic inhalation hazards (TIH) were considered to be within the scope of this event category. This choice effectively excludes accidental spills or releases of chemicals in liquid or solid form, which form the class most likely to cause environmental damage or contamination capable of causing human death and injury over long-term exposure, and also excludes accidents primarily involving chemicals hazardous by their flammable or explosive potential, such as propane, liquefied gas, and ammonium nitrate. Included were accidents caused by chemicals listed as toxic (T) in the RMP database, and classes 2.2 (non-flammable gases, selected because ammonia is classed in this category) and 2.3 (poisonous gases) in the PHMSA database.
- The set of accidents selected were those which either 1) caused at least one fatality outside the plant or accident location, or to a member of the public or a public responder; or 2) caused at least one fatality of any kind, public, public responder, or employee, and which also resulted in an evacuation or a shelter-in-place order. Within this set, no distinction was made between fatalities (onsite, offsite, employee, responder, or public).
- From the PHMSA transportation database, only fatalities and injuries reported as being caused by the hazardous substance were included.
- The databases contained many duplicate reports, largely updates to previous reports of the same accident event: these were eliminated manually once the small threshold set was generated.

Economic Loss

In addition to the generally applicable assumptions of those listed above, the SNRA project team used the following assumptions to estimate economic consequences caused by an accidental chemical release event:

- All economic estimates were inflation-adjusted to 2011 dollars.
- The direct economic damages which fixed facilities are required to report, and update for accuracy, to the RMP database are property damage to equipment or the facility itself, and all known or readily knowable property damage outside the facility. These damages do not include business interruption costs, medical or insurance costs, or litigation or settlement costs not overlapping with the above.[33]
- The direct economic damages carriers are required to report, and update for accuracy, to the PHMSA transportation database are the value of the material (spilled chemical) which was lost, physical damage sustained by the carrier (vehicles or other cargo), damage caused to public or private property, the dollar value of the response cost, and the dollar value of any remediation and clean-up cost. These damages do not include business interruption costs, medical or insurance costs, or litigation or settlement costs not overlapping with the costs listed above.[34]
- The SNRA project team added cost estimates tied to the number of injured or killed. The cost of medical care per injury/illness was taken as $6,600, for consistency with previous DHS risk assessments (including the Integrated Terrorism Risk Assessment conducted by the DHS Science & Technology Directorate to assess the risk of chemical, biological, radiological, and nuclear terrorism).
- The SNRA project team did not attempt to estimate an equivalent dollar value or a value of a statistical life (VSL) to determine an economic cost per fatality. Instead, only the countable direct contribution to the national economy of the average annual spending of one person in a year, which the SNRA project team set at $42,500, was multiplied by the number of fatalities to estimate the loss to the economy from accident fatalities.

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

Social displacement estimates for the SNRA chemical accidents event come from the same historical dataset of 1994-2010 historic toxic industrial chemical accidents in the United States used for the other quantitative measures of the accidental chemical substance release event.

- There is historical precedent for very large evacuations due to chemical accidents. After Hurricane Katrina, the evacuation of 210,000 people from Mississauga was the second largest evacuation in history in North America. However, the same historical dataset used for other metrics was used for social displacement to ensure consistency of scope across measures for this event.
- The PHMSA and RMP databases include evacuation estimates. The PHMSA database additionally reports total evacuation time; the RMP database reports the total duration of the chemical substance release itself, which the SNRA project team used as a proxy for evacuation time.[35] Only two events in the historical data set, as reported in these databases, had evacuations lasting 48 hours or more (see Data Table).
- The low, best, and high social displacement estimates represent the low (0), average (260), and high (5,400) of this set.

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[36] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field

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32 The concept of 'voluntary' versus 'involuntary' risk is discussed in the introduction to [EPA-1974]; see also [EPA-1983].

33 [RMP-reqts].

34 [HMIR].

35 E.g. the SNRA project team assumed that people would not return to their homes while the toxic substance was still being released, and that they would return shortly thereafter.

36 The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + \frac{1}{2}\ D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: accidental Chemical Substance Spill or Release was given a C_{EF} of 1.1.

The numerical estimates calculated from this formula are reported in Appendix G. The semi-quantitative risk matrix is discussed in the Findings (Psychological Distress Risk).

operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (such as chemical or biological agent, contamination extent, persistence and toxicity—both chronic and acute toxicity—or infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental consequences as “Moderate.” Experts made this estimate given that the primary set of scenarios considered for this event were releases of toxic gases which could cause large numbers of human casualties. The widespread release of a toxic gas could contaminate tens to hundreds of acres with toxic material, but not on a catastrophic scale compared with other types of disaster.
- The greater likelihood for toxic releases to happen in sparsely populated areas, although decreasing human fatalities, increases the potential for ecological damage.
- Persistence was also judged to be a possible issue. The more persistent the chemical, the greater the impact it will have on the environment. There is also a potential for water contamination (depending on the contamination, and the spread of the contaminant through water), which could elevate a chemical disaster to an environmentally high impact event.

Potential Mitigating Factors

It appears that the risk from chemical accidents has been decreasing in recent years and, should current trends continue, is expected to continue decreasing. The combination of new reporting requirements for fixed facilities in this country introduced in the years 1986-1999 following the Bhopal catastrophe, pressure from local and issue-oriented public policy groups, and sharply increased public and political attention on the potential attractiveness of chemical facilities to terrorist attack following 9/11 has resulted in a significant reduction in the quantities of highly toxic chemicals held by fixed facilities located in the most populated areas nationwide, largely due to the substitution of less toxic intermediates where possible.[37] Although attempts at directly reducing the risk from transportation accidents by regulation and rerouting have been less successful,[38] the decreased end-user need for the most toxic chemicals at fixed facilities has also reduced the quantities being transported, reducing the overall risk from transported toxic chemicals in a similar fashion.[39]

Additional Relevant Information

Although the majority of fatal chemical accidents which have occurred in recent years have occurred in rural areas or small population centers, because road and rail traffic is so routinely routed through urban centers of high population density[40] and because of cities’ dependence on water treatment plants which frequently use large amounts of chlorine,[41] some of the risk from the most catastrophic chemical accidents appears to be broadly spread among the American population. However, much of the risk appears to be geographically and socially distributed less evenly. As noted above, Chicago is at particular risk from chemical accidents by rail, and earthquake-prone regions such as California from fixed facilities. The bulk of the nation’s chlorine production factories are located on the Gulf Coast:[42] although these factories withstand hurricanes on a regular basis,[43] their location increases that region’s risk exposure to at least transportation accidents as their manufactures must be shipped out.[44] A risk factor particular to the fixed chemical sector, having possible social consequence as demonstrated by the government’s experience of Hurricane Katrina, is the finding from studies of RMP accident data that fixed chemical facilities rated as ‘highest risk’ are disproportionally situated in counties having higher minority populations. This correlation persists after other demographic factors, including geographic location and poverty levels, are factored out.[45]

[37] In addition to accidents, the EPA’s Risk Management Program requires facilities holding more than a threshold quantity of a listed hazardous chemical in a single container or set of interconnected containers to submit risk assessments including modeling the consequences of the worst-case-possible scenario on surrounding populations. The number of reporting facilities substantially decreased from the first reporting period 1995-2000 to the second 2000-2005, in large part because many sites reduced the amount of chemical on-site or the amounts in any one ruptureable container below the reporting thresholds [Wharton]. Concerns about terrorists targeting chemical plants predate 9/11, and were the primary reason the EPA partially restricted the RMP data from public access [Wharton], [CRS]. Other risk reduction examples include the widespread substitution of sodium hypochlorite (concentrated bleach) for pure liquefied chlorine by water treatment facilities and the consumer bleach manufacturer Clorox, and DuPont’s switching a pesticide manufacturing process from a batch production process requiring 40-50,000 pounds of the Bhopal chemical methyl isocyanate to a continuous process consuming the intermediate as it is produced, such that no more than two pounds of the chemical exists on-site at any one time [SHG] pp 3-2 – 3.4. Also see [CAP-2006], [CAP-2008], [PIRG].

[38] [Branscomb] pp 7-9, 41-46 for unsuccessful rerouting attempts by local city councils, recent safety standards on new railcars not yet realized because of low turnover in railcar fleet.

[39] Recent annual shipment rates of chlorine (30,000 rail shipments in 2007) are lower than the historical average (2.2 million over 42 years, average 52,000 annually) [ACC].

[40] See note 13.

[41] [CAP-2007], map p 11. Also [PIRG], [CAP-2006], [CAP-2008], [SHG].

[42] [Branscomb] figure 1, p 12.

[43] [Challener].

[44] [DoT-1988] pp 7 to 8, page 3-12.

[45] [Wharton] pp 98, 119-122; [Elliott-2004]. See also [Cutter-1989].

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Data Table

Commodity Short Name	Date	City	State	Fixed Site or Transport	Source	'Public' Fatalities	Employee Fatalities	Total Hazmat Fatalities	Total Hazmat Injuries	Reported Loss or Damages	CPI	Adjusted (2011$)	SNRA Direct Economic Damage
Ammonia (anhydrous)	12/13/1994	Pensacola	FL	Fixed	RMP	0	4	4	27	$220,200,000	1.49	$327,330,768	$327,678,968
Chlorine	4/11/1996	Alberton	MT	Transport	PHMSA	1	0	1	787	$10,000,000	1.44	$14,438,815	$19,675,515
Ammonia (conc 20% or greater)	8/26/1997	Lancaster	OH	Fixed	RMP	5	0	5	0	$0	1.39	$0	$212,500
Ammonia (anhydrous)	11/3/1997	Sacaton	AZ	Fixed	RMP	0	1	1	1	$50,000	1.39	$69,492	$118,592
Chlorine	2/23/1998	Orlando	FL	Fixed	RMP	9	0	9	1	$0	1.39	$0	$389,100
Ammonia (conc 20% or greater)	4/22/1998	Centralia	KS	Fixed	RMP	12	0	12	0	$0	1.39	$0	$510,000
Ammonia (anhydrous)	10/10/1998	Tacoma	WA	Fixed	RMP	5	0	5	0	$11,400,000	1.36	$15,501,879	$15,714,379
Ammonia (anhydrous)	10/26/1998	Franklinton	LA	Fixed	RMP	25	0	25	0	$0	1.36	$0	$1,062,500
Ammonia (anhydrous)	1/5/2000	Green River	WY	Fixed	RMP	1	0	1	2	$0	1.32	$0	$55,700
Hydrogen chloride (anhydrous) [Hydrochloric acid]	5/17/2000	Jefferson	OK	Fixed	RMP	15	0	15	0	$300	1.32	$395	$637,895
Ammonia (anhydrous)	4/2/2001	Hammond	LA	Fixed	RMP	1	0	1	12	$5,800,000	1.28	$7,419,317	$7,541,017
Chlorine	7/14/2001	Newberg	OR	Fixed	RMP	0	3	3	51	$115,000	1.26	$144,818	$608,918
Ammonia (anhydrous)	10/16/2001	Mesquite	NM	Fixed	RMP	1	0	1	2	$600,000	1.26	$755,570	$811,270
Ammonia (anhydrous)	1/18/2002	Minot	ND	Transport	PHMSA	1	0	1	0	$0	1.26	$0	$42,500
Ammonia (conc 20% or greater)	4/11/2003	Soddy Daisy	TN	Fixed	RMP	0	1	1	0	$6,015,000	1.23	$7,405,805	$7,448,305
Ammonia (anhydrous)	4/21/2003	Lakewood	CO	Fixed	RMP	1	0	1	6	$100	1.23	$123	$82,223
Ammonia (anhydrous)	7/13/2003	Pampa	TX	Fixed	RMP	1	0	1	3	$0	1.20	$0	$62,300
Ammonia (anhydrous)	11/4/2003	Paynesville	MN	Fixed	RMP	1	0	1	1	$0	1.20	$0	$49,100
Vinyl acetate monomer [Acetic acid ethenyl ester]	4/23/2004	Illiopolis	IL	Fixed	RMP	0	5	5	6	$0	1.20	$0	$252,100
Ammonia (anhydrous)	5/25/2004	Seymour	IN	Fixed	RMP	10	0	10	0	$0	1.20	$0	$425,000
Chlorine	6/28/2004	Macdona	TX	Transport	PHMSA	2	1	3	66	$0	1.20	$0	$563,100
Chlorine	1/6/2005	Graniteville	SC	Transport	PHMSA	8	1	9	631	$8,018,600	1.16	$9,301,453	$13,848,553
Carbon dioxide (refrigerated liquid)	1/8/2005	Sanford	FL	Transport	PHMSA	1	1	2	0	$0	1.16	$0	$85,000
Ammonia (anhydrous)	8/28/2006	Ebensburg	PA	Fixed	RMP	10	0	10	4	$0	1.09	$0	$451,400
Titanium tetrachloride	6/27/2007	Westlake	LA	Fixed	RMP	0	1	1	1	$178,000	1.09	$194,485	$243,585
Argon (refrigerated liquid)	5/20/2008	Hollywood	FL	Transport	PHMSA	3	0	3	0	$0	1.05	$0	$127,500
Ammonia (anhydrous)	7/15/2009	Swansea	SC	Transport	PHMSA	1	0	1	7	$700	1.04	$727	$89,427
Ammonia (anhydrous)	11/16/2009	Cincinnati	OH	Fixed	RMP	2	0	2	0	$0	1.04	$0	$85,000

Commodity Short Name	Date	Evacuated (RMP)	Shelter in Place (RMP)	Public Evacuated (PHMSA)	Employees Evacuated (PHMSA)	Evacuated > 48 hours	Environ-mental Damage	Mode of Transportation (PHMSA) or Industry (RMP)	Cause
Ammonia (anhydrous)	12/13/1994	2,000	80			2,000	Yes	Nitrogenous Fertilizer Manufacturing	Equipment Failure
Chlorine	4/11/1996			0	0	0	No	Rail (Transportation)	Derailment
Ammonia (conc 20% or greater)	8/26/1997	0	0			0	No	Farm Supplies Wholesalers	Equipment Failure
Ammonia (anhydrous)	11/3/1997	30	0			0	Yes	Apiculture	Human Error
Chlorine	2/23/1998	0	0			0	No	Sewage Treatment Facilities	Human Error
Ammonia (conc 20% or greater)	4/22/1998	0	0			0	No	Farm Supplies Wholesalers	Equipment Failure
Ammonia (anhydrous)	10/10/1998	0	0			0	No	Refrigerated Warehousing and Storage	Equipment Failure
Ammonia (anhydrous)	10/26/1998	6	0			0	No	Corn Farming	Human Error
Ammonia (anhydrous)	1/5/2000	6	0			0	No	Ice Manufacturing	Equipment Failure
Hydrogen chloride (anhydrous) [Hydrochloric acid]	5/17/2000	0	0			0	No	All Other Basic Organic Chemical Manufacturing	Unknown
Ammonia (anhydrous)	4/2/2001	0	0			0	No	Fluid Milk Manufacturing	Unknown
Chlorine	7/14/2001	2,000	0			0	Yes	Petrochemical Manufacturing	Equipment Failure
Ammonia (anhydrous)	10/16/2001	0	0			0	Yes	Corn Farming	Human Error
Ammonia (anhydrous)	1/18/2002			0	0	0	No	Rail (Transportation)	Derailment
Ammonia (conc 20% or greater)	4/11/2003	26	1,500			0	Yes	Flavoring Syrup & Concentrate Manufacturing	Equipment Failure
Ammonia (anhydrous)	4/21/2003	20	0			0	Yes	Farm Supplies Merchant Wholesalers	Human Error
Ammonia (anhydrous)	7/13/2003	0	0			0	No	Fresh and Frozen Seafood Processing	Equipment Failure
Ammonia (anhydrous)	11/4/2003	0	0			0	No	Other Farm Product Raw Material Merchant Wholesalers	Human Error
Vinyl acetate monomer [Acetic acid ethenyl ester]	4/23/2004	980	0			0	No	Plastics Material and Resin Manufacturing	Unknown
Ammonia (anhydrous)	5/25/2004	8	4			0	No	Farm Supplies Merchant Wholesalers	Equipment Failure
Chlorine	6/28/2004			0	0	0	Yes	Rail (Transportation)	Crash/Derailment
Chlorine	1/6/2005			5,400	0	5,400	Yes	Rail (Transportation)	Derailment
Carbon dioxide (refrigerated liquid)	1/8/2005			0	0	0	No	Highway (Transportation)	Human Error (Loading Accident)
Ammonia (anhydrous)	8/28/2006	0	0			0	No	Animal Slaughtering and Processing	Equipment Failure
Titanium tetrachloride	6/27/2007	0	100			0	No	Inorganic Dye and Pigment Manufacturing	Equipment Failure
Argon (refrigerated liquid)	5/20/2008			0	0	0	No	Water (Transportation)	Equipment Failure (Corrosion)
Ammonia (anhydrous)	7/15/2009			0	5	0	No	Highway (Transportation)	Equipment Failure
Ammonia (anhydrous)	11/16/2009	0	0	0	0	0	No	Farm Supplies Merchant Wholesalers	Unknown

Dam Failure

Accidental conditions where dam failure and inundation results in one fatality or greater. This event does not include releases caused by malicious acts.[1]

Data Summary[2]

In the following table, note that the low and high likelihoods do not correspond to the low and high consequences. In addition, low and high consequences are not necessarily correlated with each other between different consequence categories.

Description	Metric	Low	Best	High
Fatalities	Number of Fatalities[3]	1	17	170
Injuries and Illnesses	Number of Injuries or Illnesses[4]	0	50	3,000
Direct Economic Loss	U.S. Dollars	N/A[5]		
Social Displacement	Displaced from Homes ≥ 2 Days[6]	1	500	250,000
Psychological Distress	Qualitative Bins	See text		
Environmental Impact	Qualitative Bins[7]	Moderate[8]		
Frequency of Events	Number per Year[9]	0.17	0.54	3

Event Background

A catastrophic dam failure may be caused by extraordinary levels of rainfall or snowmelt, leading to water levels higher than the dam can handle. Dam failures can also be caused by earthquakes, mechanical failure of the dam, and other mechanisms. The most common cause of dam failure is prolonged rainfall that produces flooding.[10]

The scope of this event does not include dam failures caused by intentional attacks, whether kinetic (e.g. explosives) or cyber attacks, which are considered within the Explosives Terrorist Attack and the Cyber Event affecting Physical Infrastructure events respectively. The U.S. Department of Homeland Security is the lead Sector-Specific Agency for managing risks to the Dams Sector due to intentional attack under the National Infrastructure Protection Plan.[11] Scenarios analogous to the levee failure of Hurricane Katrina, where the levees are local to the community suffering destruction and their failure is directly caused by a hurricane which itself directly impacts the community, are also excluded from the scope of this event to avoid double counting with the Hurricane event.

There are 83,000 dams listed in the National Inventory of Dams.[12] People, property, and infrastructure downstream of dams could be subject to a devastating loss of life and damage in the event of sudden and unexpected collapse. The United States Society on Dams, a professional organization devoted to dam engineering, safety, and environmental issues, notes that 17 dams in the U.S. are over 500 feet in height, and there are 16 dams with reservoir capacities over 3 million acre-feet.[13] The number of high-hazard-potential dams (dams whose failure would cause loss of human life) has increased to 13,000, with more than 3,300 high and significant dams located within one mile of a downstream population center and more than 2,400 located within two miles.[14,15]

In addition to single dam failures, there is also the possibility of a failed dam stressing other dams downstream, causing a cascading and escalating catastrophic disaster.

The most significant factor determining the magnitude of life loss from a dam collapse is the speed and extent of population evacuation before the water arrives, which is primarily dependent upon warning time, communications, local emergency planning and preparedness, and whether local road networks allow for the rapid evacuation of downstream populations to higher ground within what may be only minutes.[16,17,18] Deaths on a massive scale may result if an evacuation cannot be quickly implemented to move people above inundation levels.

Assumptions

Although numerous estimates of failure likelihoods and consequences for particular dams may be found in the literature,[19,20,21,22,23,24,25,26,27,28,29] many of which are based upon detailed quantitative modeling,[30,31] the SNRA project team was unable to locate an overall quantitative assessment of national dam risk during the research phase of the SNRA project. The closest example of such an assessment was a quantitative risk assessment of major California dams[32] done for the U.S. Atomic Energy Commission's 1974 WASH-1400 report, a comparative assessment of civilian nuclear power risk relative to other catastrophic risks to the Nation which parallels the SNRA in many respects.[33] Although this dams study pioneered a number of quantitative methods used by subsequent studies, because it was the first of its kind and because of its limited geographic scope the SNRA project team were unable to determine how representative its

[1] The data and findings for the SNRA Dam Failure event were completed in 2011, but a separate risk summary sheet for the event was not completed (the data were reported as a spreadsheet). This risk summary sheet as a text description for this data was written in 2013 using material written for the main body of the Technical Report.
[2] The data reported in this table represent historical U.S. dam failures reporting one or more human fatality from 1960-2009, compiled by the Dams Sector Office (DHS/NPPD) from U.S. Bureau of Reclamation historical data (Table 1).
[3] Low, best, and high estimates for fatalities come from the low, average, and high values of the set of events meeting threshold criteria.
[4] The high injury estimate is the highest reported injury from a subset of the events in the overall data set for which injury reports were available. The low injury estimate was selected to be zero by the SNRA project team, as the most reasonable assumption consistent with the sparse data available and the pattern observed from fatality counts from the set. The best estimate is the geometric mean of the high estimate and 1 (since a geometric mean cannot be taken of zero). See Injuries discussion for details.
[5] Additional analysis is required to estimate the direct economic impacts of dam failure. Studies of some specific dams have estimated economic impacts in the hundreds of millions to billions of dollars, but may not be representative of the full set of dams in the U.S.. See Economic discussion for details.
[6] See Social Displacement discussion for details.
[7] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.
[8] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'best' estimate.
[9] Frequency estimates correspond to the inverse of the number of years of the longest interval between accident events (low), the mean frequency of the accident events (best), and the greatest number of accidents within one year (high) of the set described in note 2 above.
[10] Federal Emergency Management Agency (1997). Multi-Hazard Identification and Risk Assessment (MHIRA), chapter 20: Dam Failure.
[11] U.S. Department of Homeland Security (2013). Dams Sector Resources [web resource]. At http://www.dhs.gov/dams-sector-resources (accessed April 2013).
[12] Federal Emergency Management Agency (2009, February). Dam Safety in the United States. FEMA P-759; at http://www.fema.gov/library/viewRecord.do?id=3677 (checked April 2013).
[13] United States Society on Dams. Dam, Hydropower and Reservoir Statistics. Accessed July 25, 2011. http://ussdams.org/uscold_s.html.
[14] Association of State Dam Safety Officials, Dam Safety 101, available at http://www.damsafety.org.
[15] FEMA (2009, February).
[16] Aboelata, M.A. and Bowles, D.S. (2005). LIFESim: A Model for Estimating Dam Failure Life Loss. Institute for Dam Safety Risk Management, Utah State University, Logan, Utah, Report to Institute for Water Resources, U.S. Army Corps of Engineers and Australian National Committee on Large Dams.
[17] McClelland et al (2002, July). Estimating life loss for dam safety risk assessment – a review and new approach. IWR Report 02-R-3, Institute for Dam Safety Risk Management, Utah State University; at http://planning.usace.army.mil/toolbox/library/IWRServer/02-R-3.pdf (checked April 2013).
[18] Graham, W.J. (2009, September). A procedure for estimating loss of life caused by dam failure. U.S. Department of Interior. Bureau of Reclamation, DSO-99-06, 1999; at http://www.usbr.gov/ssle/damsafety/Risk/Estimating%20life%20loss.pdf (checked April 2013).
[19] Oregon Partnership for Disaster Resilience. (2009, October). Eugene/Springfield Multi-Jurisdictional Natural Hazards Mitigation Plan. Prepared for The Cities of Eugene and Springfield, Oregon. Accessed July 19, 2011: www.eugene-or.gov/portal/server.pt/gateway/PTARGS_0_2_355923_0_0_18/NHMP09.pdf.
[20] Bowles et al (1999, November). Alamo Dam demonstration risk assessment. Proceedings of the Australian Committee on Large Dams (ANCOLD) Annual Meeting, Jindayne, New South Wales, Australia. At http://www.engineering.usu.edu/uwrl/www/faculty/dsb/alamo.html (checked April 2013).
[21] Bowles et al (2005) Risk-based evaluation of operating restrictions to reduce the risk of earthquake-induced dam failure [model Lake Success Dam, California]. At http://uwrl.usu.edu/people/faculty/DSB/ussd2005.pdf (checked April 2013).
[22] Lewis et al (2011, April). Approaches to estimating consequences due to levee failure, St. Paul Levee system beta test. Proceedings, 31st Annual U.S. Society of Dams Conference, San Diego, pp 1105-1115; at http://ussdams.com/proceedings/2011Proc/1105-1116.pdf (checked April 2013).
[23] Texas Colorado River Floodplain Coalition, 2004. Dam Failure. 2004 Hazard Mitigation Action Plan - Creating a Disaster-Resistant Lower Colorado River Basin, chapter 15. At www.tcrfc.org/member-resources/hazard-mitigation/2004-hazard-mitigation-action-plan/ (checked April 2013).
[24] Needham et al (2011, June). Consequence Estimation for the Herbert Hoover Dike Dam [Florida] Safety Risk Assessment. Presentation, USACE Infrastructure Systems Conference, June 13-17 2011; at http://www.usace-isc.org/presentation/HHC%20-%20Hydrologic%20Engineering/Consequence%20Estimation%20for%20the%20HHD%20Dam%20Safety%20Risk%20Assessment_Ochs_Elke2.pdf (checked April 2013).
[25] Department of Water Resources, State of California (2008, December). Delta Risk Management Strategy Phase 1 Risk Analysis Report, section 12 (Consequences Modeling); at www.water.ca.gov/floodmgmt/dsmo/sab/drmsp/docs/Risk_Report_Section_12_Final.pdf (checked April 2013).
[26] Eiker et al (2000, October). Application of risk-based analysis to planning reservoir and levee flood damage reduction systems [risk assessment Folsom Dam]. Presentation; at http://www.hec.usace.army.mil/publications/TechnicalPapers/TP-160.pdf (checked April 2013).
[27] Goettel, K.A. (2001, September 24). Regional All Hazard Mitigation Master Plan for Benton, Lane and Linn Counties, Phase Two. Prepared for the Benton County Project Impact and the Oregon Cascades Regional Emergency Management Coordinating Council.
[28] City of Livermore, California (2005). Comprehensive Emergency Management Plan, Annex D: All Hazard Vulnerability Assessment. At http://www.cityoflivermore.net/civicax/filebank/documents/4184/ (checked April 2013).
[29] City of Los Angeles (2008). Citywide General Plan Framework Final Environmental Impact Report, Section 2.17, Geologic/Seismic Conditions; at http://cityplanning.lacity.org/housinginitiatives/housingelement/frameworkeir/FrameworkFEIR.pdf (checked April 2013).
[30] U.S. Army Corps of Engineers (1987). Socioeconomic considerations in dam safety risk analysis. IWR Report 87-R-7, Risk Analysis Research Program USACE; at http://planning.usace.army.mil/toolbox/library/IWRServer/IWR001-000255-000433.pdf (checked April 2013).
[31] Dam Safety Office, U.S. Bureau of Reclamation (1998, July). Prediction of embankment dam breach parameters: a literature review and needs assessment. Report DSO-98-004, Water Resources Research Laboratory; www.usbr.gov/pmts/hydraulics_lab/twahl/breach/breach_links.html (checked April 2013).
[32] Ayyaswamy et al (1974). Estimates of the risks associated with dam failure. University of California – Los Angeles report UCLA-ENG-7423 for the U.S. Atomic Energy Commission; at http://www.osti.gov/energycitations/product.biblio.jsp?query_id=1&page=0&osti_id=6387737 (checked April 2013).
[33] Rasmussen, Norman (1975, October). Reactor Safety Study: An assessment of accident risks in U.S. commercial nuclear power plants. Chapter 6: Comparison of nuclear accident risks to other societal risks. U.S. Nuclear Regulatory Commission, WASH-1400 (NUREG 75/014). Available at http://teams.epri.com/PRA/Big%20List%20of%20PRA%20Documents/WASH-1400/02-Main%20Report.pdf (checked April 2013).

results were of the true risk of catastrophic dam failure for the entire Nation in the present day.

For this reason, the SNRA project team elected to use U.S. historical data for its quantitative estimates of likelihood and fatalities for the dam event. The historical data were provided to the SNRA project by the Dams Sector Office of the Office of Infrastructure Protection, DHS/NPPD as part of a prepublication draft report on consequence estimation for dam failures.[34] The threshold selected for the Dam Failure national-level event for the SNRA project was one or more human fatalities. Since this source's data set included all dam failures with one or more fatality from 1960-2009 but only failures causing 25 or more fatalities before 1960, the SNRA project team selected 1960-2009 as the temporal window for its own data set. After consolidation of entries for secondary dam failures caused by the failure of upstream dams, which the SNRA treated as single cascading failure events, 26 historical events remained in the set (see Table 1 below).

Likelihood

Estimates in the literature for the annual probability of failure of a generic dam range from 10^{-5} to 10^{-3}, clustering around 10^{-4}. Given an expected lifetime of 100 years, this corresponds to a generic probability of failure of 10^{-2} for a given dam over its lifetime. As these generic estimates are ultimately based upon extrapolations from historical data, by construction these theoretical estimates are usually in good agreement with estimates derived with historical data sets such as that used by the SNRA.[35,36,37,38,39] Expected failure likelihoods of particular dams vary from one dam to another, depending on size, age, construction, local geological factors, and use.[40,41,42]

Of the historical events in table 2, the low, best, and high estimates for frequency correspond to the inverse of the longest interarrival time (in years) between events in the historical set (low estimate), the average interarrival time (best estimate), and the maximum number of events occurring within the same calendar year (high estimate).

Fatalities and Injuries

Fatality estimates correspond to the low, average, and maximum number of fatalities from events in the set. As a minimum of one fatality was used as the threshold for inclusion in the set, all events had fatalities to count.

Injuries were not reported by the primary data source relied upon for event frequency and fatalities, but were obtained separately for a limited number of events from the set by additional staff research. Of this set, the low number was 2 (Bergeron Pond Dam failure, New Hampshire, 1996) and the high number was 3000 (Canyon Lake Dam, South Dakota, 1972). The SNRA project team made the assumption that zero injuries was a reasonable low assumption. Given the sparseness of injury data, the project team decided to use a geometric mean of the high estimate (3,000) and 1 injury (since a geometric mean cannot be taken of zero) for the best estimate. This approach seemed reasonable given that the arithmetic average of the set of fatalities (17) was on the order of the geometric mean (13) of the same set.

Economic Loss

The SNRA project team could not obtain reasonably defensible estimates of economic damage from dam failure during the research phase of the SNRA project.[43] Studies of specific dam failure scenarios have estimated economic impacts in the hundreds of millions to billions of dollars. Examples include estimates ranging from $400M to $2.9B for failures of the Miller Dam and Mansfield Dam in Austin, Texas;[44] estimates ranging from $78M to $4.5B for dams in northeastern Idaho;[45] and an estimate of approximately $20B for a catastrophic failure of the Hills Creek Dam in Oregon.[46] However, the SNRA project team was unable to determine how representative this limited set of regional scenarios were of the economic risk of dam failure for the Nation as a whole.

Social Displacement

The breaching of a major dam would force an enormous evacuation of downstream residents. Studies of two different dams predicted over 250,000 people would be required to evacuate if there were a catastrophic dam failure at the Hills Creek Dam[47] in Oregon or the Folsom Dam in California.[48] The expectation would be that disruption and displacement in the inundated area would last for an extended period, given the physical destruction of housing and infrastructure. Towns and residential areas scoured by the wall of water would take years to rebuild.

The SNRA project team was not able to collect data over the full range of dam breach events within the historical data set. Because fatalities, the scale for which the SNRA project team was able to determine consequences for each event in the data set by construction, clustered at the minimum of 1 and included very few much larger-consequence events, the SNRA project team assumed a similar pattern for social displacement, assuming a minimal value (1 displaced) for the low estimate of social displacement. As with injuries, the SNRA project team selected the geometric mean of the low and high estimates (500) as the best estimate.

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[49] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

[34] U.S. Department of Homeland Security (2011, September), Estimating Loss of Life for Dam Failure Scenarios. Dams Sector Office, Office of Infrastructure Protection, National Protection and Programs Directorate; at http://www.damsafety.org/media/Documents/Security/DamsSectorConsequenceEstimation-LossofLife.pdf (accessed April 2013).

[35] Baecher et al (1980, June). Risk of dam failure in benefit-cost analysis. Water Resources Research 16(3) 449-456. This reference is the source of a common tabulation of estimates, and may be the primary origin of 10-4 being used as a common rule of thumb for dam risk estimation. The tabulation of prior estimates is substantively reproduced in Wang, Z. Melching, S. Management of Impounded Rivers. http://www.irtces.org/zt/training2007/ppt/ch-7%20IMPOUNDED-3.pdf. [accessed July 2011] and Salas, Jose D. (2006), Dam Breach Floods [instructional handout], at www.engr.colostate.edu/~jsalas/classes/ce624/Handouts/Dam%20Break%20Floods-Introduction.pdf (accessed April 2013).

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[37] Bowles et al (2005), op cit.

[38] Crum, Douglas (2009, January 28). Dams Safety Program [presentation], slide 22. Presentation, Society of American Military Engineers (SAME) Industry Day 2009, University of Missouri-Kansas City; at http://www.sameomaha.org/Files/Kansas%20City%20Post%20Industry%20Day%20Presentations%20-%20January%2027-28,%202009/Douglas%20Crum,%20P.E._USACE_Dams%20Safety%20Program.pdf (accessed April 2013).

[39] Hirschberg et al (1998, November). Severe accidents in the energy sector (1st ed.). Paul Scherrer Institut report number 98-16; at http://manhaz.cyf.gov.pl/manhaz/szkola/materials/S3/psi_materials/ENSAD98.pdf (checked April 2013).

[40] National Research Council (1985). Safety of dams: flood and earthquake criteria. Committee on Safety Criteria for Dams, Water Science and Technology Board, National Academies; at http://www.nap.edu/catalog.php?record_id=288 (checked April 2013).

[41] U.S. Bureau of Reclamation (2008, March 19). Dam safety – managing risk [presentation]. Slide 27, Reclamation Risk Profile. Presentation, Tolerable Risk Workshop, U.S. Bureau of Reclamation, U.S. Federal Energy Regulatory Commission, U.S. Army Corps of Engineers, March 18-19 2008; at http://www.usbr.gov/ssle/damsafety/jointventures/tolerablerisk/11Muller.pdf (checked April 2013).

[42] McClenathan, Jeffrey T. (2010). Update for screening portfolio risk analysis for U.S. Army Corps of Engineers dams. Proceedings, 30th Annual U.S. Society on Dams Conference April 12-16 2010, 1355-1366; at http://ussdams.com/proceedings/2010Proc/1355-1366.pdf (checked April 2013).

[43] The primary data source did not report economic loss estimates. For an approach relating economic losses to Population At Risk (PAR), see page 13 of Dams Sector (2011, September): Estimating Economic Consequences for Dam Failure Scenarios. Office of Infrastructure Protection, National Protection and Programs Directorate (NPPD), U.S. Department of Homeland Security; http://www.damsafety.org/media/Documents/Security/DamsSectorConsequenceEstimation-EconomicConsequences.pdf (checked April 2013).

[44] Texas Colorado River Floodplain Association, op cit.

[45] Northeastern Idaho Region, 2008. All Hazard Mitigation Plan Regional Summary, p 33.

[46] Goettel, *op cit.*

[47] Oregon Partnership for Disaster Resilience. (2009). Eugene/Springfield Multi-Jurisdictional Natural Hazards Mitigation Plan. Prepared for The Cities of Eugene and Springfield, Oregon. October 2009. Accessed July 19, 2011: http://www.eugene-or.gov/portal/server.pt/gateway/PTARGS_0_2_355923_0_0_18/NHMP09.pdf.

[48] Ayyaswamy, supra note 2. The 250,000 estimate is actually of fatalities, largely in Sacramento, following a catastrophic breach of Folsom Dam. This does not, however, take into account the effects of evacuation: given the distance between the dam and the most populated portion of the city, an instantaneous break would still give 2-3 hours of water travel time for warning and evacuation of this downstream population time (according to an experimental evacuation model provided by Ayyaswamy but not applied to Folsom in the study) assuming no impairment of civil communications or transport. Hence the SNRA project team considered this was unlikely to be a realistic fatality estimate for the most likely Folsom Dam breach scenario. However, since few homes in the path of the water would remain habitable, it was considered to be a reasonable estimate for social displacement, defined as the number of people displaced from their homes for two or more days.

[49] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + ½\ D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: dam failures were given a C_{EF} of 1.0.

The numerical estimates calculated from this formula are reported in Appendix G. The semi-quantitative risk matrix is discussed in the Findings (Psychological Distress Risk).

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (such as chemical or biological agent, contamination extent, persistence and toxicity—both chronic and acute toxicity—or infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental consequences as "Moderate." Experts assessed that the water released could impact a significant area, but the duration of impact would likely be short term, with a year or more for recovery.

Table 1. Historical U.S. Dam Failures causing Loss of Life, 1960-2009[1]

Dam	State	Date of Failure	Failure Cause	Dam Height (Feet)	Volume Released (Ac-Ft)	Size Category	Warning Time (Hours)[2]	People at Risk[3]	Loss of Life	Injuries
Electric Light Pond Dam	NY	1/1/1960	n/a	26	n/a	Small	n/a	n/a	1	
Mohegan Park Dam	CT	3/6/1963	Piping during elevated level from rainfall	20	138	Small	0	500	6	6[4]
Little Deer Creek Dam	UT	6/16/1963	Piping during normal weather	86	1,150	Intermediate	0	50	1	
Baldwin Hills Dam	CA	12/14/1963	Piping during normal weather	66	700	Intermediate	1.3	16,500	5	
Swift Dam	MT	6/8/1964	Overtopping	157	34,300	Large	Probably 0	n/a	19	
Cripple Creek Dam No. 3 and domino failure of Dam No. 2	CO	6/17/1965	Rainfall caused failure of No. 3, then overtopping failure of No. 2	n/a	640	Small	0	10	1	
Lee Lake Dam	MA	3/24/1968	Piping during normal weather	25	300	Small	0	80	2	
Virden Creek Dam	IA	7/17/1968	Overtopping	20	1,100	Intermediate	n/a	5,400	1	
Buffalo Creek Coal Waste Dam	WV	2/26/1972	Slumping of dam face during 2-year rainfall	46	404	Intermediate	0	4,000	125	1,000[5]
Lake "O" Hills	AK	4/1/1972	n/a	15	48	NJS[6]	n/a	n/a	1	
Canyon Lake Dam	SD	6/9/1972	Overtopping; 245 total deaths from area-wide flood	30	700 (10,100 flood total)	Intermediate	0	10,750	165	3,000[7]
Lakeside Dam	SC	9/18/1975	Overtopping	n/a	n/a	n/a	n/a	n/a	1	
Bear Wallow Dam	NC	2/22/1976	Rainfall; probable overtopping	36	40	Small	0	8	4	
Teton Dam	ID	6/5/1976	Piping during initial reservoir filling	305	250,000	Large	1.2	25,000	11	800[8]
Laurel Run Dam	PA	7/20/1977	Overtopping	42	450	Intermediate	0	150	40	
Kelly Barnes Dam	GA	11/6/1977	Embankment slope failure during 10-year flood	40	630	Intermediate	0	250	39	
Eastover Mining Co. Dam	KY	12/18/1981	n/a	n/a	77	Small	n/a	100	1	
Lawn Lake Dam + Cascade Lake Dam[9]	CO	7/15/1982	Piping during normal weather; Overtopping resulting from Lawn Lake Dam failure	26; 17	674; 25	Small; NJS	0; some	25; 4,275	3	
D.M.A.D. Dam	UT	6/23/1983	Backcutting from collapse of downstream diversion dam	29	16,000	Intermediate	1+	500	1	
Nix Lake Dam	TX	3/29/1989	Overtopping	23	837	Small	0	6	1	
Evans Dam + Lockwood Dam[10]	NC	9/15/1989	Overtopping; Overtopping resulting from Evans failure	18; 14	72; 32	Small; NJS	n/a; n/a	n/a; n/a	2	
Kendall Lake Dam	SC	10/10/1990	Overtopping	18	690	Small	0	n/a	4	
Timberlake Dam	VA	6/22/1995	Overtopping	33	1,449	Intermediate	0	Road traffic[11]	2	
Bergeron Pond Dam	NH	3/13/1996	Dam not overtopped	36	193	Small	0	50	1	2[12]
Mike Olson Dam (Grand Forks County Comm. No. 1 Dam)	ND	6/12/2000	Undermining of downstream end of spillway conduit	29	263	Small	0	n/a	2	
Ka Loko Dam	HI	3/14/2006	Overtopping	44	1,400	Intermediate	0	7	7	

[1] U.S. Bureau of Reclamation records of historical dam failures 1960-2009, extracted from a longer table compiled by the Dams Sector Office, Office of Infrastructure Protection, DHS/NPPD and provided to the SNRA project team September 2011. The source table corresponds to Table 2 of U.S. Department of Homeland Security (2011, September), Estimating Loss of Life for Dam Failure Scenarios, with the addition of reported injury estimates for a limited number of entries culled from other sources (as noted).
[2] "Warning Time" is defined as the interval between the first issuance of dam failure warnings and the initiation of dam failure. This definition of warning time may differ from that used elsewhere in this [the source] document. Most of the entries in this column are zero, indicating that dam failure warnings were not issued prior to dam failure. In some cases in which no warnings preceded dam failure, none of the people at risk were warned. In other cases, people living close to the dam were not warned, but warnings were issued for areas farther downstream as the dam failure was discovered or the flooding was observed. In some cases, warnings were issued for areas downstream from a dam due to natural flooding not associated with the dam failure; this was not considered a dam failure warning and was therefore assigned a zero in the table. [Footnote in source.]
[3] "People at Risk" is defined as the number of people in the dam failure floodplain immediately prior to the issuance of any flood or dam failure warning. [Footnote in source.]
[4] "Connecticut Dam Breaks, Fear Six Dead." Daily Courier, Connellsville Pennsylvania, from United Press International, March 7, 1963. At http://www3.gendisasters.com/connecticut/18029/norwich-ct-earthen-dam-breaks-mar-1963 (checked April 2013).
[5] "Buffalo Creek" [website]. West Virginia Division of Culture and History, unknown date; at http://www.wvculture.org/history/buffcreek/buff1.html (checked April 2013).
[6] Non-Jurisdictional Size.
[7] Association of State Dam Safety Officials, 2011 (April 1). Dam Failures, Dam Incidents (Near Failures). Datasheet, at http://www.damsafety.org/media/Documents/PRESS/US_FailuresIncidents(1).pdf (pdf date 4/1/11, checked April 2013).
[8] Graham, op cit; p 11.
[9] The entries for the 7/15/1982 failures of Lawn Lake Dam and Cascade Lake Dam were considered a single event (cascading failure) for the purposes of the SNRA. The columns for Failure Cause through People at Risk give each dam's information on a line of its own; the Loss of Life column gives the combined fatalities.
[10] The entries for the 9/15/1989 failures of Evans Dam and Lockwood Dam were considered a single event (cascading failure) for the purposes of the SNRA. The columns for Failure Cause through People at Risk give each dam's information on a line of its own; the Loss of Life column gives the combined fatalities.
[11] A 2-lane and 4-lane road [entry in source].
[12] U.S. Water News (1996, April). Dam break in New Hampshire damages homes, washes out highway. Online Archives, at http://www.uswaternews.com/archives/arcsupply/6newhamp.html (checked April, 2013).

Radiological Substance Release

Accidental conditions where reactor core damage causes release of radiation. This event does not include releases caused by malicious acts.

Data Summary

In the following table, note that the low and high likelihoods do not correspond to the low and high consequences. In addition, low and high consequences are not necessarily correlated with each other between different consequence categories.

Description	Metric	Low	Best	High
Fatalities[1]	Number of Fatalities	0[2]	230[3]	2200[4]
Injuries and Illnesses[5]	Number of Injuries or Illnesses	0[2]	240[3]	2300[4]
Direct Economic Loss	U.S. Dollars	$7.5B[6]	$8.6B[3]	$16B[4]
Indirect Economic Loss	U.S. Dollars	$9.4B[6]	$11B[3]	$23B[4,7]
Social Displacement[8]	Displaced from Homes ≥ 2 days	76,000	147,000	500,000
Psychological Distress	Qualitative Bins	See text		
Environmental Impact	Qualitative Bins[9]	Moderate[10]		
Frequency of Events	Number per Year	6 e-3[11]	9 e-3[3]	1 e-2[12]

Event Background

An accidental radiological release could come from a nuclear power plant accident or public exposure to lost or stolen radioactive sources. Most recorded exposure deaths and illnesses involve patients in medical accidents, workers and scientists working with radiological materials, or releases for criminal purposes (Johnston's Archive, 2010; Mohtadi, 2006; Streeper, Lombardi, & Cantrell, 2008). There have been a few accidental releases of lost material worldwide, but the documented exposures of this type are small and less likely to happen in the United States considering the standards regulating the maintenance and transport of radioactive material. Given the consequences of a large, radiological release from a power plant, this analysis focuses on nuclear power plant accidents.

A national-level power plant accident is defined in this scenario as any accident which damages the reactor core. The risk to the public and environment based on this type of accident is highly dependent on radiation containment and the location of the reactor. Accidents causing a radiological release from spent fuel are not considered in this summary sheet as their fatality and illness risk has been calculated to be more than an order of magnitude less than that of a core damage accident (United States Nuclear Regulatory Commission (T.E. Collins, G. Hubbard), 2001).

Assumptions

Fatalities and Illnesses/Injuries

Health and safety consequences were estimated based on the following assumptions:

- The fatalities and illnesses involved in a nuclear reactor accident are latent cancer fatalities and illnesses, determined as an increase over expected background illnesses and fatalities in an unexposed population. These would occur over the lifetimes of the exposed population with no expected deaths immediately after exposure.
- The fatalities and cancer illnesses were calculated from the dose consequence information in the license renewal applications available on the website of the Nuclear Regulatory Commission (United States Nuclear Regulatory Commission).
- The High and Low consequence values use the largest consequence release events and lowest consequence events available in each report. Some reactors do not report the most likely scenarios, which make the Low consequence values higher than would be expected for the most likely scenario. The most probable low consequence scenario would be quite similar to the accident at Three Mile Island in 1979 in which it was determined that the radiological release would not raise the exposure of the population enough to cause an additional case of cancer above the expected background (Perham, 1980).
- All of the consequence estimates assume that the accident is confined to a single reactor. Damage to multiple reactors could cause higher consequences. Also, the consequences associated with external events could be greater than those for internal events (the basis for consequences in NRC models) due to potential difficulties in evacuation.

Economic Loss

Economic consequences were estimated based on the following assumptions:

- The costs associated with a nuclear power plant accident listed with the license renewal application at the website of the Nuclear Regulatory Commission (United States Nuclear Regulatory Commission) include the offsite costs associated with land remediation and business interruption for areas affected outside of the power plant, the direct costs of decontamination and disposal at the power plant site, and the cost to replace the power that would have been generated at the plant.
- The offsite costs vary depending on the size of the release. The cost of onsite decontamination and disposal as well as the cost of using a different power generator are assumed fixed.
- In determining the overall economic consequences for a radiological release incident, the SNRA project team used an approach to estimating direct, indirect, and induced economic losses. The definitions for direct, indirect, and induced costs are listed in Table 1 below:

Table 1. Definitions for Direct, Indirect, and Induced Costs

Direct Costs include:

- **Decontamination, Disposal, and Physical Destruction:** DDP costs covered the repair, replacement and environmental clean-up which are considered expenditures by the government. It was assumed the government would recoup this spending through tax increases, causing a reduction of household spending of that same amount. However, this spending would be received as income by some sectors, such as waste management and environmental consulting services. The increase in spending into the waste management and environmental consulting services is treated as increase in annual output for these sectors.
- **Business Interruption:** Business interruption impacts considered losses due to decreased output at the target area, along with other increases and decreases to related sectors due to behavioral changes resulting from the event.

[1] Latent cancer fatalities: deaths resulting from cancer that became active after a latent period following exposure to radiation.
[2] The case with zero fatalities is drawn from the Three Mile Island core meltdown (Perham, 1980). A value of 58 fatalities and 61 illnesses would result from the most frequent, lowest consequence scenarios that were outlined in each of the license renewal reports. Despite choosing the lowest consequence events outlined in the report, some reports only contained somewhat rare, medium consequence events, raising the overall expected fatalities. Therefore, the use of the Three Mile Island accident was selected as a more representative example of the most likely results of core damage accident.
[3] The Best estimates use a simulation of the expected core damage frequencies obtained from the license renewal applications for a number of individual reactors available from the public website of the Nuclear Regulatory Commission (United States Nuclear Regulatory Commission). The data from the license renewal applications is used to perform cost/benefit analyses on reactor upgrades and the baseline data was not developed for use in a general risk assessment. Currently, this is the most recent publicly available data and adequate for order of magnitude estimates of the SNRA. An alternative analysis was also conducted using fatality, injury, and core damage frequency data from NUREG-1150, and the best estimates from this analysis were within the same order of magnitude as the results obtained using data from license renewal applications (United States Nuclear Regulatory Commission, 1990). The expected consequences are weighted by the likelihood of a core damage accident for each reactor using a Crystal Ball simulation. The details are explained in the Additional Relevant Information section.
[4] The High consequence estimates also come from the license renewal applications (United States Nuclear Regulatory Commission). The consequences correspond to the highest consequence scenarios outlined in the report. These usually involve a large, early release and assume that there is not enough time for successful evacuation. The frequency of these events is typically one to two orders of magnitude less than the frequency of any core damage event. Note that the likelihood values in the table do not correspond to the consequences for the High and Low categories.
[5] Latent cancer morbidities.
[6] The Low values of economic damage are determined from the results of the most frequent types of core damage accidents in each report as discussed in Footnote 2. The economic costs are mostly fixed values associated with business interruption and are consistent with the $1B in decontamination costs from the shutdown of Reactor 2 at Three Mile Island (*New York Times*, 1993). The replacement power costs assumed in the model should be applicable here.
[7] The current cost estimates for the Fukushima disaster are in the hundreds of billions of dollars. This includes the damage directly from the earthquake and the tsunami as well as the nuclear power plant disaster (Japanese Ministry of Economy, Trade, and Industry).
[8] The low and best estimates reflect published estimates of displacement from the Three Mile Island incident. The high estimate reflects published estimates of displacement from the Chernobyl incident (see text).
[9] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.
[10] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event.
[11] This number is the 5th percentile of the core damage frequencies taking into account variability across the different reactors and the uncertainty of a single reactor. Note that this frequency incorporates the uncertainty and variability of the expectation and does not directly correspond to the Low consequence values.
[12] This number is the 95th percentile of the core damage frequencies taking into account variability across the different reactors and the uncertainty of a single reactor. This does not correspond to the High consequence values which have likelihoods one to two orders of magnitude lower than the Best CDF value.

- **Loss in Spending from Fatalities:** This SNRA project team estimated a loss of spending of $42,500 for each fatality. In addition, $6,000 is included in increased output for mortuary services for each fatality.
- **Medical Costs:** Costs of medical mitigation were considered to be borne through private spending and insurance companies, while the hospital sector received an offsetting increase in output.

Indirect Costs include:

- Costs incurred by the suppliers and vendors in the associated expenditure sectors for the industries impacted by the direct costs above.

Induced Costs include:

- The induced costs are those incurred due to reduced spending by households with members employed in any of the directly or indirectly affected industries. Induced costs can also include substitution effects or likely transfers of economic activity from one set of sectors to another set, such as avoidance of air or other travel or altered transportation mode preferences to other sectors following an attack on the commercial air transport sector.

- In order to apply this model to the set of costs available, the offsite, disposal and decontamination, and alternate power generation costs must be binned into the above direct costs categories.
- Because the offsite costs are assumed to mostly be due to business interruption, they are placed in that category. The alternative power generation would also be a business interruption cost. Both of these values are several billion dollars and expected to contain the majority of business interruption costs from the accident.
- Onsite decontamination and disposal should be the primary area where this type of work would need to be conducted, so these costs are directly used for the decontamination, disposal, and physical destruction category.

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

- For the accidental Radiological Substance Release event, the low and best estimates reflect published estimates of displacement from the Three Mile Island incident. This displacement represented voluntary evacuation by individuals and families rather than a mandatory evacuation order: the SNRA's social displacement metric counts all people displaced from homes for two or more days, whether the displacement was directed or not.[13] The high estimate reflects published estimates of displacement from the Chernobyl incident.[14]

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[15] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (such as chemical or biological agent, contamination extent, persistence and toxicity—both chronic and acute toxicity—or infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental consequences as "moderate." Nuclear power plant disruption could cause radioactive airborne releases that could travel for large distances and settle into down-range eco-systems, with possible disruptions. In addition, releases into water bodies may have impacts on aquatic life.

Key Mitigating Factors

The consequences caused by a nuclear release are currently mitigated through several preparedness strategies. Monitoring systems indicate the need for individuals in the designated evacuation zone to evacuate to the recommended safe distance. The monitoring and warning systems are regularly tested to ensure that they are functioning properly when an event occurs. Additionally, evacuation and safe routes are identified and communicated to individuals residing or working in the evacuation zones. Further, a properly prepared and deployed response team could potentially aid in limiting exposure to the radiological substance and reducing the size of the contaminated area.

Additional Relevant Information

The frequencies of radiological releases were determined by Core Damage Frequency (CDF)[16] results provided in license renewal applications, which are available at the website of the Nuclear Regulatory Commission (United States Nuclear Regulatory Commission). Of the 104 active nuclear reactors in the United States, 81 have either completed applications for license renewal or have applications that are currently under review. As part of this license renewal process, each reactor includes an environmental report with a Severe Accident Mitigation Alternatives (SAMA) analysis, which is where the CDFs can be found. Information for reactors that do not have current license renewal applications is not available, but it was assumed that the data available on the 81 reactors with current renewal application is representative of the remaining reactors without current license renewal applications. Therefore, in accordance with this assumption, the mean internal CDFs[17] are drawn from the distribution of the 81 reactors whose information is available.

Regarding the SAMA data in the license renewal applications, it is important to note that data from SAMA analyses are developed and used to perform cost/benefit analyses on reactor upgrades, not to perform general risk assessments. However, SAMA data are the best publicly available data for our purposes and are adequate for the order-of-magnitude estimates of the SNRA. The NRC is currently re-evaluating severe accident consequences using two pilot plants. Preliminary results from this State-of-the-Art Reactor Consequence Analysis (which is still in progress[18]) indicate that selected accident scenarios could reasonably be mitigated, either preventing core damage or delaying/reducing the radiation release. For scenarios assumed to proceed without mitigation, accidents progress more slowly and result in smaller and more delayed radiological releases than previously predicted (e.g. in NUREG-1150) (Gauntt, 2008).

Furthermore, each of the reactor license renewal applications includes the CDFs associated with internal events, which are accidents arising from plant activities, such as worker error or parts malfunctions. Uncertainty

[13] Sources for the low and best estimates of displacement due to Accidental Radiological Substance Release are Cutter, Susan, and Kent Barnes. 1982. "Evacuation Behavior and Three Mile Island." *Disasters* 6.2: 116-124.; and Soffer, Yechiel, Dagan Schwartz, Avishay Goldberg, Maxim Henenfeld and Yaron Bar-Dayan. 2008. "Population Evacuations in Industrial Accidents: A Review of the Literature about Four Major Events." *Prehospital and Disaster Medicine* 23.3: 276-281.

[14] Soffer, Yechiel, Dagan Schwartz, Avishay Goldberg, Maxim Henenfeld and Yaron Bar-Dayan. 2008. "Population Evacuations in Industrial Accidents: A Review of the Literature about Four Major Events." *Prehospital and Disaster Medicine* 23.3: 276-281.

[15] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\,Fat + Inj + \frac{1}{2} D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: accidental Radiological Substance Release was given a C_{EF} of 1.1.

The numerical estimates calculated from this formula are reported in Appendix G. The semi-quantitative risk matrix is discussed in the Findings (Psychological Distress Risk).

[16] **Core Damage Frequency (CDF)** - An expression of the likelihood that, given the way a reactor is designed and operated, an accident could cause the fuel in the reactor to be damaged (United States Nuclear Regulatory Commission, 2011).

[17] **Individual Plant Examination for External Events (IPEEE)** - While the "individual plant examination" takes into account events that could challenge the design from things that could go awry internally (in the sense that equipment might fail because components do not work as expected), the "individual plant examination for external events" considers challenges such as earthquakes, internal fires, and high winds (United States Nuclear Regulatory Commission, 2011).

[18] As of August 2011.

around these CDFs was collected for 15 license renewal applications, which report 5th and 95th percentiles along with mean CDFs. For example, in Reactor 1 this value is 2.10 for the ratio of the 95th percentile to the mean and 0.462 for the 5th percentile to the mean, and in Reactor 2 the ratio of the 95th percentile to the mean is 1.40, and the ratio of the 5th percentile to the mean is 0.687. However, uncertainty was collected in only 15 of the 81 CDFs (not all reports included these values), and the functions associated with the Monte Carlo runs that underlie the uncertainty are not reported. Therefore, to address this lack of information and assign uncertainty to all CDFs for all the reactors, the 15 available reports on uncertainty are used to calculate 15 separate ratios of the 95th percentile to mean and of the 5th percentile to mean. Also, it was assumed that the distributions of the 5th-mean and 95th-mean ratios for the available 15 cases would be representative of all reactors. Crystal Ball was used to find a statistical best fit for the distributions of these ratios. Then to assign uncertainty to all CDFs, the 15 reference values were used for their corresponding reactors and drew randomly from the best fit 95th-mean and 5th-mean distributions for all other reactors, multiplying their CDFs by the randomly assigned ratios in order to derive 5th and 95th percentile values for the CDFs. These distributions were chosen independently for each of the reactors, and it was assumed that the uncertainty for each of the reactors is independent: the model does not simulate a systematic dependency among the reactors' uncertainties, which could push all of the reactors' CDFs in the same direction (high or low).

The frequency of core damage caused by external events (fire, earthquake, flood, plane crash, etc.) is included in some – but not all – of the applications. For the reactors where external CDFs are readily available, they have been included directly in the frequency calculation. In the examples examined, external CDFs including fire, seismic events, and high winds are frequencies that share the same order of magnitude as the internal CDFs. For example, for two given reactors, the internal CDFs are 1.79e-5 for Reactor 1 and 1.15e-5 for Reactor 2. The external CDF values are 5.01e-5 for Reactor 1 and 5.20e-5 for Reactor 2. For reactors without external CDFs, a lognormal distribution based on the selection of 18 known external CDF/internal CDF ratios is used to calculate the variation in external factors. (The lognormal distribution was chosen based on a Crystal Ball best fit.)

The other frequency of interest is the Large, Early Release Frequency (LERF).[19] For example, in Reactor 1 the CDF of 1.79e-5 corresponds to a LERF of 6.50e-7. Similarly in Reactor 2, the CDF of 1.15e-5 corresponds to a LERF of 9.43e-7. Any event with core damage is assumed to cross the threshold of national significance and influence national preparedness goals. Therefore, the CDF is the frequency listed in the risk characteristics table above, which will include all large, early release events. Based on the data from 16 reactors, the frequency of a large, early release is between one and two orders of magnitude lower than the frequency of a more general core damage event.

The results of the analysis using license renewal applications were compared to an alternative analysis that was conducted using fatality, injury, and core damage frequency data from NUREG-1150 (United States Nuclear Regulatory Commission, 1990.). The average of the core damage frequencies taken from NUREG-1150 was multiplied by 104 (the number of active nuclear reactors in the United States) and the fatalities and dose rates taken from NUREG-1150 were used to determine the comparability of the results of the two data sources. The best estimates from the NUREG-1150 analysis were within the same order of magnitude as the results obtained using data from license renewal applications.

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[19] **Large, Early Release Frequency (LERF)** - The frequency of those accidents leading to significant, unmitigated releases from containment in a time frame prior to effective evacuation of the close-in population such that there is a potential for early health effects. Such accidents generally include un-scrubbed releases associated with early containment failure at or shortly after vessel breach, containment bypass events, or loss of containment (United States Nuclear Regulatory Commission, 2002).

Cyber Event affecting Data (Data as Target)

A cyber event[1] occurs which seriously compromises the integrity or availability of data (the information contained in a computer system) or data processes, resulting in economic losses of $1 billion or greater.

Data Summary

Description	Metric	Low	Best	High
Fatalities	Number of Fatalities	Not determined		
Injuries and Illnesses	Number of Injuries or Illnesses	Not determined		
Total Economic Loss	U.S. Dollars	Not determined		
Social Displacement	Number of Displaced from Homes for ≥ 2 Days	0		
Psychological Distress	Qualitative Bins	See text		
Environmental Impact	Qualitative Bins[2]	None[3]		
Frequency of Events	Number per Year	See classified data table		

Event Background

This category includes cyber attacks that focus on compromising data or data processes as the primary result. Such attacks could take many forms and be perpetrated in order to achieve many goals. Some examples might include the altering of records in a healthcare or financial system or an attack which causes the internet, communications networks, or data processes to cease.

While frequency information about the type of data/data processes attacks included in this category is difficult to locate in open source material, there are several observations that can assist in setting the context.

A 2010 Verizon report analyzing 141 data breach cases from 2009 (worked by either the Verizon Investigative Response Team or the U.S. Secret Service) estimated the total number of data records compromised across these cases to exceed 143 million.[4] Consistent with previous years, most of the losses in 2009 came from only a few of the 141 breaches. The average number of records lost per breach was 1,381,183, the median only 1,082, and the standard deviation 11,283,151.[5]

In the case of denial-of-service events, according to a 2010 CSIS-McAfee survey of 200 critical infrastructure executives from the energy, oil/gas, and water sectors in 14 countries, nearly 80 percent of the respondents reported facing a large-scale denial-of-service attack in 2010 (up from just over half in 2009), with a quarter reporting daily or weekly denial-of-service attacks on a large scale.[6]

Additionally, one in four of the CSIS-McAfee respondents said they had been the victim of extortion through attack or threat of attack to IT networks in the past two years—an increase from one in five respondents from the previous year.[7]

Consequences for the types of attacks in this event category are difficult to quantify, as they depend on the particular system attacked, the vulnerability and resilience of the network, specific data backup provisions, and other factors. A sample of several historical data/data processes-related cyber attacks is presented in the "Additional Relevant Information" section below. In addition, details on the Wall Street "Flash Crash" are included in the list, in order to provide context on the potential magnitude of consequences produced by events in this category.

[1] The Cyber Attack against Data national-level event was renamed Cyber Event affecting Data in 2013 to address stakeholder concerns.
[2] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and *de minimus* (none) categories.
[3] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'Best' estimate.
[4] Verizon RISK Team, 2010 Data Breach Investigations Report (2010): 7.
[5] Ibid.: 40.
[6] McAfee and the Center for Strategic and International Studies, *In the Dark: Crucial Industries Confront Cyberattacks* (April 2011): 6.
[7] Ibid.

Assumptions

Likelihood

Frequency estimates were elicited from the Intelligence Community (IC) by the SNRA project team in July-August 2011.[8] Only attacks resulting in $1 billion in losses or greater were considered. The frequency estimates for this event are classified, but are provided in the data tables of the classified SNRA Technical Report.

Frequency estimates were based on the following assumptions regarding the scope of events in this category.

- **General Scope:** This category includes cyber attacks that focus on compromising data or data processes as the primary result. Although events in this category almost always have indirect effects that "go beyond the computer," only events in which these types of effects are a function of modern reliance on computer systems—rather than the primary objective of the attack—were considered.
- **Actor Types:** Given the goal of capturing the full range of national-level possibilities within each type of incident, events in which cyber attacks are intentionally caused by any type of human actor, including, e.g., hackers, activists, states, terrorists, malicious insiders, or criminals, were considered. Unintentional human-caused events (such as unintentional breaches or accidents) or non-human-caused events (such as those caused by natural disasters or equipment malfunctions) were not considered.
- **Weapon Types:** All types of cyber weapons, including but not limited to malicious software, botnets, distributed denial-of-service attacks, etc., were considered.
- **Target Types:** Any type of civilian target was considered. Note that for the purposes of the SNRA—which is intended to inform civilian capability development—direct attacks on defense systems were not considered. Additionally, state- and non-state- sponsored espionage was not considered.
- **Time Period:** The SNRA focuses on estimating risk within the next five years, in support of the overall need to focus on future-oriented core capability development.
- **National-level Threshold:** As stated above, the SNRA is designed to assess the risks of those events and incidents which create consequences that rise to a strategic, national-level of impact. Thus, small-scale attacks, which occur on a daily basis, were not considered. Instead, only high-impact events, which could produce a national level of awareness due to major consequences related to life safety, economic damage, psychological damage, social displacement, or environmental damage were considered.

Fatalities, Injuries and Illnesses, Economic Damage

Defensible estimates could not be obtained on these consequence measures. Additional analysis will be needed to quantify the human health and economic impacts of the Cyber Event affecting Data event.

Psychological Distress

Since the SNRA measure of psychological distress is tied to fatality and illness/injury estimates, psychological distress estimates were not reported in the SNRA for the Cyber Event affecting Data national-level event.[9]

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

[8] IC participants in the Cyber Event affecting Data frequency elicitation included subject matter experts from multiple agencies. The frequency estimates (see classified SNRA Technical Report) reflect the opinion of the group and have not been formally vetted by any of the agencies which participated.
[9] The SNRA measures psychological distress by a Significant Distress Index calculated from fatality, illness/injury, and social displacement estimates using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + \frac{1}{2}\ D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is anexpert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.
The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: experts assessed a C_{EF} of 1.0 for the Cyber Event affecting Data national-level event.
Although the SNRA determined null social displacement estimates for the Cyber Event affecting Data, scenarios which could credibly threaten human health and safety without forcing people to flee their homes remained part of the event scope and so the SNRA project team could not assume zero estimates for fatalities and illnesses/injuries as well.

- As the Cyber Event affecting Data national-level event is restricted to cyber events not directly causing impacts on the physical world, the SNRA project team assessed the low, best, and high estimates for social displacement to be zero.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental consequences as “de minimus” or none.

Potential Mitigating Factors

The risk of this type of cyber attack can be mitigated through several preparedness strategies. Practices such as employing advanced authentication measures, the use of encryption technologies, and the monitoring of network use for anomaly detection would help to prevent, more quickly identify, and facilitate a timely response to cyber attacks.[10] In addition, organizations can employ tailored strategies that increase resilience to cyber attacks on data. These could include strategies such as employing back-up systems and developing plans for maintaining operations without the use of computer systems.

Additional Relevant Information

A sample list of several historical data/data processes related to cyber attacks is presented below. Details on the Wall Street “Flash Crash” are included in the list, in order to provide context on the potential magnitude of consequences produced by events in this category.

Attacks on Data and the Potential Magnitude of Compromised Data Integrity or Accessibility[11]
Seattle Hospital Denial of Access. Cyber criminals in 2007 compromised the networks of a Seattle hospital, causing system malfunctions including the crash of the Intensive Care Unit Network.
Wall Street “Flash Crash.” In Wall Street’s May 2010 “flash crash,” complex automated trades created enough market volatility to hemorrhage approximately 1 trillion dollars in only minutes, with some stocks dropping more than 90 percent in value. While the volatility was unintentional and the stocks recovered, the crash illustrates the potential consequences of sophisticated cyber attacks against a financial system that relies increasingly on automated high-frequency trading.[12]

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[10] See McAfee and the Center for Strategic and International Studies: 24.
[11] This list was provided to the participants in the frequency elicitation, to encourage consideration of potential consequences of a cyber attack against data.
[12] Quoted in full from David Pett, “High-Frequency Swaps, Dark Pools Under Scrutiny,” *National Post’s Financial Post & FP Investing* (8 May 2010) and Kara Scannell and Tom Lauricella, “Flash Crash Is Pinned On One Trade,” *The Wall Street Journal* (2 October 2010) as cited in Lord and Sharp: 1:25.

Cyber Event affecting Physical Infrastructure (Vector)

A cyber event[1] in which cyber means are used as a vector to achieve effects which are "beyond the computer" (i.e., kinetic or other effects), resulting in one or more fatalities or economic losses of $100 million or more.

Data Summary

Description	Metric	Low	Best	High
Fatalities	Number of Fatalities	Not determined		
Injuries and Illnesses	Number of Injuries or Illnesses	Not determined		
Total Economic Loss	U.S. Dollars	Not determined		
Social Displacement	Displaced from Homes ≥ 2 Days	0	400	Not determined
Psychological Distress	Qualitative Bins	See text		
Environmental Impact	Qualitative Bins[2]	None[3]		
Frequency of Events	Number per Year	See classified data table		

Event Background

This category encompasses cyber attacks that directly produce national-level effects outside the virtual world. These types of events could involve a variety of targets, such as large-scale assets in a variety of critical infrastructure sectors. Examples might include the electric grid, a dam, or the water system.

The threat of this type of event has seen increased prominence recently, as the extent of the Stuxnet infections have come to light. According to a 2010 CSIS-McAfee survey of 200 critical infrastructure executives from the energy, oil/gas, and water sectors in 14 countries, around 40 percent of respondents found Stuxnet on their computers.[4] While three-quarters of respondents who found Stuxnet were confident it has been removed from their systems, the potential for widespread sabotage through the introduction of malware into SCADA systems was clearly demonstrated.[5] The 2007 "Aurora" tests conducted at Idaho National Labs further confirmed the proposition that hackers could gain remote access to a control system and, in that case, remotely change the operating cycle of a generator, sending it out of control.[6]

More than 40 percent of the executives interviewed in the CSIS-McAfee survey reported they expected a major cyber attack within 12 months—i.e., an attack that would cause severe loss of services for at least 24 hours, a loss of life or personal injury, or the failure of a company.[7] It should be noted, however, that the types of attacks cited in the study—though important for individual companies—would not necessarily produce consequences that would rise to the threshold for a national-level event.

Consequences for the types of attacks in this event category are sector dependent and difficult to quantify. Approximately 85% of critical infrastructure is believed to be owned and operated by the private sector, and system vulnerability and resilience is highly sector-dependent and localized.[8] A sample of historical attacks on the SCADA systems of critical infrastructure assets, along with a list of unintentional or non-cyber related failures within critical infrastructure sectors is included in the "Additional Relevant Information" section below.

[1] The Cyber Attack against Physical Infrastructure national-level event was renamed Cyber Event affecting Physical Infrastructure in 2013 to address stakeholder concerns.
[2] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.
[3] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'Best' estimate.
[4] McAfee and the Center for Strategic and International Studies, *In the Dark: Crucial Industries Confront Cyberattacks* (April 2011): 8.
[5] Ibid.
[6] James A. Lewis, "The Electrical Grid as a Target for Cyber Attack," Center for Strategic and International Studies (March 2010).
[7] McAfee and the Center for Strategic and International Studies: 10.
[8] According to the Office of Infrastructure Protection, Department of Homeland Security. http://www.dhs.gov/files/partnerships/editorial_0206.shtm.

Assumptions

Likelihood

Frequency estimates were elicited from the Intelligence Community (IC) by the SNRA project team in July-August 2011.[9] Only attacks resulting in one or more fatalities, or $100 million in losses or greater were considered. The frequency estimates for this event are classified, but are provided in the data tables of the classified SNRA Technical Report.

Frequency estimates were based on the following assumptions regarding the scope of events in this category:

- **General Scope:** This event encompasses cyber attacks that directly produce national-level effects outside the virtual world. While the attacks in this category may involve the manipulation of data as a means to an end, an event whose *direct* result is only compromised data (such as intellectual property theft or altered healthcare records) was not considered.
- **Actor Types:** Given the goal of capturing the full range of national-level possibilities within each type of incident, events in which cyber attacks are intentionally caused by *any* type of human actor, including, e.g., hackers, activists, states, terrorists, malicious insiders, or criminals, were considered. Unintentional human-caused events (such as unintentional breaches or accidents) or non-human-caused events (such as those caused by natural disasters or equipment malfunctions) were not considered.
- **Weapon Types:** All types of cyber weapons, including but not limited to malicious software, botnets, distributed denial-of-service attacks, etc., were considered.
- **Target Types:** Any type of civilian target was considered. Note that for the purposes of the SNRA—which is intended to inform civilian capability development—direct attacks on defense systems were not considered. Additionally, state- and non-state- sponsored espionage was not considered.
- **Time Period:** The SNRA focuses on estimating risk within the next five years, in support of the overall need to focus on future-oriented core capability development.
- **National-level Threshold:** As stated above, the SNRA is designed to assess the risks of those events and incidents which create consequences that rise to a strategic, national-level of impact. Thus, small-scale attacks, which occur on a daily basis, were not considered. Instead, only high-impact events, which could produce a national level of awareness due to major consequences related to life safety, economic damage, psychological damage, social displacement, or environmental damage were considered.

Fatalities, Injuries and Illnesses, Economic Damage

Defensible estimates could not be obtained on these consequence measures. Additional analysis will be needed to quantify the human health and economic impacts of the Cyber Event affecting Physical Infrastructure event.

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

- Low and best estimates of social displacement estimates for the Cyber Event affecting Physical Infrastructure national-level event were provided by the National Consortium for the Study of Terrorism and Responses to Terrorism (START).[10] The low estimate of 0 reflects assessed judgment of START subject matter experts. The best estimate of 400 comes from a case study of an evacuation of an U.S. Army base due to a large but accidental power outage: this historical event was considered a reasonable proxy for displacement due to an intentional power outage following a cyber attack on the electrical grid.[11]
- No high estimate was determined. However, START subject matter experts noted that a cyber event causing a prolonged power outage over a large area

[9] IC participants in the Cyber Event affecting Physical Infrastructure frequency elicitation included subject matter experts from multiple agencies. The frequency estimates (see classified SNRA Technical Report) reflect the opinion of the group and have not been formally vetted by any of the agencies which participated.
[10] START is a Department of Homeland Security University Center of Excellence that focuses on social and behavioral aspects of terrorism, natural disasters, and technological accidents, and the social, behavioral, cultural and economic factors influencing responses to and recovery from catastrophes.
[11] Reed, Charlie and Grant Okubo. "Flooding, power outages force evacuations at Yokota." *Stars and Stripes* (July 6, 2010). http://www.stripes.com/news/pacific/japan/flooding-power-outages-force-evacuations-at-yokota-1.110071.

could result in several thousand people evacuating, regardless of the outage cause.

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[12] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impacts

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g. chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental consequences as “de minimus” or none. Experts indicated, however, that this depends on the duration of the event. If the consequences of the event (e.g., power outages) occur for longer than a few days, then backup systems for sewage plants, chemical facilities, etc. could fail and result in more severe environmental consequences.

Potential Mitigating Factors

The risk of this type of cyber attack can be mitigated through preparedness strategies that act on both cyber systems and the actual target itself. Cyber strategies include practices such as the use of encryption technologies and the monitoring of network use for anomaly detection.[13] Target specific strategies include the range of measures that are typically employed to manage the risk to critical infrastructure systems. These will vary from sector to sector, but, in general, s**t**rategies to increase resilience will likely assist in mitigating the consequences from this type of cyber attack, as well as other threats and hazards.

Additional Relevant Information

A sample of historical attacks on the SCADA systems of critical infrastructure assets is presented below, in order to provide context for the type of consequences that might reasonably be considered within this event category. Because many, if not all, of these attacks did not produce national-level consequences, a second list of unintentional or non-cyber related failures within the critical infrastructure sectors is presented, in order to provide context on the potential magnitude of consequences produced by events in this category.

Targeted and Nontargeted Attacks on Critical Infrastructure Control Systems[14]
Worcester air traffic communications. In March 1997, a teenager in Worcester, Massachusetts, disabled part of the telephone network using a dial-up modem connected to the system. This disabled phone service to the airport control tower, airport security, the airport fire department, the weather service, and the carriers that use the airport. Also, the tower’s main radio transmitter and another transmitter that activates runway lights were shut down, as well as a printer that controllers use to monitor flight progress. The attack also disrupted phone service to 600 homes in a nearby town.
Maroochy Shire sewage spill. In the spring of 2000, a former employee of an Australian organization that develops manufacturing software applied for a job with the local government, but was rejected. Over a 2-month period, this individual reportedly used a radio transmitter on as many as 46 occasions to remotely break into the controls of a sewage treatment system. He altered electronic data for particular sewerage pumping stations and caused malfunctions in their operations, ultimately releasing about 264,000 gallons of raw sewage into nearby rivers and parks.
Los Angeles traffic lights. According to several published reports, in August 2006, two Los Angeles city employees hacked into computers controlling the city’s traffic lights and disrupted signal lights at four intersections, causing substantial backups and delays. The attacks were launched prior to an anticipated labor protest by the employees.
CSX train signaling system. In August 2003, the Sobig computer virus was blamed for shutting down train signaling systems throughout the East Coast of the United States. The virus infected the computer system at CSX Corporation’s Jacksonville, Florida, headquarters, shutting down signaling, dispatching, and other systems. According to an Amtrak spokesman, 10 Amtrak trains were affected. Train service was either shut down or delayed up to 6 hours.
Davis-Besse power plant. The Nuclear Regulatory Commission confirmed that in January 2003, the Microsoft SQL Server worm known as Slammer infected a private computer network at the idled Davis-Besse nuclear power plant in Oak Harbor, Ohio, disabling a safety monitoring system for nearly 5 hours. In addition, the plant’s process computer failed, and it took about 6 hours for it to become available again.
Zotob worm. In August 2005, a round of Internet worm infections knocked 13 of DaimlerChrysler’s U.S. automobile manufacturing plants offline for almost an hour, leaving workers idle as infected Microsoft Windows systems were patched. Zotob and its variations also caused computer outages at heavy-equipment maker Caterpillar Inc., aircraft maker Boeing, and several large U.S. news organizations.
Harrisburg, Pennsylvania, water system. In October 2006, a foreign hacker penetrated security at a water filtering plant. The intruder planted malicious software that was capable of affecting the plant’s water treatment operations. The infection occurred through the Internet and did not seem to be an attack that directly targeted the control system.
Lodz, Poland, tram system. In early 2008, a 14-year old boy jerry-rigged an infrared transmitter that allowed him to hack into the switching network of the Lodz, Poland, city tram system and cause four trams to derail, injuring at least a dozen riders.
Siberian hydro-electric plant. In Russia in the summer of 2009, maintenance personnel for a Siberian hydro-electric plant remotely logged on to the plant’s control network and set the turbines to operate beyond safe parameters. One of the turbines was ejected from its moorings damaging additional turbines, leading to the generator room being flooded and causing a transformer explosion. The turbine room was destroyed and 75 workers were killed.

[12] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + \frac{1}{2} D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: experts assessed a C_{EF} of 1.0 for the Cyber Event affecting Physical Infrastructure event.

As fatality and injury/illness estimates were not determined, psychological distress estimates could not be calculated for this event.

[13] See McAfee and the Center for Strategic and International Studies: 24.

[14] The first seven entries in this table are quoted in whole from Government Accountability Office, Critical Infrastructure Protection: Multiple Efforts to Secure Control Systems Are Under Way, but Challenges Remain (September 2007): 15–17.

The Potential Magnitude of Critical Infrastructure Failures[15,16] *(provided for context to encourage participants to consider potential consequences of a cyber attack)*
Northeast power blackout. In August 2003, failure of the alarm processor in the control system of FirstEnergy, an Ohio-based electric utility, prevented control room operators from having adequate situational awareness of critical operational changes to the electrical grid. This problem was compounded when the state estimating program at the Midwest Independent System Operator failed due to incomplete information on the electric grid. When several key transmission lines in northern Ohio tripped due to contact with trees, they initiated a cascading failure of 508 generating units at 265 power plants across eight states and a Canadian province.
Taum Sauk Water Storage Dam failure. In December 2005, the Taum Sauk Water Storage Dam, approximately 100 miles south of St. Louis, Missouri, suffered a catastrophic failure, releasing a billion gallons of water. According to the dam's operator, the incident may have occurred because the gauges at the dam read differently than the gauges at the dam's remote monitoring station.
Bellingham, Washington, gasoline pipeline failure. In June 1999, 237,000 gallons of gasoline leaked from a 16-inch pipeline and ignited an hour and a half later, causing three deaths, eight injuries, and extensive property damage. The pipeline failure was exacerbated by poorly performing control systems that limited the ability of the pipeline controllers to see and react to the situation.
Browns Ferry power plant. In August 2006, two circulation pumps at Unit 3 of the Browns Ferry, Alabama, nuclear power plant failed, forcing the unit to be shut down manually. The failure of the pumps was traced to excessive traffic on the control system network, possibly caused by the failure of another control system device.

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U.S. Department of Homeland Security (2011, August). Information Technology Sector Baseline Risk Assessment; at http://www.dhs.gov/xlibrary/assets/nipp_it_baseline_risk_assessment.pdf (checked April 2013).

[15] This list was provided to the participants in the frequency elicitation, to encourage consideration of potential consequences of a cyber attack against physical infrastructure.
[16] The entries in this table are quoted in whole from Government Accountability Office: 16–17.

Aircraft-as-a-Weapon

A hostile non-state actor(s) crashes a commercial or general aviation aircraft into a physical target within the U.S.

Data Summary

Description	Low	Best	High
Fatalities	See FOUO data sheet		
Injuries and Illnesses			
Direct Economic Loss	See FOUO data sheet		
Indirect Economic Loss			
Social Displacement[1]	0	50,000	1 Million
Psychological Distress	See text		
Environmental Impact[2]	Low		
Frequency of Events	See classified data sheet		

(UNCLASSIFIED)

Event Background

Terrorists have long viewed aviation as a target for attack and exploitation. Successful attacks in the air domain can inflict mass casualties and grave economic damage, and attract significant public attention. Historically, large passenger aircraft have been at the greatest risk to terrorism, whether bombings, taking of hostages, traditional hijacking, and attack using human-portable surface-to-air missiles. Aircraft have also been used as weapons against targets on the ground, most notably but not limited to the attacks of September 11, 2001.[3]

For this incident, the SNRA only considered the risk of aircraft being used as a kinetic mode of attack (e.g. a 9/11 style attack) rather than the risk of an improvised explosive device (IED) being detonated on an aircraft. The latter risk is considered under the explosives incident category in the SNRA.

Assumptions

Likelihood

Frequency estimates used for the Aircraft as a Weapon and Explosives Terrorism Attack events in the SNRA were elicited from DHS subject matter experts in late 2009 - early 2010 by the DHS/NPPD Office of Risk Management & Analysis (RMA) for the RAPID 2010 assessment.[4] These estimates are classified, but are provided in the data tables of the classified SNRA Technical Report.

Fatalities and Injuries

The SNRA project team used the following to estimate health and safety consequences resulting from an aircraft-as-a-weapon attack:

- Historical events: the SNRA project team analyzed a set of ten historical events in which aircraft intentionally or unintentionally crashed into buildings or crowds of people. A detailed listing of these events is found in Table 1 under "Additional Relevant Information." The analysis does not take into account possible higher-consequences events that have not yet occurred, but rather assumes maximum fatalities and injured counts from the 9/11 attacks in New York.

Economic Loss

Total economic loss to the U.S. economy was estimated using indirect and induced costs to the U.S. economy given inputs of several direct economic costs, including business interruption costs, lost demand from fatalities, medical costs and decontamination, disposal, and property damage (DDP) costs.

The SNRA project team used the following assumptions to estimate the direct economic costs resulting from an aircraft-as-a-weapon attack:

- Business Interruption and DDP Costs: The SNRA project team randomly sampled business interruption and DDP cost values from scenarios corresponding to the SNRA fatality estimates, using economic consequence models for aircraft-as-a-weapon attacks previously developed for use with the RAPID 2010 computational risk modeling tool. Note that these scenarios only consider aircraft used against commercial facilities.
- Medical Costs: The numbers of injured were based on the set of events listed above. To account for the distribution of injuries and corresponding medical costs from single events, the SNRA project team multiplied total injuries from the events in the historical data set by a uniform distribution over $13,490 to $122,802, the distribution used by the RAPID assessment for medical costs associated with Explosives/Kinetic/ Incendiary (E/K/I) injuries,[5] by repeated random sampling from each distribution.
- Lost Demand from Fatalities: To estimate the costs of lost demand from deaths, the SNRA project team multiplied the number of deaths listed in Table 1 by $42,500, a value used by prior DHS assessments.[6]

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

- The SNRA project team selected 0 as the low estimate of social displacement, for consistency with the scope of the Aircraft as a Weapon national-level event as defined by the range of fatalities in Table 1: it is possible that an attack on a non-residential district resulting in only two fatalities would not cause extensive enough damage to force people from their homes for two or more days.
- The best and high social displacement estimates were provided by staff researchers and subject matter experts at the National Consortium for the Study of Terrorism and Responses to Terrorism (START).[7] The best estimate of 50,000 reflects expert judgment. The high estimate of 1 million reflects literature estimates of the number of people displaced from Lower Manhattan after the 9/11 attacks.[8]

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[9] The numerical outputs of

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[1] The SNRA measure of social displacement was defined as the number of people forced to leave home for a period of two days or longer.

[2] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and *de minimus* (none) categories. Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'Best' estimate.

[3] U.S. Department of Homeland Security (2007, March 26). *National Strategy for Aviation Security.* At http://www.dhs.gov/publication/national-strategy-aviation-security.

[4] The Risk Assessment Process for Informed Decision Making (RAPID) 2010 is a strategic level, DHS-wide process to assess risk and inform strategic planning priorities developed by the DHS Office of Risk Management & Analysis (National Protection & Programs Directorate). The RAPID engine is a suite of computational tools for calculating human and economic measures of risk and the relative effectiveness of different DHS programs in risk reduction. Like the SNRA it is a quantitative tool for calculating and comparing risks in the homeland security mission space with each other, but unlike the SNRA it is designed for additionally calculating the comparative effectiveness of different governmental programs in buying down risk.

RAPID has a different event structure breakdown than the SNRA, but its construction from event trees for multiple granular attack modes, for each of which frequencies were elicited separately, permitted the previously elicited frequencies to be separated and re-mapped to the SNRA event set.

[5] Medical costs from E/K/I injuries taken as a class are comparatively well studied and were used as a proxy for medical costs in the Aircraft as a Weapon attack SNRA event.

[6] RAPID 2010, the 2008 Bioterrorism Risk Assessment (BTRA 2008) (the BTRA as a whole is classified Secret, but its economic methodology appendix is U//FOUO).

[7] START is a Department of Homeland Security University Center of Excellence that focuses on social and behavioral aspects of terrorism, natural disasters, and technological accidents, and the social, behavioral, cultural and economic factors influencing responses to and recovery from catastrophes.

[8] Sources for the Aircraft as a Weapon displacement estimates include: Fritsch, Jane (September 12, 2001), "A Day of Terror – The Response: Rescue Workers Rush In, and Many Do Not Return", *New York Times*; and "Boats evacuated one million New Yorkers after WTC attack,"; at http://www.marinelog.com/DOCS/NEWSMM/MMISep19.html. The high estimate may count residents as well as non-resident workers evacuating from Lower Manhattan, and thus may be an overestimate of displacement.

[9] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + ½\ D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events,

this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- The environmental assessment included effects resulting from terrorism threats, but did not include human health effects or effects in urban areas because these effects are already reflected in other consequence measures.
- Experts identified the best estimate for environmental consequences as "Low." Experts indicated that one airplane could cause tens of acres of environmental impact of a limited duration but the identified event would likely occur in an urban environment. Consequences could be elevated to "Medium" depending on the target (e.g., a chemical plant).

Potential Mitigating Factors

The frequency estimates related to this event depend on the ability of potential terrorists to gain access to an airplane through either hostile takeover or other means using illicit documents, or a legal process.

The nature of the consequences is related to the size of the airplane and the ability to direct it to a desired target.

Additional Relevant Information

Table 1 lists the events analyzed and includes total fatalities and injuries for each event.

was provided by subject matter experts for each national-level event included in the SNRA: the Aircraft as a Weapon terrorist attack event was given a C_{EF} of 1.2.

The numerical psychological distress estimates for this event and the complete semi-quantitative risk matrix may be found in Appendix G and the Findings sections, respectively, of the full SNRA Technical Report.

Table 1. List of Analyzed Events

#	Event	Date	Fatalities	Injuries
1	Ramstein Air Show Disaster (Ramstein, Germany)	8/28/1988	70[10]	1,500[11]
2	Flight 1862 Crash (Amsterdam, Netherlands)	10/4/1992	47[12]	26[13]
3	Air France Concorde Crash (Paris, France)	7/25/2000	113[14]	6[15]
4	September 11th Attacks (New York, NY, USA)	9/11/2001	2,753[16]	5,124[17]
5	Small Plane Hits the Pirelli Tower (Milan, Italy)	4/18/2002	3[18]	30[19]
6	Small Plane Crashes in Park (San Dimas, CA, USA)	7/4/2002	4[20]	9[21]
7	Ukraine Air Show Disaster (Lviv, Ukraine)	7/27/2002	77[22]	241[23]
8	Military Plane Crashes into Building (Tehran, Iran)	12/6/2005	115[24]	90[25]
9	Small Plane Hits Apartment Complex (New York, NY, USA)	10/11/2006	2[26]	3[27]
10	Suicide Attack on IRS Building (Austin, TX, USA)	2/18/2010	2[28]	13[29]

(Table in its entirety is UNCLASSIFIED)

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26 "Aircraft Accident Brief." National Transportation Safety Board. July 16, 2011. http://www.ntsb.gov/doclib/reports/2007/AAB0702.pdf.
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29 Ibid.

Armed Assault

A hostile, non-state actor(s) uses assault tactics to conduct strikes on vulnerable target(s) within the U.S., resulting in at least one fatality or injury.

Data Summary

Description	Low	Best	High
Fatalities	See FOUO data sheet		
Injuries and Illnesses			
Direct Economic Loss	See FOUO data sheet		
Indirect Economic Loss			
Total Economic Loss			
Social Displacement[1]	0	2,000	N/A
Psychological Distress	See text		
Environmental Impact[2]	*De minimus*[3]		
Frequency of Events	See classified data sheet		

(UNCLASSIFIED)

Discussion

For the SNRA, the health and safety consequences of a hostile, non-state actor(s) using assault tactics to conduct strikes on vulnerable target(s) was estimated using historical data from the Global Terrorism Database (GTD).[4] To capture the range of terrorist attacks with small arms including large-scale assault/siege-type attacks like the 2008 complex attack in Mumbai, India, historical incidents of successful armed assault and explosives attacks, involving the use of firearms but excluding biological and chemical weapons were included in the data set used to determine fatality and injury estimates. Direct economic damage estimates for incidents of corresponding scope to this historical incident set were calculated using the DHS RAPID 2010 risk modeling engine.[5]

New data about the frequency of successful armed assault attacks in the United States were elicited from Intelligence Community subject matter experts for the SNRA project. An overview of the elicitation process is given in Appendix B: additional details and results may be found in Appendix B of the classified SNRA Technical Report.

Assumptions

Likelihood

Frequency estimates were elicited from the Intelligence Community (IC) by the SNRA project team in July-August 2011.[6] These estimates are classified, but are provided in the data tables of the classified SNRA Technical Report.

Health and Safety

Health and safety information was calculated using historical data from the Global Terrorism Database (GTD). The GTD is an open-source database including information on terrorist events around the world (including domestic, transnational, and international incidents) from 1970 through 2010. For each GTD incident, information is available on the date and location of the incident, the weapons used and nature of the target, the number of casualties, and - when identifiable - the group or individual responsible.[7]

In order to identify events in the GTD database that were most comparable to the definition of a complex attack presented above, the following search criteria were used:

- Attack Type: Armed Assault or Bombing/Explosion
- Weapon Type: Require Firearms; Exclude biological, chemical, radiological, nuclear
- Terrorism Criteria: Require Criteria I,[8] II,[9] and III be met[10]
- Exclude ambiguous cases[11]
- Exclude unsuccessful attacks[12]

Events that produced zero injuries and zero deaths were removed from the resulting set, in order to better meet the "national-level" threshold. All events involving vehicle borne explosives were also removed, in order to order to best fit the definition of the event above. The highest injury-producing event (10,000 injured in Peru) was considered an outlier and removed. In addition, incidents that were part of multi-incident events were aggregated to produce more comprehensive injury/death totals. The resulting set included 10,161 events, which were then used to calculate the minimum, maximum, and mean, which are presented as low, best, and high estimates in the table above.

Economic Loss

Total economic loss to the U.S. economy was estimated using IMPLAN, software for input-output economic modeling. IMPLAN calculates indirect and induced costs to the U.S. economy given inputs of certain direct economic costs. These include business interruption costs, lost demand from fatalities, medical costs, and decontamination, disposal, and property damage (DDP) costs.

Direct economic costs were calculated by the SNRA project team using the following assumptions:

- Business Interruption Costs: The SNRA project team used the business interruption numbers from the DHS RAPID 2010[13] Explosives/ Kinetic/ Incendiary (E/K/I) models for government sector buildings, commercial sector buildings, and national monuments and icons as targets. These densely-populated targets were chosen to best fit the definition of complex attack, as described above. The total costs for business interruption is also a function of the number of targets affected. The SNRA project team chose to use a uniform distribution over 1 to 5 targets. The minimum of 1 was chosen to be sufficient for the definition of complex attack, and the maximum of 5 was based on the number of geographically distinct targets in the 2008 Mumbai attacks. The use of a uniform distribution over this range reflects agnosticism about the relative frequencies between the minimum and maximum—the GTD does not provide information on the number of targets in an event, so the SNRA project team could not create a histogram to inform any judgment on the shape of the distribution between the minimum and maximum.
- Lost Demand from Fatalities: The cost of per fatality loss of demand was based on assumptions from RAPID 2010 and the 2008 Biological Terrorism

[1] The SNRA measure of social displacement was defined as the number of people forced to leave home for a period of two days or longer.
[2] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.
[3] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'Best' estimate.
[4] The Global Terrorism Database (GTD) is an open-source database including information on terrorism events around the world (including domestic, transnational, and international incidents) from 1970 to 2010. For each GTD incident, information is available on the date and location of the incident, the weapons used and nature of the target, the number of casualties, and – when identifiable – the group or individual responsible. National Consortium for the Study of Terrorism and Responses to Terrorism (START) (2011, July). Global Terrorism Database [Data file]: at http://www.start.umd.edu/gtd.
[5] The Risk Assessment Process for Informed Decision Making (RAPID) 2010 is a strategic level, DHS-wide process to assess risk and inform strategic planning priorities developed by the DHS Office of Risk Management & Analysis (National Protection & Programs Directorate). The RAPID engine is a suite of computational tools for calculating human and economic measures of risk and the relative effectiveness of different DHS programs in risk reduction. Like the SNRA it is a quantitative tool for calculating and comparing risks in the homeland security mission space with each other, but unlike the SNRA it is designed for additionally calculating the comparative effectiveness of different governmental programs in buying down risk.
[6] IC participants in the Armed Assault frequency elicitation included subject matter experts from multiple agencies. The frequency estimates reflect the opinion of the group and have not been formally vetted by any of the agencies which participated.

[7] National Consortium for the Study of Terrorism and Responses to Terrorism (START). (2011). Global Terrorism Database [Data file]. Retrieved from: http://www.start.umd.edu/gtd. The GTD is currently the most comprehensive unclassified database on terrorist events in the world, containing information on over 98,000 terrorist attacks with at least 45 to more than 120 variables for each incident. Over 3,500,000 news articles and 25,000 news sources were reviewed to collect incident data from 1998 to 2010 alone. The GTD Database is supervised by an advisory panel of 12 terrorism research experts.
[8] Criterion I states: "The act must be aimed at attaining a political, economic, religious, or social goal."
[9] Criterion II states: "There must be evidence of an intention to coerce, intimidate, or convey some other message to a larger audience (or audiences) than the immediate victims."
[10] Criterion III states: "The action must be outside the context of legitimate warfare activities, i.e. the act must be outside the parameters permitted by international humanitarian law (particularly the admonition against deliberately targeting civilians or non-combatants)."
[11] According to the GTD: "In certain cases there may be some uncertainty whether an incident meets all of the criteria for inclusion." These "ambiguous cases, where there is a strong possibility, but not certainty, that an incident represents an act of terrorism," were excluded.
[12] According to the GTD: "Success of a terrorist strike is defined according to the tangible effects of the attack. For example, in a typical successful bombing, the bomb detonates and destroys property and/or kills individuals, whereas an unsuccessful bombing is one in which the bomb is discovered and defused or detonates early and kills the perpetrators. Success is not judged in terms of the larger goals of the perpetrators. For example, a bomb that exploded in a building would be counted as a success even if it did not, for example, succeed in bringing the building down or inducing government repression."
[13] RAPID has a different event structure breakdown than the SNRA, but its construction from event trees for multiple granular attack modes, for each of which frequencies were elicited separately, permitted the previously elicited frequencies to be separated and re-mapped to the SNRA event set.

Risk Assessment (BTRA). The number of deaths was based on the analysis of events from the GTD database, as described above.

- Medical Costs: The range of medical mitigation costs was based on assumptions for the RAPID 2010 E/K/I incident set. The number of injured was based on the analysis of events from the GTD database, as described above.
- DDP Costs: The SNRA project team used the DDP cost assumptions for an E/K/I man-portable IED from RAPID 2010 for targets including commercial sector buildings, government sector buildings, national monuments and icons, and airports.[14]
  - These costs were then multiplied by a uniform distribution to model DDP costs of an attack equivalent to 0–5 explosions (each equivalent to 65 lbs. TNT), to capture the complex nature of the attack. A minimum of 0 was chosen to be inclusive of events that do not include explosives.
  - The choice of the upper bound was more difficult, as reporting is inconsistent on the number of explosions that occurred during the 2008 Mumbai attack. Furthermore, RAPID 2010 only models the DDP effects of a man-portable IED, not that of a grenade or firearms, which were also used in the Mumbai attack and could be considered inside the scope of a complex attack as defined for this event. The SNRA project team made the analytic assumption that 5 IED equivalents would be the most appropriate upper bound for modeling a comparable event using the RAPID engine.

Based on these assumptions, a Monte Carlo simulation was run, and for each trial the total direct economic loss was calculated. Low, best, and high estimates of direct economic cost represent the trials at the 5th percentile, mean, and 95th percentile of the resulting distribution.

The low, best, and high estimates of direct economic loss were used as inputs to IMPLAN to calculate low, best, and high estimates of indirect and total economic loss.

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

- For the Armed Assault national-level event, the low and best social displacement estimates of 0 and 2,000 respectively reflect subject matter expert judgments provided by the National Consortium for the Study of Terrorism and Responses to Terrorism (START).[15]
- A high estimate was not determined for this event.

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[16] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- The environmental assessment included effects resulting from terrorism threats, but did not include human health effects or effects in urban areas because these effects are already reflected in other consequence measures.
- Experts identified the best estimate for environmental consequences as "*de minimus*." Environmental impacts would be minimal.

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[14] The airport target was not used for the business interruption modeling. While the SNRA project team assumed that DDP costs for a man-portable IED attack at an airport would be representative of DDP costs in a complex attack, the team did not assume that the knock-on implications for business interruption would be similarly representative. The team also noted that all DDP costs for a man-portable IED attack at an airport were within the range already created by DDP values for government buildings, commercial buildings, and monuments. Therefore, the airport DDP numbers only served to add more numbers to sample from. These may or may not have had a significant effect on the mean; however, they did not alter the bounds on the range that the project team sampled from.

[15] START is a Department of Homeland Security University Center of Excellence that focuses on social and behavioral aspects of terrorism, natural disasters, and technological accidents, and the social, behavioral, cultural and economic factors influencing responses to and recovery from catastrophes.

[16] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\,Fat + Inj + ½\,D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: the Armed Assault terrorist attack event was given a C_{EF} of 1.1.

The numerical psychological distress estimates for this event and the complete semi-quantitative risk matrix may be found in Appendix G and the Findings sections, respectively, of the full SNRA Technical Report.

Biological Terrorism Attack (non-food)

A hostile non-state actor(s) acquires, weaponizes, and releases a biological agent against an outdoor, indoor, or water target directed at a concentration of people within the U.S.

Data Summary

Description	Low	Best	High
Fatalities	See classified data sheet		
Injuries and Illnesses	See classified data sheet		
Total Economic Loss	See classified data sheet		
Social Displacement	0	1,800	N/A
Psychological Distress	See classified data sheet		
Environmental Impact	Low[1]		
Frequency of Events	See classified data sheet		

(UNCLASSIFIED)

Event Background

The SNRA considered the risk from a non-food biological attack in which a hostile non-state actor(s) acquires, weaponizes, and releases a biological agent against an outdoor, indoor, or water target with a concentration of people within the United States. Frequency estimates for this event only include data for successful attacks (e.g., detonation of a device or release of an agent). Examples of failed attacks not included in the SNRA include interdiction during the fabrication and assembly of the dissemination device, interdiction during travel to the United States, or failure of the dissemination device.

Biological agents can be isolated from sources in nature, acquired from laboratories or a state bioweapons stockpile, or synthesized or genetically manipulated in a laboratory. Potential dissemination mechanisms of a biological agent by terrorists include aerosol dissemination from sprayers or other devices outdoors or through the ventilation system of a building, subway, or airplane, human carriers, insects or other animal vectors, or physical distribution through the U.S. Mail or other means. Biological agents include transmissible agents that spread from person to person (e.g. smallpox, Ebola) or agents that may cause adverse effects in exposed individuals but which do not make these individuals contagious (e.g. anthrax, botulinium toxin).[2]

Unlike a nuclear or chemical attack, a biological attack may go undetected for hours, days, or potentially weeks (depending on the agent) until humans, animals, or plants show symptoms of disease. If there are no immediate signs of the attack as with the anthrax letters, a biological attack will probably first be detected by local health care workers observing a pattern of unusual illness, or by early warning systems that detect airborne pathogens. There may be uncertainties about crucial facts such as the exact location or extent of the initial release, the type of biological agent used, and likelihood of additional releases. The exact infectious dose (the number of organisms needed to make one sick, referred to as dose response) and the long-term health consequences for those who survive exposure are key scientific knowledge gaps for many biological agents: while approximate ranges and prognoses for humans have been extrapolated from animal studies, they comprise additional uncertainties which may complicate the public health response to a biological attack.[3]

This National-Level Event focuses on non-food biological attacks. Note that the risks of intentional biological food contamination are considered in a separate National-Level Event in the SNRA and should not be considered for this event.

Assumptions

The SNRA leveraged classified data from the DHS/S&T 2011 Integrated Terrorism Risk Assessment (ITRA)[4] for quantitative frequency, fatality, illness/injury, and economic loss estimates for the biological (non-food) terrorism attack event. The data relies heavily on the Intelligence Community (IC) and other technical experts to develop scenarios and estimate the likelihoods of those scenarios for analysis. The DHS Science and Technology Directorate (S&T) extracted ITRA data for biological attacks on targets other than food and agriculture targets for the SNRA project to correspond to the scope of the SNRA biological (non-food) terrorism attack event.

SNRA analysis for this national-level event adopted the definition of a terrorist attack from the Homeland Security Act of 2002, which is any activity that:

- Involves an act that is dangerous to human life or potentially destructive of critical infrastructure or key resources;
- Involves an act that is a violation of the criminal laws of the United States or any State or other subdivision of the United States;
- Appears to be intended to intimidate or coerce a civilian population;
- Appears to be intended to influence the policy of a government by intimidation or coercion; or
- Appears to be intended to affect the conduct of government by mass destruction, assassination, or kidnapping.

In addition to this general definition, SNRA analysis considered the following categories of actors:

- International Terrorist Organizations: Terrorist organizations that operate both inside and outside of the U.S. that are not sponsored by a nation (e.g., al-Qaeda);
- State-Sponsored Terrorist Organizations: Terrorist organizations that operate inside and/or outside of the U.S. that are sponsored by a nation; sponsorship is defined as the provision of technical assistance, equipment, or chemical by a state program (e.g., Hezbollah);
- Domestic Terrorist Organizations: Terrorist organizations that operate only within the U.S. that are not sponsored by a nation (e.g., Animal Liberation Front and Rajneesh);
- Small Groups/Individuals Terrorist Organizations: Small groups (i.e., 2 to 3 members) or individuals that operate only within the U.S. that are not sponsored by a nation (e.g., the Unabomber and Timothy McVeigh).

Biological agents can be classified into different categories and disseminated in different modes (e.g., wet or dry aerosol). The SNRA considers the following categories of biological agents:

- Traditional Biological Agents: Includes bacterial, viral, toxin, and prion agents; these agents are most often considered in biological agent assessments;
- Enhanced Biological Agents: Refers to traditional agents that have been modified to increase the hazard associated with the agent, such as bacterial agents enhanced to be antibiotic resistant;
- Emerging Biological Agents: Includes organisms that were not previously considered significantly pathogenic but are currently recognized for that potential. The Severe Acute Respiratory Syndrome (SARS) is an example of such an agent.[5]

Frequency estimates for this National-level Event only include data for successful attacks, e.g., detonation of a device or release of an agent. Failed attacks are not considered during this assessment process. Examples of failed attacks include interdiction during the fabrication and assembly of the dissemination device, interdiction during travel to United States, or failure of the dissemination device.

The SNRA project team used the definitions of direct, indirect, and induced economic costs given in Table 1 for economic loss estimates of this national-level event.

Table 1. Definitions for Direct, Indirect, and Induced Costs

Direct Costs include:

- **Decontamination, Disposal, and Physical Destruction**: DDP costs covered the repair, replacement and environmental clean-up which are considered expenditures by the government. It was assumed the government would recoup this spending through tax increases, causing a reduction of household spending of that same amount. However, this spending would be received as income by some sectors, such as waste management and environmental consulting services. The increase in spending into the waste management and environmental consulting services is treated as increase in annual output for these sectors.
- **Business Interruption**: Business interruption impacts considered losses due to decreased output at the target area, along with other increases and decreases to related sectors due to behavioral changes resulting from the event.

[1] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'Best' estimate.
[2] National Academies and U.S. Department of Homeland Security (2004). Biological attack: human pathogens, biotoxins, and agricultural threats. Retrieved from http://www.dhs.gov/biological-attack-fact-sheet via http://www.ready.gov.
[3] Ibid.
[4] DHS Directorate of Science & Technology (2011), Integrated CBRN Terrorism Risk Assessment (reference is SECRET//NOFORN).

[5] Bush, George W. (2001, January 31). Homeland Security Presidential Directive/HSPD-18 – Medical Countermeasures against Weapons of Mass Destruction: at http://fas.org/irp/offdocs/nspd/hspd-18.html. HSPD-18, the mandate for the Integrated CBRN Terrorism Risk Assessment (ITRA 2011) which the Biological Attack (non-food) national-level event leverages for its frequency, fatality, illness, and economic consequences data, defined the traditional/enhanced/emerging/advanced agent classification used in characterizing biological terrorism agents.

- **Loss in Spending from Fatalities**: This SNRA project team estimated a loss of spending of $42,500 for each fatality. In addition, $6,000 is included in increased output for mortuary services for each fatality.
- **Medical Costs**: Costs of medical mitigation were considered to be borne through private spending and insurance companies, while the hospital sector received an offsetting increase in output.

Indirect Costs include:

- Costs incurred by the suppliers and vendors in the associated expenditure sectors for the industries impacted by the direct costs above.

Induced Costs include:

- The induced costs are those incurred due to reduced spending by households with members employed in any of the directly or indirectly affected industries. Induced costs can also include substitution effects or likely transfers of economic activity from one set of sectors to another set, such as avoidance of air or other travel or altered transportation mode preferences to other sectors following an attack on the commercial air transport sector.

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

- Low and best estimates of social displacement for the Biological Terrorism Attack (non-food) national-level event were provided by the National Consortium for the Study of Terrorism and Responses to Terrorism (START).[6]
- The low estimate of 0 reflects assessed judgment of START subject matter experts. The best estimate of 1,800 represents the number of people evacuated in a historical outbreak of tuberculosis in East Timor in 1999, used as a proxy estimate for a small-scale but deliberate dissemination of a contagious agent.[7]
- A high estimate for social displacement was not determined for this event.

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[8] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental consequences as "Low." The environmental impact will vary on agent or persistence, but the highest potential would be an increase in animal disease. However, this potential is low given the focus on human diseases. Additionally, the disposal of contaminated waste could result in a higher risk for environmental consequences.

Potential Mitigating Factors

Viable human-health surveillance techniques, to include DHS Bio-Watch detection systems where available, should be employed in order to minimize the time window between attack and start of treatment. Emergency notification systems should be operational, with special care taken to provide the most accurate and current information to hospitals that they may take steps to mitigate surge capacity problems and diagnose patients effectively. The appropriate Prevention/Deterrence, Preparedness, Emergency Assessment/Diagnosis, Emergency Management/Response, Hazard Mitigation, Evacuation/Shelter, Victim Care, Investigation/Apprehension and Recovery/Mediation mission areas should be activated to ensure a comprehensive, integrated response and minimize the impact of an attack.

Weather can have an ameliorating effect on biological agents as humidity, wind currents and ultraviolet radiation may decrease their potency. Therefore, agents are often most harmful when released in enclosed spaces.

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[6] START is a Department of Homeland Security University Center of Excellence that focuses on social and behavioral aspects of terrorism, natural disasters, and technological accidents, and the social, behavioral, cultural and economic factors influencing responses to and recovery from catastrophes.

[7] (Source: Connolly, Maire, 1999. "Communicable Disease Surveillance and Control in East Timor." World Health Organization.) Subject matter experts consulted for the SNRA noted that this estimate is arbitrary given the large range of potential biological attack scenarios; the high estimate could be significantly higher than the best estimate provided if there is a need to decontaminate a large area.

[8] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + ½\ D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: Biological Terrorism Attack (non-food) was given a C_{EF} of 1.3.

The numerical psychological distress estimates for this event and the complete semi-quantitative risk matrix may be found in Appendix G and the Findings sections, respectively, of the full SNRA Technical Report.

Chemical Terrorism Attack (non-food)

A hostile non-state actor(s) acquires, weaponizes, and releases a chemical agent against an outdoor, indoor, or water target directed at a concentration of people, using an aerosol, ingestion, or dermal route of exposure.

Data Summary

Description	Low	Best	High
Fatalities	See classified data sheet		
Injuries and Illnesses	See classified data sheet		
Direct Economic Loss	See classified data sheet		
Indirect Economic Loss	See classified data sheet		
Social Displacement	0	100,000	700,000
Psychological Distress	See classified data sheet		
Environmental Impact[1]	Moderate[2]		
Frequency of Events	See classified data sheet		

(UNCLASSIFIED)

Event Background

The Department of Homeland Security (DHS) and Federal Bureau of Investigations (FBI) define a chemical attack as follows:[3]

> A chemical attack is the spreading of chemicals with the intent to do harm. The Chemical Weapons Convention defines a chemical weapon as "any toxic chemical or its precursor that can cause death, injury, temporary incapacitation, or sensory irritation through its chemical action." A variety of chemicals could be used in an attack, to include toxic commercial and industrial chemicals and warfare agents developed for military use. The chemical could be used in various forms or states—such as gas, liquid, or solid. The toxicity of chemicals varies greatly; some are acutely toxic (causing immediate symptoms) in small doses, others are not toxic at all. Chemicals in liquid or vapor form generally create greater exposure than chemicals in solid form.

Chemical agents can be disseminated in various modes. Potential delivery mechanisms of a chemical agent by terrorists include building ventilation systems, misting or aerosolizing devices, passive release (container of chemical left open), explosives, improvised devices combining readily available chemicals to produce a dangerous chemical, or sabotage of industrial facilities or vehicles containing chemicals.[4]

This National-level Event focuses on non-food chemical attacks. Note that the risks of intentional chemical food contamination are considered in a separate National-level Event in the SNRA and should not be considered for this event.

Assumptions

The SNRA leveraged classified data from the DHS/S&T 2011 Integrated Terrorism Risk Assessment (ITRA)[5] for quantitative frequency, fatality, illness/injury, and economic loss estimates for the chemical (non-food) terrorism attack event. The data relies heavily on the Intelligence Community (IC) and other technical experts to develop scenarios and estimate the likelihoods of those scenarios for analysis. The DHS Science and Technology Directorate (S&T) extracted ITRA data for chemical attacks on non-food targets for the SNRA project, separate from attacks on food and beverage[6] targets, to correspond to the event structure of the SNRA.

The SNRA leveraged data for the classified risk summary sheet that assumed terrorist attack to include the following:

- Involves an act that is dangerous to human life or potentially destructive of critical infrastructure or key resources.
- Involves an act that is a violation of the criminal laws of the United States or any State or other subdivision of the United States.
- Appears to be intended to intimidate or coerce a civilian population.
- Appears to be intended to influence the policy of a government by intimidation or coercion.
- Appears to be intended to affect the conduct of government by mass destruction, assassination, or kidnapping.

The SNRA only includes data for successful attacks for this national-level event (e.g., detonation of a device or release of an agent). Failed attacks (e.g., interdiction during the fabrication and assembly of the dissemination device, interdiction during travel to United States, or failure of the dissemination device) are not considered during this assessment process.

The analysis used broad definitions of organizations that may initiate or represent potential chemical terrorism threats to the U.S., the categories of chemical agents that could be used for an attack, and the targets that may be selected for a chemical attack. The adopted criteria for general categories representing chemical terrorist threats to the U.S. are as follows:

- The International Terrorist Organization category is composed of terrorist organizations that operate both inside and outside of the U.S. that are not sponsored by a nation (e.g., al-Qaeda).
- The State-Sponsored Terrorist Organization category is composed of terrorist organizations that operate inside and/or outside of the U.S. that are sponsored by a nation. Sponsorship is defined as the provision of technical assistance, equipment, or chemical by a state program (e.g., Hezbollah).
- The Domestic Terrorist Organization category is composed of terrorist organizations that operate only within the U.S. that are not sponsored by a nation (e.g., Animal Liberation Front and Rajneesh).
- The Small Groups/Individuals Terrorist Organization category is composed of small groups (i.e., 2 to 3 members) or individuals that operate only within the U.S. that are not sponsored by a nation (e.g., the Unabomber and Timothy McVeigh).

Chemical agents can be acquired from a variety of different sources and disseminated in various modes. The analysis uses data that classifies chemical agents into the following categories:

- Toxic Industrial Materials (TIMs) and Toxic Industrial Chemicals (TICs): Includes toxic substances in solid, liquid, or gaseous form that are used or stored for use for military or commercial purposes. Chlorine is an example of this type of agent.
- Traditional Chemical Warfare Agents (CWAs): Encompasses the range of blood, blister, choking, nerve, and psychotropic agents historically developed for military use. Examples include: sulfur mustard, VX, and sarin.[7]

The SNRA project team used the definitions of direct, indirect, and induced economic costs given in Table 1 to estimate the economic losses for this national-level event.

Table 1. Definitions for Direct, Indirect, and Induced Costs

Direct Costs include: • **Decontamination, Disposal, and Physical Destruction**: DDP costs covered the repair, replacement and environmental clean-up which are considered expenditures by the government. It was assumed the government would recoup this spending through tax increases, causing a reduction of household spending of that same amount. However, this spending would be received as income by some sectors, such as waste management and environmental consulting services. The increase in spending into the waste management and environmental consulting services is treated as increase in annual output for these sectors. • **Business Interruption**: Business interruption impacts considered losses due to decreased output at the target area, along with other increases and decreases to related sectors due to behavioral changes resulting from the event. • **Loss in Spending from Fatalities**: This SNRA project team estimated a loss of spending of $42,500 for each fatality. In addition, $6,000 is included in increased output for mortuary services for each fatality. • **Medical Costs**: Costs of medical mitigation were considered to be borne through private spending and insurance companies, while the hospital sector received an offsetting increase in output.
Indirect Costs include: • Costs incurred by the suppliers and vendors in the associated expenditure sectors for the industries impacted by the direct costs above.
Induced Costs include: • The induced costs are those incurred due to reduced spending by households with members employed in any of the directly or indirectly affected industries. Induced costs can also include substitution effects or likely transfers of economic activity from one set of sectors to another set, such as avoidance of air or other travel or altered transportation mode preferences to other sectors following an attack on the

[1] Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.
[2] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'best' estimate.
[3] "Potential Terrorist Attack Methods: Joint Special Assessment", DHS & FBI, 23 April 2008, p. 15 (Reference is UNCLASSIFIED//FOR OFFICIAL USE ONLY: Extracted information is UNCLASSIFIED).
[4] National Academies and U.S. Department of Homeland Security (2004). Chemical attack: warfare agents, industrial chemicals, and toxins. Retrieved from http://www.dhs.gov/chemical-attack-fact-sheet via http://www.ready.gov.
[5] DHS Directorate of Science & Technology (2011), Integrated CBRN Terrorism Risk Assessment (reference is SECRET//NOFORN).
[6] Water systems such as city and building water supplies are included in the non-food event; attacks using bottled water as a vector are included in the chemical-biological food contamination event.
[7] National Academies, DHS (2004), Chemical attack fact sheet, *op. cit*.

commercial air transport sector.

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

- Social displacement estimates for the Chemical Terrorism Attack (non-food) national-level event were provided by staff researchers and subject matter experts at the National Consortium for the Study of Terrorism and Responses to Terrorism (START).[8]
- The low estimate of 0 reflects assessed judgment of START subject matter experts. The best and high estimates of 100,000 and 700,000 respectively represent estimated evacuation and dispersal numbers in two modeled chemical attack scenarios in the literature: an attack with a blister agent aimed at a large gathering such as a football game (best), and a terrorist attack against a petroleum plant using explosives to cause a catastrophic release of toxic industrial chemicals (high).[9]

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[10] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- The environmental assessment included effects resulting from terrorism threats, but did not include human health effects or effects in urban areas because these effects are already reflected in other consequence measures.
- Experts identified the best estimate for environmental consequences as "Moderate." Experts indicated that the consequences will most likely be localized as effects will require direct exposure to the chemical. Aquatic runoff could disseminate certain chemicals and increase the impact on the environment. Defining variables that will determine whether or not the consequences are increased or decreased include toxicity, spread, and the persistence of the chemical agent used in the attack.

[8] START is a Department of Homeland Security University Center of Excellence that focuses on social and behavioral aspects of terrorism, natural disasters, and technological accidents, and the social, behavioral, cultural and economic factors influencing responses to and recovery from catastrophes.
[9] Bea, Keith. 2005. "National Preparedness System: Issues in the 109th Congress." CRS Report for Congress. March 10, 2005.
[10] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + \frac{1}{2} D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.
The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: Chemical Terrorism Attack (non-food) was given a C_{EF} of 1.3.
The numerical psychological distress estimates for this event and the complete semi-quantitative risk matrix may be found in Appendix G and the Findings sections, respectively, of the full SNRA Technical Report.

Potential Mitigating Factors

Hazardous Material (HazMat) Teams should be prepared to quickly dispatch to the target site and detect/identify the chemical agent deployed in the attack. This will determine the response steps necessary to mitigate consequences from a particular chemical agent. The hazard should be isolated and cordoned in order to prevent spreading the agent by fleeing victims. Additionally, the evacuation effort should include populations downwind from the explosion (chemical agent dependent) and emphasize at-risk or special populations in order to enhance mitigation efforts. Planners should note the importance of effective communication during the response effort to inform the public about evacuation routes, contaminated areas, and potential victims who may have experienced exposure to the chemical agent.

Additional Relevant Information

The severity of an attack is related to the toxicity of the chemical and its concentration when it reaches people. Many variables affect the concentration of a chemical, including the volatility of the chemical and environmental conditions.

The release of toxic chemicals in closed spaces, such as subways, airports, and financial centers, could deliver doses high enough to injure or kill a large number of people. A volatile chemical will disperse to fill the space. The smaller the space, the greater the concentration of the chemical.

In an open area, a toxic chemical cloud (plume) would become less concentrated as it spreads and would have to be released in large quantities to produce many casualties. The area affected would depend upon such factors as the type and amount of chemical agent, the means of dispersal, the local topography, and the local weather conditions. A toxic cloud would spread roughly with the speed and direction of the wind. For a highly toxic chemical, lethal or immediately life-threatening results could be seen close to the release point of the agent where its concentration is highest. However, the concentration of the chemical, and consequently its human health risk, would be greatly diminished at distances far from the source.[11]

[11] National Academies and U.S. Department of Homeland Security (2004), *op. cit.*

Chemical/Biological Food Contamination Terrorism Attack

A hostile non-state actor(s) acquires, weaponizes, and disperses a biological or chemical agent into food supplies within the U.S. supply chain.

Data Summary

Description	Low	Best	High
Fatalities	See classified data sheet		
Injuries and Illnesses	See classified data sheet		
Direct Economic Loss	See classified data sheet		
Indirect Economic Loss	See classified data sheet		
Social Displacement	0	N/A	N/A
Psychological Distress	See classified data sheet		
Environmental Impact[1]	Low[2]		
Frequency of Events	See classified data sheet		

(UNCLASSIFIED)

Event Background

The SNRA considered biological and chemical attacks on the food supply chain in this event.

A terrorist attack on the Nation's food supply chain using chemical or biological agents may initially be indistinguishable from an unintentional food contamination. Depending on the type of agent used in the attack, it could take several days for individuals to show symptoms and possibly weeks before public health, food, and medical authorities suspect terrorism as the source.[3] In 1984 members of the Rajneeshees, a religious community in an accelerating political dispute with the Oregon county where they had established their commune, deliberately contaminated salad bars at eight county restaurants with *Salmonella* bacteria, infecting or sickening 751 people and hospitalizing 45.[4] However, deliberate contamination was not identified until a year later, when the commune collapsed and criminal investigations into its other activities uncovered its clandestine biological laboratories.[5,6]

Chemical and biological weapons differ in potential toxicity, specificity, speed of action, duration of effect, controllability, and residual effects. Children, the elderly, pregnant women, and immune-compromised individuals are particularly susceptible to the adverse effects of a chemical/biological food contamination.[7,8]

This National-level Event focuses on chemical and biological attacks targeting food supplies within the U.S. supply chain. Note that the risks of chemical and biological attacks aimed at non-food targets are considered in separate National-level Events in the SNRA and should not be considered for this event.

Assumptions

The SNRA leveraged classified data from the DHS/S&T 2011 Integrated Terrorism Risk Assessment (ITRA)[9] for quantitative frequency, fatality, illness/injury, and economic loss estimates for the chemical/biological food contamination terrorism attack event. The data relies heavily on the Intelligence Community (IC) and other technical experts to develop scenarios and estimate the likelihoods of those scenarios for analysis. The DHS Science and Technology Directorate (S&T) extracted ITRA data for chemical and biological attacks on food and beverage targets to permit analysis of chemical-biological food attacks as a national-level event in the SNRA distinct from attacks on non-food targets.

The SNRA leveraged data for the classified risk summary sheet that assumed terrorist attack to include the following:

- Involves an act that is dangerous to human life or potentially destructive of critical infrastructure or key resources;
- Involves an act that is a violation of the criminal laws of the United States or any State or other subdivision of the United States;
- Appears to be intended to intimidate or coerce a civilian population;
- Appears to be intended to influence the policy of a government by intimidation or coercion; or
- Appears to be intended to affect the conduct of government by mass destruction, assassination, or kidnapping.

The SNRA only includes data for successful attacks for this national-level event, e.g., detonation of a device or release of an agent. Failed attacks are not considered during this analysis (e.g., interdiction during the fabrication and assembly of the dissemination device, interdiction during travel to United States, or failure of the dissemination device).

The analysis used broad definitions of organizations that may initiate or represent potential chemical or biological terrorism threats to the U.S. supply chain, the categories of chemical agents that could be used for an attack, and the targets that may be selected for a chemical attack. The adopted criteria for general categories representing chemical/biological food terrorist threats to the U.S. are as follows:

- The International Terrorist Organization category is composed of terrorist organizations that operate both inside and outside of the U.S. that are not sponsored by a nation (e.g., al-Qaeda).
- The State-Sponsored Terrorist Organization category is composed of terrorist organizations that operate inside and/or outside of the U.S. that are sponsored by a nation. Sponsorship is defined as the provision of technical assistance, equipment, or chemical by a state program (e.g., Hezbollah).
- The Domestic Terrorist Organization category is composed of terrorist organizations that operate only within the U.S. that are not sponsored by a nation (e.g., Animal Liberation Front and Rajneesh).
- The Small Groups/Individuals Terrorist Organization category is composed of small groups (i.e., 2 to 3 members) or individuals that operate only within the U.S. that are not sponsored by a nation (e.g., the Unabomber and Timothy McVeigh).

The SNRA project team used the following assumptions identified in Table 1 to estimate the economic losses for this national-level event.

Table 1: Definitions for Direct, Indirect, and Induced Costs

Direct Costs include:

- **Decontamination, Disposal, and Physical Destruction**: DDP costs covered the repair, replacement and environmental clean-up which are considered expenditures by the government. It was assumed the government would recoup this spending through tax increases, causing a reduction of household spending of that same amount. However, this spending would be received as income by some sectors, such as waste management and environmental consulting services. The increase in spending into the waste management and environmental consulting services is treated as increase in annual output for these sectors.
- **Business Interruption**: Business interruption impacts considered losses due to decreased output at the target area, along with other increases and decreases to related sectors due to behavioral changes resulting from the event.
- **Loss in Spending from Fatalities**: This SNRA project team estimated a loss of spending of $42,500 for each fatality. In addition, $6,000 is included in increased output for mortuary services for each fatality.
- **Medical Costs**: Costs of medical mitigation were considered to be borne through private spending and insurance companies, while the hospital sector received an offsetting increase in output.

[1] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rakings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.

[2] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'best' estimate.

[3] Federal Emergency Management Agency (August 2008), Food and Agricultural Incident Annex, p. 2, at http://www.fema.gov/pdf/emergency/nrf/nrf_FoodAgricultureIncidentAnnex.pdf (retrieved January 2015).

[4] This was to test a plan to poison the county water supply on Election Day, to suppress voter turnout and enable the group to take over the county board by electing their own candidates. Török et al (1997, August 6). A large community outbreak of Salmonellosis caused by intentional contamination of restaurant salad bars. *Journal of the American Medical Association (JAMA)* 278(5) 389-395; at http://www.cdc.gov/phlp/docs/forensic_epidemiology/Additional%20Materials/Articles/Torok%20et%20al.pdf (retrieved May 2014). Although unsuccessful in identifying deliberate action as the cause of the poisoning, CDC and FBI investigations following the incident may have deterred the group from carrying out their planned Election Day attack in November. Sobel et al (2002, March 9). Threat of a biological attack on the US food supply: the CDC perspective. *Lancet* 359(9309) 874-880.

[5] Török et al, *op cit.*

[6] Carus, W. Seth (2001, February). Bioterrorism and biocrimes: the illicit use of biological agents since 1900. Pages 50-58. National Defense University; at http://www.ndu.edu/centercounter/full_doc.pdf (retrieved March 2013). Agents experimented with included *Salmonella typhimurium*, the variant which was used in the salad bar attacks, *Salmonella typhi* which causes hepatitis and typhoid fever, *Giardia*, HIV, and multiple chemical and pharmaceutical poisons. *Giardia lamblia* was to be introduced into the county water supply via dead rats and beavers, which carry the parasite (p. 54).

[7] United Nations (1970). Chemical and Bacteriological (Biological) Weapons and the Effects of Their Possible Use, p. 12. Report of the Secretary-General, UN Publication no. E.69.I.24. Reprinted by Ballantine Books, 1970.

[8] FEMA (2008), *op. cit.*

[9] DHS Directorate of Science & Technology (2011), Integrated CBRN Terrorism Risk Assessment (reference is SECRET//NOFORN).

Indirect Costs include: • Costs incurred by the suppliers and vendors in the associated expenditure sectors for the industries impacted by the direct costs above.
Induced Costs include: • The induced costs are those incurred due to reduced spending by households with members employed in any of the directly or indirectly affected industries. Induced costs can also include substitution effects or likely transfers of economic activity from one set of sectors to another set, such as avoidance of air or other travel or altered transportation mode preferences to other sectors following an attack on the commercial air transport sector.

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

- Subject matter experts from the National Consortium for the Study of Terrorism and Responses to Terrorism (START)[10] judged that although a terrorist chemical or biological attack against the food chain could sicken or kill many people, it was unlikely to force people to evacuate or leave their homes. Note that deaths and unplanned hospital stays are not considered social displacement for the purposes of the SNRA.

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[11] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- The environmental assessment included effects resulting from terrorism threats, but did not include human health effects or effects in urban areas because these effects are already reflected in other consequence measures.
- Experts identified the best estimate for environmental consequences as "low." Experts indicated that this hazard is directed towards humans leading the environmental consequences to be minimal. If the agent is introduced into an agricultural setting, there could be consequences for the local ecosystem. Waste disposal is one of the primary concerns and depending on the volume of material this could lead to more significant environmental consequences.

Potential Mitigating Factors

Population exposure can be limited with fast and accurate identification of the agent and vehicle (water, milk, lettuce, etc.) utilized to target the food supply system. A prepared public communications plan will assist in further limiting the spread, while also mitigating the economic losses associated with falsely identifying the food supply contaminant.

Additional References

Khan et al (2001). Precautions against biological and chemical terrorism directed at food and water supplies. *Public Health Review* 116 (January-February 2001) 3-14.

Mohtadi et al (2009). Risk analysis of chemical, biological, or radionuclear threats: implications for food security. *Risk Analysis* 29(9) 1317-1335.

World Health Organization (2008, May). Terrorist threats to food: Guidance for establishing and strengthening prevention and response systems. At http://www.who.int/foodsafety/publications/fs_management/terrorism/en/ (checked April 2013).

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[10] START is a Department of Homeland Security University Center of Excellence that focuses on social and behavioral aspects of terrorism, natural disasters, and technological accidents, and the social, behavioral, cultural and economic factors influencing responses to and recovery from catastrophes.

[11] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\,Fat + Inj + \tfrac{1}{2}\,D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: Chemical/Biological Food Contamination Terrorism Attack was given a C_{EF} of 1.3.

The numerical psychological distress estimates for this event and the complete semi-quantitative risk matrix may be found in Appendix G and the Findings sections, respectively, of the full SNRA Technical Report.

Explosives Terrorism Attack

A hostile non-state actor(s) deploys a man-portable improvised explosive device (IED), vessel IED, or VBIED (Vehicle-borne IED) in the U.S. against a concentration of people, and/or structures such as critical commercial or government facilities, transportation targets, or critical infrastructure sites, etc., resulting in at least one fatality or injury.

Data Summary

Description	Low	Best	High
Fatalities[1]	See FOUO data sheet		
Injuries and Illnesses[2]			
Direct Economic Loss	See FOUO data sheet		
Indirect Economic Loss[3]			
Social Displacement	0	5,000	N/A
Psychological Distress	See text		
Environmental Impact[4]	Low[5]		
Frequency of Events[6]	See classified data sheet		

(UNCLASSIFIED)

Event Background[7]

An improvised explosive device (IED) attack is the use of a "homemade" bomb and/or destructive device to destroy, incapacitate, harass, or distract. IEDs are used by criminals, vandals, terrorists, suicide bombers, and insurgents. Because they are improvised, IEDs can come in many forms, ranging from a small pipe bomb to a sophisticated device capable of causing massive damage and loss of life. IEDs can be carried or delivered in a vehicle; carried, placed, or thrown by a person; delivered in a package; or concealed on the roadside. The term IED came into common usage during the Iraq War that began in 2003.

IEDs consist of a variety of components that include an initiator, switch, main charge, power source, and a container. IEDs may be surrounded by or packed with additional materials or "enhancements" such as nails, glass, or metal fragments designed to increase the amount of shrapnel propelled by the explosion. Enhancements may also include other elements such as hazardous materials. An IED can be initiated by a variety of methods depending on the intended target.

Many commonly available materials, such as fertilizer, gunpowder, and hydrogen peroxide, can be used as explosive materials in IEDs (see Table 1). Explosives must contain a fuel and an oxidizer, which provides the oxygen needed to sustain the reaction. A common example is ANFO, a mixture of ammonium nitrate, which acts as the oxidizer, and fuel oil (the fuel source). Concern about the use of explosives created from liquid components that can be transported in a stable form and mixed at the site of attack is the reason that in 2006 the U.S. Department of Homeland Security restricted the amount of liquids that passengers can carry on commercial aircraft.

Table 1. Examples of explosives

	Common uses	Common form	Known IED use
High explosives (HE)			
Ammonium nitrate and fuel oil (ANFO)	Mining and blasting[8]	Solid	Oklahoma City bombing
Triacetone Triperoixide (TATP)	No common uses; mixed from other materials	Crystalline solid	2005 bombings in London
Semtex, C-4	Primarily military	Plastic solid	Irish Republican Army bombings
Ethylene glycol dinitrate (EGDN)	Component of low-freezing dynamite	Liquid	Millennium Bomber, intended for Los Angeles airport, 1999
Urea nitrate	Fertilizer	Crystalline solid	World Trade Center 1993
Low explosive			
Smokeless powder	Ammunition	Solid	Olympic Park bombings

The extent of damage caused by an IED depends on its size, construction, and placement, and whether it incorporates a high explosive or propellant. Table 2 predicts the damage radius based on the volume or weight of explosive (TNT equivalent) and the type of bomb. Vehicle bombs, also known as vehicle-borne IEDs, can carry significantly more explosive material, and therefore do more damage.

Table 2. Damage radius

Threat description	Explosive Capacity (High Explosives Only)	Building Evacuation distance	Outdoor evacuation distance
Small package/letter	1 lb	40 ft	900 ft
Pipe bomb	5 lb	70 ft	1,200 ft
FedEx package	10 lb	90 ft	1,080 ft
Vest/container bombs	20 lb	110 ft	1,700 ft
Parcel package	50 lb	150 ft	1,850 ft
Compact car	500 lb	320 ft	1,900 ft
Full size car/minivan	1,000 lb	400 ft	2,400 ft
Van/SUV/pickup truck	4,000 lb	640 ft	3,800 ft
Delivery truck	10,000 lb	860 ft	5,100 ft

An explosion in or near a building or public transportation venue may blow out windows; destroy walls; and shut down building systems such as power, ventilation, fire suppression, water/sewage, and others. Exit routes may be disrupted or destroyed, and smoke and dust may travel upward through stairways and elevator shafts, making navigation difficult. Building failure may result in the release of hazardous materials used within a building, such as radioactive material from medical devices, or incorporated within the structure of a building, such as asbestos insulation. An IED attack may cause disruptions in municipal services such as electricity, water, communications, and transportation, which may continue for days to weeks after the attack. Individuals and businesses should have a plan for addressing these interruptions.

A known bomber tactic is to use a distraction, such as gunfire, small bombs, or other surprises, to attract bystanders to a window, a doorway, or outside, and then to detonate a second destructive device at the gathering point. In an attack, there may be bombings at multiple locations. Rescue efforts can be hampered by the need to respond to more than one site.

The explosion of a bomb can cause secondary explosions if gasoline, natural gas, or other flammable material is ignited. Secondary hazards that result can include fire with possibly toxic smoke, disruption of electric power, ruptured natural gas lines and water mains, and debris. There can be loss of traffic control in the area of the blast with possible traffic accidents involving fleeing citizens.

Explosions create a high-pressure blast that sends debris flying and lifts people off the ground. The type of injuries and the number of people hurt will vary depending on: the physical environment and the size of the blast;

[1] Minimum, mean, and maximum values from GTD. See Discussion for search parameters.
[2] Minimum, mean, and maximum values from GTD. See Discussion for search parameters.
[3] Based on IMPLAN analysis and updated with information from GTD. See Discussion for details.
[4] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.
[5] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'Best' estimate.
[6] 5th percentile, mean, and 95th percentile of residual threat values from RAPID 2010. See Discussion for details.
[7] This section is substantially adapted from National Academies and U.S. Department of Homeland Security (2004), IED attack: improvised explosive devices. Retrieved from http://www.dhs.gov/ied-attack-fact-sheet.

[8] Ammonium nitrate (without fuel oil) is used as fertilizer.

the amount of shielding between victims and the blast; fires, or structural damage that result from the explosion; and whether the explosion occurs in a closed space or an open area. Injuries common to explosions include:

- **Overpressure damage** to the lungs, ears, abdomen, and other pressure-sensitive organs. Blast lung injury, a condition caused by the extreme pressure of a HE explosion, is the leading cause of illness and death for initial survivors of an explosion.
- **Fragmentation injuries** caused by projectiles thrown by the blast – material from the bomb, shrapnel, or flying debris that penetrates the body and causes damage.
- **Impact injuries** caused when the blast throws a victim into another object, i.e. fractures, amputation, and trauma to the head and neck.
- **Thermal injuries** caused by burns to the skin, mouth, sinus, and lungs.
- Other injuries including exposure to toxic substances, crush injuries, and aggravation of pre-existing conditions (asthma, congestive heart failure, etc.).

Some health effects caused by IEDs, including eye injuries and abdominal injuries, may not be apparent initially, but can cause symptoms and even fatalities hours to months after the event. Psychological effects in attack survivors, first responders, and others are not unusual in the aftermath of a high-casualty event. While most symptoms diminish with time, in some cases assistance and guidance from mental health professionals may be required.

Methodology and Assumptions

Likelihood

Frequency estimates used for the Aircraft as a Weapon and Explosives Terrorism Attack events in the SNRA were elicited from DHS subject matter experts in late 2009 - early 2010 by the DHS/NPPD Office of Risk Management & Analysis (RMA) for the RAPID 2010 assessment.[9] These estimates are classified, but are provided in the data tables of the classified SNRA Technical Report.

Health and Safety

Health and safety consequence estimates were calculated from the Global Terrorism Database (GTD). The GTD is an open-source database including information on terrorist events around the world (including domestic, transnational, and international incidents) from 1970 through 2010. The GTD is currently the most comprehensive unclassified data base on terrorist events in the world, containing information on over 98,000 terrorist attacks with at least 45 to more than 120 variables for each incident. Over 3,500,000 news articles and 25,000 news sources were reviewed to collect incident data from 1998 to 2010 alone. The GTD Database is supervised by an advisory panel of 12 terrorism research experts.

In order to identify events in the GTD that were most comparable to the definition of the Explosive National-level Event the following search criteria were used:

- Attack Type: Bombing/Explosion
- Weapon Type: Explosives/Bombs/Dynamite OR Incendiary
- Require Criteria I[10], II[11], III[12] be met, with ambiguous cases[13] excluded
- Exclude unsuccessful attacks[14]
- Target Type: limited to Airports and Airlines, Business, Government (Diplomatic), Government (General), Military, Other, Telecommunication, Tourists, Transportation, Unknown, Utilities

In addition to the search criteria listed above, events in the GTD that killed 0 persons AND wounded 0 persons were excluded for the purpose of estimating Health and Safety consequences. The minimum, mean, and maximum values of the number of fatalities and injuries associated with the incidents that met the GTD search criteria were gathered to populate the risk characteristics table above.

Economic

The SNRA Project team used the GTD to calculate economic consequences for an explosives event:

- Total economic loss to the U.S. economy was estimated using indirect and induced costs to the U.S. economy given inputs of several direct economic costs, namely, business interruption costs, lost demand from fatalities, medical costs, and decontamination, disposal, and property damage (DDP) costs.
- To estimate these direct costs, injury and fatality information from the GTD was combined with estimates from previous assessments. For some events, the GTD records "Property Damage" which includes any reported direct costs of the event. While these values were not directly used in the modeling process, they were compared to other assessments' estimates for the purpose of validation.
- Business Interruption and DDP Costs: Assumptions for Man-Portable IED, Vessel IED, and VBIED weapon types against all target classes were used.
- Lost Demand from Fatalities: Data on the number of fatalities per incident was gathered from the GTD and combined with the assumption of a $42,500 per fatality cost.
- Medical Costs: Data on the number of injuries per incident was gathered from the GTD and combined with the RAPID assumption of a U ($13,490, $122,802)[15] per injury cost.

For comparison, total economic loss to the U.S. economy resulting from the 1993 bombing at the World Trade Center has been estimated at $1 billion.[16] Economic loss resulting from the 1995 bombing in Oklahoma City has been estimated at $414 million. This figure includes $234 million in physical loss, $54 million in loss of income from worker fatalities and injuries, $67 million in business interruption losses, and $59 million in resources reallocated to recovery efforts.

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

- Low and best estimates of social displacement for the Explosives Terrorism Attack national-level event were provided by the National Consortium for the Study of Terrorism and Responses to Terrorism (START).[17]
- The low estimate of 0 reflects assessed judgment of START subject matter experts. The best estimate of 5,000 reflects subject matter expert judgment based on an evacuation radius of several blocks from a deliberately set improvised explosive device (IED).
- A high estimate for social displacement was not determined for this event.

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based

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[9] In order to leverage previous DHS risk assessments, likelihood estimates were calculated using the Risk Assessment Process for Informed Decision Making (RAPID) 2010. Specific weapon types were identified that were most comparable to the definition of the Explosive National-level Event.
RAPID is a strategic level, DHS-wide process to assess risk and inform strategic planning priorities developed by the DHS Office of Risk Management & Analysis (National Protection & Programs Directorate). The RAPID engine is a suite of computational tools for calculating human and economic measures of risk and the relative effectiveness of different DHS programs in risk reduction. Like the SNRA it is a quantitative tool for calculating and comparing risks in the homeland security mission space with each other, but unlike the SNRA it is designed for additionally calculating the comparative effectiveness of different governmental programs in buying down risk.
RAPID has a different event structure breakdown than the SNRA. However, its construction from event trees for multiple granular attack modes, for each of which frequencies were elicited separately, permitted the previously elicited frequencies to be separated and re-mapped to the SNRA event set.
Likelihood estimates in the classified version of this summary sheet were calculated using residual threat values from RAPID 2010 for the weapon types corresponding to the SNRA Explosives Terrorism Attack national-level event (see event definition). Residual threat is estimate of the likelihood of a successful attack. It is a weighted average that incorporates adversary preferences among the different attack scenarios as well as the ability of DHS and non-DHS programs to detect and interdict these attacks.

[10] Criteria I states: "The act must be aimed at attaining a political, economic, religious, or social goal."

[11] Criteria II states: "There must be evidence of an intention to coerce, intimidate, or convey some other message to a larger audience (or audiences) than the immediate victims."

[12] Criteria III states: "The action must be outside the context of legitimate warfare activities, i.e. the act must be outside the parameters permitted by international humanitarian law (particularly the admonition against deliberately targeting civilians or non-combatants)."

[13] According to the GTD: "In certain cases there may be some uncertainty whether an incident meets all of the criteria for inclusion." These "ambiguous cases, where there is a strong possibility, but not certainty, that an incident represents an act of terrorism," have been excluded.

[14] According to the GTD: "Success of a terrorist strike is defined according to the tangible effects of the attack. For example, in a typical successful bombing, the bomb detonates and destroys property and/or kills individuals, whereas an unsuccessful bombing is one in which the bomb is discovered and defused or detonates early and kills the perpetrators. Success is not judged in terms of the larger goals of the perpetrators. For example, a bomb that exploded in a building would be counted as a success even if it did not, for example, succeed in bringing the building down or inducing government repression."

[15] A uniform distribution over the interval [13,490, 122,802].

[16] U.S. House of Representatives (March 10, 1993) WORLD TRADE CENTER BOMBING. Congressional Record. [Online] http://www.fas.org/irp/congress/1993_cr/h930310-terror.htm.

[17] START is a Department of Homeland Security University Center of Excellence that focuses on social and behavioral aspects of terrorism, natural disasters, and technological accidents, and the social, behavioral, cultural and economic factors influencing responses to and recovery from catastrophes.

on the type of event, but as a secondary input.[18] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- The environmental assessment included effects resulting from terrorism threats, but did not include human health effects or effects in urban areas because these effects are already reflected in other consequence measures.
- Experts identified the best estimate for environmental consequences as "Low." Experts explained that the overall environmental consequences are low, but that they could become more severe if a water treatment plant or chemical plant were targeted.

Additional References

FBI Bomb Data Center (1999). *1998 Bombing Incidents*. General Information Bulletin 98-1, Federal Bureau of Investigation, U.S. Department of Justice.

North et al (1999, August 23). Psychiatric disorders among survivors of the Oklahoma City bombing. *Journal of the American Medical Association* 282(8) 755-762.

Verger et al (2004, August). The psychological impact of terrorism: an epidemiologic study of posttraumatic stress disorder and associated factors in victims of the 1995-1996 bombings in France. *American Journal of Psychiatry* 161(8) 1384-1389.

[18] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + \frac{1}{2} D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: Explosives Terrorist Attack was given a C_{EF} of 1.2.

The numerical psychological distress estimates for this event and the complete semi-quantitative risk matrix may be found in Appendix G and the Findings sections, respectively, of the full SNRA Technical Report.

Nuclear Terrorism Attack

A hostile non-state actor(s) acquires an improvised nuclear weapon through manufacture from fissile material, purchase, or theft, and detonates it within a major U.S. population center.

Data Summary

Description	Low	Best	High
Fatalities		See classified data sheet	
Injuries and Illnesses		See classified data sheet	
Direct Economic Loss		See classified data sheet	
Indirect Economic Loss		See classified data sheet	
Social Displacement	330,000	2 million	3 million
Psychological Distress		See text	
Environmental Impact[1]		High[2]	
Frequency of Events		See classified data sheet	

(UNCLASSIFIED)

Event Background

The Department of Homeland Security (DHS) and Federal Bureau of Investigations (FBI) define a nuclear attack as follows:

> A nuclear weapon is a device with explosive power resulting from the release of energy unleashed by the splitting of nuclei of a heavy chemical element, such as plutonium or uranium (fission), or by the fusing of nuclei from a light element, such as hydrogen (fusion). Fusion (thermonuclear) bombs can be significantly more powerful than fission bombs, but are at this point believed to be beyond the capability of terrorists to construct.[3]

A successful nuclear attack would cause substantial fatalities, injuries, and infrastructure damage from the heat and blast of the explosion, and significant radiological consequences from both the initial nuclear radiation and the radioactive fallout that settles after the initial event. A nuclear detonation in a modern urban area would impact the medical system more than any disaster previously experienced by the Nation.[4] An electromagnetic pulse from the explosion could also disrupt telecommunications and power distribution. Significant economic, social, psychological, and environmental impacts would be expected.[5]

Nuclear explosions are classified by yield, or the amount of energy they produce, relative to how many tons of TNT would be needed to produce an equivalent explosive yield. Strategic nuclear weapon systems held by state actors deliver weapons with yields in the multi-hundred kilotons to megaton (1,000 kiloton) range. Generally, when considering nuclear explosion scenarios perpetrated by terrorists, experts assume a low-yield nuclear device detonated at ground level, where low yield in this context ranges from factions of a kiloton (kT) to 10 kT.[6] This is still orders of magnitude greater than conventional explosives which may be used in a terrorist attack: for comparison, the 1995 Oklahoma City bombing was equivalent to 2 tons of TNT, or 0.002 kilotons.[7]

There are two general types of nuclear weapons a terrorist may acquire and use: illicitly acquired weapons produced by nation-states and improvised nuclear devices (INDs).

- The former are designed, constructed, and usually tested using the resources of a sovereign state. They are typically reliable, high-yield weapons designed for a delivery vehicle, such as an aircraft or missile.
- An IND, by contrast, would be a crude nuclear device built from components of a stolen weapon or from scratch using nuclear material. The primary obstacle to terrorists attempting to construct a viable IND is obtaining the weapons-grade fissile material – plutonium, highly enriched uranium, or a stolen state-manufactured weapon – needed to produce a nuclear explosion.
- Crude nuclear weapons are typically heavy, ranging from a few hundred pounds to several tons. Smaller, specially designed systems such as the so-called suitcase nuclear weapons are much lighter but more technically difficult to produce.[8]

Assumptions

The SNRA leveraged classified data from the DHS/S&T 2011 Integrated Terrorism Risk Assessment (ITRA)[9] for quantitative frequency, fatality, illness/injury, and economic loss estimates for the nuclear terrorism attack event. The data relies heavily on the Intelligence Community (IC) and other technical experts to develop scenarios and estimate the likelihoods of those scenarios for analysis. The DHS Science and Technology Directorate (S&T) extracted ITRA data for successful terrorist attacks corresponding to the five CBRN national-level events in the SNRA.

The SNRA leveraged data for the classified risk summary sheet that assumed terrorist attack to include the following:

- Involves an act that is dangerous to human life or potentially destructive of critical infrastructure or key resources;
- Involves an act that is a violation of the criminal laws of the United States or any State or other subdivision of the United States;
- Appears to be intended to intimidate or coerce a civilian population;
- Appears to be intended to influence the policy of a government by intimidation or coercion;
- Appears to be intended to affect the conduct of government by mass destruction, assassination, or kidnapping.

Nine U.S. cities were considered in calculating the probabilities and consequences of the attack. The cities were chosen to sample a variety of locations and population densities and included New York, Washington, Houston, and Miami. Impacts of the attack were evaluated for four yields across the nine cities and were evaluated 12 times throughout the year to sample atmospheric conditions at detonation.

The SNRA project team used the following assumptions identified in Table 1 to estimate the economic losses for this national-level event.

Table 1. Definitions for Direct, Indirect, and Induced Costs

Direct Costs include:
• **Decontamination, Disposal, and Physical Destruction:** DDP costs covered the repair, replacement and environmental clean-up which are considered expenditures by the government. It was assumed the government would recoup this spending through tax increases, causing a reduction of household spending of that same amount. However, this spending would be received as income by some sectors, such as waste management and environmental consulting services. The increase in spending into the waste management and environmental consulting services is treated as increase in annual output for these sectors. • **Business Interruption:** Business interruption impacts considered losses due to decreased output at the target area, along with other increases and decreases to related sectors due to behavioral changes resulting from the event. • **Loss in Spending from Fatalities:** This SNRA project team estimated a loss of spending of $42,500 for each fatality. In addition, $6,000 is included in increased output for mortuary services for each fatality. • **Medical Costs:** Costs of medical mitigation were considered to be borne through private spending and insurance companies, while the hospital sector received an offsetting increase in output.
Indirect Costs include:
• Costs incurred by the suppliers and vendors in the associated expenditure sectors for the industries impacted by the direct costs above.
Induced Costs include:
• The induced costs are those incurred due to reduced spending by households with members employed in any of the directly or indirectly affected industries. Induced costs can also include substitution effects or likely transfers of economic activity from one set of sectors to another set, such as avoidance of air or other travel or altered transportation mode preferences to other sectors following an attack on the commercial air transport sector.

[1] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.
[2] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'best' estimate.
[3] "Potential Terrorist Attack Methods: Joint Special Assessment", DHS & FBI, 23 April 2008, p. 36. (Reference is (UNCLASSIFIED//FOR OFFICIAL USE ONLY): Extracted information is UNCLASSIFIED.)
[4] National Security Staff Interagency Policy Coordination Subcommittee for Preparedness and Response to Radiological and Nuclear Threats.(2010, June), *Planning Guidance for Response to a Nuclear Detonation* (2nd ed), p. 81.
[5] National Academies, U.S. Department of Homeland Security (2005). Nuclear attack. Fact sheet for the public (series, Communicating in a Crisis). Retrieved from http://www.dhs.gov/xlibrary/assets/prep_nuclear_fact_sheet.pdf via http://www.ready.gov (checked April 2015).
[6] It should be noted that if a state-built weapon were available to terrorists, the presumption of low yield may no longer hold. NSS (2010) *op cit.*, p. 15.
[7] National Academies, DHS (2005), Nuclear attack public fact sheet, *op cit.;* p. 16, NSS 2010, *op cit.*
[8] National Academies, DHS (2005), Nuclear attack public fact sheet, *op cit.*
[9] DHS Directorate of Science & Technology (2011), Integrated CBRN Terrorism Risk Assessment (reference is SECRET//NOFORN).

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

- Social displacement estimates for the Nuclear Terrorism Attack national-level event were provided by the National Consortium for the Study of Terrorism and Responses to Terrorism (START).[10]
- The low, best, and high social displacement estimates of 330,000, 2 million, and 3 million for the Nuclear Terrorism Attack event reflect judgments from START subject matter experts, based on published evacuation/shelter-in-place estimates for a detonated 10 kiloton improvised nuclear device.[11]

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[12] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- The environmental assessment included effects resulting from terrorism threats, but did not include human health effects or effects in urban areas because these effects are already reflected in other consequence measures.
- Experts identified the best estimate for environmental consequences as "High." Experts indicated that the environmental consequences would be high due to the size and effect of the fallout and the persistence of the material. The relative toxicity may be moderate, since isotopes could be remediated. Ultimately, the long-term impact to the environment could be more moderate, but the impact would be high for in the short and intermediate term (1 year or more).

Additional Relevant Information

The consequences of a nuclear attack would be determined by the following effects of a detonation:

- *Air blast:* As with a conventional explosive, a nuclear detonation produces a shock wave, or air blast wave.
- *Heat:* The second effect would be extreme heat, a fireball, with temperatures reaching to millions of degrees.
- *Initial radiation:* The initial radiation is produced in the first minute following detonation.
- *Ground shock:* Ground shocks roughly equivalent to a large localized earthquake would also occur. This could cause additional damage to buildings, communications, roads, utilities and other critical infrastructure.
- *Secondary radiation:* Secondary radiation exposure from fallout would occur primarily downwind from the blast, but changing weather conditions could spread radioactivity and enlarge the affected area.

A failed detonation is potentially hazardous to the extent that it results in a fizzle yield, which occurs if the fissile material mechanically disassembles before a significant yield is generated. Even a fizzle yield, however, can produce a fairly large explosion that could disperse radioactive material widely.

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[10] START is a Department of Homeland Security University Center of Excellence that focuses on social and behavioral aspects of terrorism, natural disasters, and technological accidents, and the social, behavioral, cultural and economic factors influencing responses to and recovery from catastrophes.

[11] Davis, Tracy C. 2007. "Stages of Emergency: Cold War Nuclear Civil Defense." Duke University Press.; Meade C, Molander R.C. Considering the Effects of a Catastrophic Terrorist Attack. Santa Monica, CA: RAND Center for Terrorism Risk Management Policy; 2006. http://www.rand.org/pubs/technical_reports/2006/RAND_TR391.pdf; National Security Staff Interagency Policy Coordination Subcommittee for Preparedness and Response to Radiological and Nuclear Threats. Planning Guidance for Response to a Nuclear Detonation. 2nd Edition; 2010. http://www.remm.nlm.gov/PlanningGuidanceNuclearDetonation.pdf.

[12] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\,Fat + Inj + \frac{1}{2}\,D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: Nuclear Terrorism Attack was given a C_{EF} of 1.3.

The numerical psychological distress estimates for this event and the complete semi-quantitative risk matrix may be found in Appendix G and the Findings sections, respectively, of the full SNRA Technical Report.

Radiological Dispersal Device Attack

A hostile non-state actor(s) acquires radiological materials and disperses them through explosive or other means or creates a radiation exposure device (RED).

Data Summary

Description	Low	Best	High
Fatalities	See classified data sheet		
Injuries and Illnesses	See classified data sheet		
Direct Economic Loss	See classified data sheet		
Indirect Economic Loss	See classified data sheet		
Social Displacement	25,000	50,000	100,000
Psychological Distress	See text		
Environmental Impact[1]	Low[2]		
Frequency of Events	See classified data sheet		

(UNCLASSIFIED)

Event Background

Radiological devices used for terrorism may include radiological dispersal devices (RDD) and radiological exposure devices (RED). The principal type of RDD is a "dirty bomb" that combines a conventional explosive with radioactive material. A second type involves radioactive material dispersed in air or water by other mechanical means, such as a water spray truck, a crop duster, or manually spread. An RED may comprise a powerful radioactive source hidden in a public place, such as a trash receptacle in a busy train or subway station, to expose passers-by to a potentially significant dose of radiation.[3]

It is very difficult to design an RDD that would deliver radiation doses high enough to cause immediate health effects or fatalities in a large number of people. Most injuries from a dirty bomb would probably occur from the heat, debris, and force of the conventional explosion used to disperse the radioactive material, affecting individuals close to the site of the explosion. At the low radiation levels expected from an RDD, the immediate health effects from radiation exposure would likely be minimal.[4] Subsequent decontamination of the affected area could involve considerable time and expense. A dirty bomb could have significant psychological and economic effects.[5]

Most radiological devices would have very localized effects, ranging from less than a city block to several square miles. Factors determining the area of contamination would include the amount and type of radioactive material, the means of dispersal, the physical and chemical form of the radioactive material (for example, material dispersed in the form of fine particles may be carried by the wind over a relatively large area), local topography and location of buildings, and local weather conditions.[6]

Preparedness and effectiveness of response teams will play a significant role in mitigating the consequences caused by an RDD attack. Early identification of a radiological attack is important in determining whether or not to evacuate the area or shelter in place and the size of the area requiring cordoning.

There is evidence indicating terrorist organizations have expressed interest in using RDDs, though experts disagree as to how attractive they are as a tactic due to the limited number of expected casualties and the challenges associated with acquiring and handling radiological material.

[1] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.
[2] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'Best' estimate.
[3] U.S. Environmental Protection Agency (2006, October). OSC Radiological Response Guidelines. Office of Solid Waste and Emergency Response, Office of Air and Radiation, U.S. EPA; at http://www.uscg.mil/hq/nsfweb/foscr/ASTFOSCRSeminar/References/EnvResponsePapersFactSheets/OSCRadResponseGuidelines.pdf (retrieved April 2013).
[4] National Academies and U.S. Department of Homeland Security (2005). Radiological attack: dirty bombs and other devices. Retrieved from http://www.dhs.gov/radiological-attack-fact-sheet via http://www.ready.gov.
[5] EPA (2006) OSC Radiological Response Guidelines, *op. cit.*.
[6] Ibid.

However, others assert that the resulting psychological and economic consequences may be enough for terrorists to risk the difficulties in pursuing this as a method for attack.[7]

Assumptions

The SNRA leveraged classified data from the DHS/S&T 2011 Integrated Terrorism Risk Assessment (ITRA)[8] for quantitative frequency, fatality, illness/injury, and economic loss estimates for the radiological terrorism attack event. The data relies heavily on the Intelligence Community (IC) and other technical experts to develop scenarios and estimate the likelihoods of those scenarios for analysis. The DHS Science and Technology Directorate (S&T) extracted ITRA data for successful terrorist attacks corresponding to the five CBRN national-level events in the SNRA.

The SNRA leveraged data for the classified risk summary sheet that assumed the qualifiers for terrorist attack to include the following:

- Involves an act that is dangerous to human life or potentially destructive of critical infrastructure or key resources;
- Involves an act that is a violation of the criminal laws of the United States or any State or other subdivision of the United States;
- Appears to be intended to intimidate or coerce a civilian population;
- Appears to be intended to influence the policy of a government by intimidation or coercion;
- Appears to be intended to affect the conduct of government by mass destruction, assassination, or kidnapping.

The analysis only included data for successful attacks for this national-level event, e.g. detonation of the device or successful spread into the food or water system. Failed attacks were not included in this analysis (e.g., interdiction during the fabrication and assembly of the dispersal device, interdiction during travel to United States, or failure of the dispersal device).

The analysis used broad definitions of organizations that may initiate or represent potential radiological terrorism threats to the U.S., the categories of radionuclides that could be used for an attack, and the targets that may be selected for a radiological attack. The adopted criteria for general categories representing radiological terrorist threats to the U.S. are as follows:

- The International Terrorist Organization category is composed of terrorist organizations that operate both inside and outside of the U.S. that are not sponsored by a nation (e.g., al-Qaeda).
- The Domestic Terrorist Organization category is composed of terrorist organizations that operate only within the U.S. that are not sponsored by a nation (e.g., Animal Liberation Front and Rajneesh).
- The Small Groups/Individuals Terrorist Organization category is composed of small groups (i.e., 2 to 3 members) or individuals that operate only within the U.S. that are not sponsored by a nation (e.g., the Unabomber and Timothy McVeigh).

The SNRA project team used the following assumptions identified in Table 1 to estimate the economic losses for this national-level event.

Table 1. Definitions for Direct, Indirect, and Induced Costs

Direct Costs include:

- **Decontamination, Disposal, and Physical Destruction**: DDP costs covered the repair, replacement and environmental clean-up which are considered expenditures by the government. It was assumed the government would recoup this spending through tax increases, causing a reduction of household spending of that same amount. However, this spending would be received as income by some sectors, such as waste management and environmental consulting services. The increase in spending into the waste management and environmental consulting services is treated as increase in annual output for these sectors.
- **Business Interruption**: Business interruption impacts considered losses due to decreased output at the target area, along with other increases and decreases to related sectors due to behavioral changes resulting from the event.
- **Loss in Spending from Fatalities**: This SNRA project team estimated a loss of spending of $42,500 for each fatality. In addition, $6,000 is included in increased output for mortuary services for each fatality.
- **Medical Costs**: Costs of medical mitigation were considered to be borne through private spending and insurance companies, while the hospital sector received an offsetting increase in output.

[7] Dana A. Shea, "Radiological Dispersal Devices: Select Issues in Consequence Management," Congressional Research Service for the Library of Congress (December 7, 2004).
[8] DHS Directorate of Science & Technology (2011), Integrated CBRN Terrorism Risk Assessment (reference is SECRET//NOFORN).

Indirect Costs include: • Costs incurred by the suppliers and vendors in the associated expenditure sectors for the industries impacted by the direct costs above.
Induced Costs include: • The induced costs are those incurred due to reduced spending by households with members employed in any of the directly or indirectly affected industries. Induced costs can also include substitution effects or likely transfers of economic activity from one set of sectors to another set, such as avoidance of air or other travel or altered transportation mode preferences to other sectors following an attack on the commercial air transport sector.

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

- Social displacement estimates for the Radiological Terrorism Attack national-level event were provided by the National Consortium for the Study of Terrorism and Responses to Terrorism (START).[9]
- The low, best, and high social displacement estimates of 25,000, 50,000, and 100,000 for the Radiological Terrorism Attack event reflect judgments from START subject matter experts, based on published evacuation/shelter-in-place estimates for radiological dispersal device (RDD) attack scenarios.[10]

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[11] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agents, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- The environmental assessment included effects resulting from terrorism threats, but did not include human health effects or effects in urban areas because these effects are already reflected in other consequence measures
- Experts identified the best estimate for environmental consequences as "Low." Experts indicated that the environmental impact would be limited because: fallout would be restricted to an urban area, toxicity from likely materials would be relatively low, and the dispersion area could be relatively limited as well. Environmental consequences could be elevated to "Medium" depending on the specific scenario.

Potential Mitigating Factors

Though the effects of an RDD attack will vary by the size of the detonation device, the means of dispersal, weather conditions, and the selected radionuclide, the preparedness level and effectiveness of response teams will play a significant role in mitigating the consequences caused by an RDD attack. Those closest to the detonation site would likely sustain injuries from the explosion, but as the radioactive material spreads it becomes less concentrated and harmful.[12] Early identification of a radiological attack is important in determining whether or not to evacuate the area or shelter in place and the size of the area requiring cordoning. Additionally, the evacuation effort should include populations downwind from the explosion and also consider the needs of at-risk and special populations. Planners should note the importance of effective communication during the response effort to inform the public about evacuation routes and areas that are potentially contaminated.

In general, protection from radiation is afforded by utilizing the following principles:

- Minimizing the time exposed to radioactive materials;
- Maximizing the distance from the source of radiation; and
- Shielding from external exposure and inhaling radioactive material.[13]

[9] START is a Department of Homeland Security University Center of Excellence that focuses on social and behavioral aspects of terrorism, natural disasters, and technological accidents, and the social, behavioral, cultural and economic factors influencing responses to and recovery from catastrophes.

[10] Worcester, Maxim. "International Terrorism and the Threat of a Dirty Bomb." Institute Fur Strategies, Politik, Sicherheits, und Wirtschaftsberatung, Berlin.

[11] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + ½\ D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: Radiological Terrorism Attack was given a C_{EF} of 1.3.

The numerical psychological distress estimates for this event and the complete semi-quantitative risk matrix may be found in Appendix G and the Findings sections, respectively, of the full SNRA Technical Report.

[12] "Dirty Bombs: Backgrounder", United States Nuclear Regulatory Commission, May 2007.

[13] Ibid.

APPENDIX K: SNRA DATA SET

Table K.1: SNRA Data Summary

National-Level Event	Frequency			Fatalities			Injuries/Illnesses			Direct Economic Cost ($M)			Social Displacement			Psychological Distress			EFF*	Environmental	
	Low	Best	High	Low	Best	High	Low	Best	High	Low	Best	High	Low	Best	High	Low	Best	High		Best	2nd Best
Aircraft as a Weapon													0	50,000	1,000,000				1.2	Low	Moderate
Armed Assault													0	2,000					1.1	De minimus	De minimus
Explosives Terrorism Attack													0	5,000					1.2	Low	Moderate
Biological Food Contamination	0.20	0.64	1.2	0	11	42	200	17,000	45,000				0	400	950	200	17,000	46,000	1	Moderate	Low
Chemical Substance Spill or Release	0.61	1.6	5	1	5	25	0	60	790	0.04	14	330	0	255	5,400	6	230	4,000	1.1	Moderate	High
Dam Failure	0.17	0.54	3	1	17	170	0	50	3,000				1	500	250,000	6	390	130,000	1	Moderate	Moderate
Radiological Substance Release	0.0062	0.0093	0.014	0	230	2,200	0	240	2,300	7,500	8,600	16,000	76,000	150,000	500,000	42,000	82,000	290,000	1.1	Moderate	High
Animal Disease Outbreak	0.04	0.1	0.1	0	0	0	0	0	0	2,300	15,200	69,000	0	1,000			500		1	Low	Moderate
Earthquake	0.11	0.27	2	0	370	8,900	0	8,700	210,000	107	8,700	105,000	160	27,000	2,000,000	90	27,000	1,400,000	1.1	Moderate	High
Flood	0.5	4	10	0	3	25	0	95	4,500	104	740	16,000	150	29,000	200,000	75	15,000	100,000	1	Moderate	Moderate
Human Pandemic Outbreak	0.017	0.033	0.10	140,000	250,000	440,000	62,000,000	77,000,000	110,000,000	84,000	170,000	260,000	0	0	0	63,000,000	78,000,000	110,000,000	1	Low	Moderate
Hurricane	0.33	1.9	7	0	26	1,200	0	650	30,000	100	5,700	92,000	430	520,000	5,000,000	220	260,000	2,500,000	1	Moderate	High
Space Weather		0.01																	1	De minimus	Moderate
Tsunami	0.0024	0.005	0.0074	1	300	1,000	1	300	1,000	700	1,500	3,300	8,600	15,000		4,300	9,200	13,000	1	Moderate	High
Volcanic Eruption	0.001	0.002	0.01	340	520	780	2,000	17,000	150,000	4,300	10,000	16,000	1,300	130,000	2,100,000	4,400	85,000	1,200,000	1	High	Moderate
Wildfire	0.2	0.8	3	0	5	25	0	63	190	100	900	2,800	770	110,000	640,000	390	55,000	320,000	1	Low	High
Biological Terrorism Attack (non-food)													0	1,800					1.3	Low	Low
Chemical Terrorism Attack (non-food)													0	100,000	700,000				1.3	Moderate	High
CB Food Contamination Terrorism Attack													0						1.3	Low	Moderate
Nuclear Terrorism Attack													330,000	2,000,000	3,000,000				1.3	High	High
Radiological Terrorism Attack													25,000	50,000	100,000				1.3	Low	Moderate
Cyber Event affecting Data													0	0	0				1	De minimus	De minimus
Cyber Event affecting Phys. Infrastructure													0	400					1	De minimus	Low

* Event Familiarity Factor (See Appendix G)

Cell color key	
	Data are classified
	Data are For Official Use Only
	No data
	Not reported in quantitative charts

Table K.2: SNRA Core Data

Record Type	Event Group	NLE	Place	State	Event Start	Comments/Identifiers	SNRA Fatalities	SNRA Inj/Ill	SNRA Displaced	EFF	SNRA Psych.Distress	SNRA Direct Economic Damage	Event End	Observation Period Start	Observation Period End	Observation Period (years)	Incident Likelihood	Source
Scenario	Natural	Animal Disease					0	0	1,000	1.0	500	$15,200,000,000					0.1	See RSS
Scenario	Natural	Human Pandemic					250,000	77,000,000	0	1.0	78,250,000	$170,000,000,000					0.033	See RSS
Scenario	Natural	Tsunami					300	300	14,700	1.0	9,150	$1,530,000,000					0.0057	See RSS
Scenario	Natural	Volcanic Eruption					515	17,000	130,000	1.0	84,575	$8,300,000,000					0.002	See RSS
Incident	Natural	Earthquake	San Francisco	CA	4/18/1906	Assumption 1% annual mitigation	8,896	209,056		1.1	278,890	$104,905,367,626		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	El Centro	CA	6/22/1915	Assumption 1% annual mitigation	13	306		1.1	408	$131,076,352		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	San Jacinto/Riverside County	CA	4/21/1918	Assumption 1% annual mitigation	0	0		1.1	0	$193,990,095		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Mona Passage	PR	10/11/1918	Assumption 1% annual mitigation	138	3,243		1.1	4,326	$1,943,953,812		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Santa Barbara	CA	6/29/1925	Assumption 1% annual mitigation	44	1,034		1.1	1,379	$1,371,950,746		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Long Beach	CA	3/11/1933	Assumption 1% annual mitigation	358	8,413		1.1	11,223	$7,565,220,534		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Helena	MT	10/19/1935	Assumption 1% annual mitigation	5	118		1.1	157	$960,000,000		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Helena	MT	10/31/1935	Assumption 1% annual mitigation	3	71		1.1	94	$512,380,253		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	El Centro/Imperial Valley	CA	5/19/1940	Assumption 1% annual mitigation	6	141		1.1	188	$392,000,000		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Puget Sound/Olympia	WA	4/13/1949	Assumption 1% annual mitigation	24	564		1.1	752	$3,403,585,667		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Terminal Island	CA	11/18/1949	Assumption 1% annual mitigation	0	0		1.1	0	$414,893,442		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Terminal Island	CA	8/15/1951	Assumption 1% annual mitigation	0	0		1.1	0	$109,913,608		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Kern County/Bakersfield	CA	7/21/1952	Assumption 1% annual mitigation	26	611		1.1	815	$1,820,696,601		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Kern County/Bakersfield	CA	8/22/1952	Assumption 1% annual mitigation	4	94		1.1	125	$662,071,491		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Hebgen Lake	MT	8/18/1959	Assumption 1% annual mitigation	54	1,269		1.1	1,693	$706,863,603		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Prince William Sound/Anchorage	AK	3/28/1964	Assumption 1% annual mitigation	220	5,170		1.1	6,897	$11,213,495,628		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Seattle	WA	4/29/1965	Assumption 1% annual mitigation	9	212		1.1	282	$299,194,941		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Santa Rosa	CA	10/2/1969	Assumption 1% annual mitigation	2	47		1.1	63	$120,000,000		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	San Fernando	CA	2/9/1971	Assumption 1% annual mitigation	81	1,904		1.1	2,539	$5,083,948,997		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Imperial Valley	CA	10/15/1979	Assumption 1% annual mitigation	0	0		1.1	0	$129,806,214		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Whittier/Los Angeles	CA	10/1/1987	Assumption 1% annual mitigation	9	212	9,000	1.1	5,232	$795,888,336		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Loma Prieta/San Francisco	CA	10/18/1989	Assumption 1% annual mitigation	60	1,410	32,500	1.1	19,756	$10,485,000,000		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Ferndale/Fortuna/Petrolia	CA	4/25/1992	Assumption 1% annual mitigation	0	0		1.1	0	$106,971,740		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Landers/Yucca Valley	CA	6/28/1992	Assumption 1% annual mitigation	3	71	750	1.1	507	$202,144,394		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Northridge/Los Angeles	CA	1/17/1994	Assumption 1% annual mitigation	62	1,457	120,000	1.1	67,944	$78,235,199,499		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Seattle/Tacoma/Olympia	WA	2/28/2001	Assumption 1% annual mitigation	1	24	400	1.1	251	$2,378,245,427		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Paso Robles/San Simeon	CA	12/22/2003	Assumption 1% annual mitigation	2	47	160	1.1	151	$328,283,332		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Flood			3/27/1993	Flooding in SC and TN.	3	0		1.0	15	$238,068,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			5/8/1993	Heavy rain in parts of OK, AR, and TX.	5	0		1.0	25	$103,635,700		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			5/8/1993	Extensive flooding, South Central Kansas.	0	0		1.0	0	$157,000,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			5/8/1993	Flooding in OK.	0	0	31,000	1.0	15,500	$157,000,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			8/31/1993	Great Flood of 93.	0	0		1.0	0	$15,700,000,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			9/24/1993	Steady rains in and around Springfield MO.	1	0		1.0	5	$119,013,850		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			8/18/1994	Heavy rains, flash floods in PA and NY.	3	6		1.0	21	$111,766,500		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			10/16/1994	Texas flooding.	15	0	14,070	1.0	7,110	$399,146,400		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			1/10/1995	Flooding, Kern, Los Angeles, San Diego CA.	0	0		1.0	0	$166,135,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			3/1/1995	Flooding from Kern to Tulare CA.	0	0		1.0	0	$168,072,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			3/10/1995	Salinas River flooding in Monterey County CA.	0	0		1.0	0	$447,000,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			1/18/1996	Rain, snow melt caused flooding from VA to NY.	22	1		1.0	111	$475,800,480		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			2/6/1996	Northern Oregon river flooding.	7	0	24,900	1.0	12,485	$576,000,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			7/17/1996	Record breaking rainfall over Illinois.	0	0		1.0	0	$111,888,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			7/19/1996	Heavy thunderstorms in PA.	2	1		1.0	11	$326,160,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			1/1/1997	Melting snow, heavy rain in Southern Oregon.	0	0	18,100	1.0	9,050	$126,900,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			1/1/1997	Damages in CA from Sierra Nevada rain, snow melt.	3	52	125,000	1.0	62,567	$1,635,600,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			3/1/1997	Flooding from excessive rain in KY, OH, and WV.	10	3		1.0	53	$153,368,520		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			3/1/1997	Record 24 hour rainfall in Jefferson County, KY.	2	0		1.0	10	$296,100,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			4/8/1997	Sheyenne River flooding in ND.	0	0	50,400	1.0	25,200	$5,428,500,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			6/20/1997	Flash floods in MN and WI.	0	6		1.0	6	$141,751,530		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			7/28/1997	Heavy rains, flash floods in CO.	5	40	424	1.0	277	$289,162,800		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			8/11/1997	Hail, wind, torrential rain Lakewood, Denver CO.	0	0		1.0	0	$180,480,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			2/4/1998	Slow moving Nor'easter battered eastern VA.	0	0		1.0	0	$104,250,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			2/23/1998	Powerful Pacific storm, southern and central CA.	5	3		1.0	28	$152,316,200		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			3/8/1998	Slow moving system dumped much rain on AL.	4	0	18,000	1.0	9,020	$165,389,150		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			3/8/1998	Gulf storm dumped up to 14 inches of rain, AL, GA.	1	1		1.0	6	$543,490,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			3/10/1998	Nearly six inches of rain, multiple counties FL.	0	0		1.0	0	$510,130,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			6/1/1998	Agricultural damage from Sierra Nevada snow melt.	0	0		1.0	0	$139,556,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			6/26/1998	Sustained flooding, parts of East Central OH.	10	0	14,000	1.0	7,050	$281,502,800		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			8/5/1998	Slow moving thunderstorms moved through WI.	2	5		1.0	15	$114,410,900		1/1/1993	12/31/2005	13.00	0.0769	See RSS

Record Type	Event Group	NLE	Place	State	Event Start	Comments/Identifiers	SNRA Fatalities	SNRA Inj/Ill	SNRA Displaced	EFF	SNRA Psych.Distress	SNRA Direct Economic Damage	Event End	Observation Period Start	Observation Period End	Observation Period (years)	Incident Likelihood	Source
Incident	Natural	Flood			8/5/1998	Flooding from Devils Lake in ND.	0	0		1.0	0	$136,000,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			10/17/1998	The Great October Flood in west Texas.	25	4,520		1.0	4,645	$559,266,500		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			5/7/2000	Heavy rainfall, Jefferson and Franklin county MO.	2	0	300	1.0	160	$132,660,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			6/19/2000	Heavy thunderstorms in MN, record rainfall amounts.	0	0		1.0	0	$147,840,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			8/12/2000	Thunderstorms, near torrential downpours, NJ.	0	0	175	1.0	88	$237,996,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			10/3/2000	Massive rainfall in South West FL.	0	0		1.0	0	$1,254,000,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			4/1/2001	Flooding from rapid snow melt and rain.	3	1		1.0	16	$256,000,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			7/8/2001	Severe flash flooding in WV and VA.	1	0		1.0	5	$280,748,800		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			10/11/2001	High water in Columbia AR.	0	0		1.0	0	$153,606,400		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			5/2/2002	Flash floods in KY, VA, and WV.	4	0		1.0	20	$141,233,400		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			6/10/2002	Heavy rainfall, Roseau River overflowed dikes.	0	0		1.0	0	$252,000,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			4/6/2003	Heavy rains, flooding, several counties MS.	2	0		1.0	10	$325,683,090		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			5/5/2003	Flooding TN, GA and AL.	3	6		1.0	21	$1,474,800,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			7/21/2003	Thunderstorm, flash floods throughout OH.	5	0	1,200	1.0	625	$288,261,570		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			5/23/2004	Stationary front, flooding SE Michigan.	0	0		1.0	0	$120,000,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			6/1/2004	Heavy rains, southern WI.	0	0		1.0	0	$301,860,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			1/10/2005	Stalled storm system dumped rain throughout UT.	1	6		1.0	11	$348,000,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			12/30/2005	Widespread flooding, several CA counties.	0	0	3,600	1.0	1,800	$476,298,320		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Hurricane			1970	Celia	11	275		1.0	330	$6,850,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1971	Doria	6	150		1.0	180	$2,400,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1971	Edith	1	25		1.0	30	$310,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1971	Fern	1	25		1.0	30	$480,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1971	Ginger	0	0		1.0	0	$190,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1972	Agnes	122	3,050		1.0	3,660	$20,300,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1973	Delia	5	125		1.0	150	$300,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1974	Carmen	1	25		1.0	30	$1,140,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1974	Subtropical Storm 1 1974	0	0		1.0	0	$130,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1975	Eloise	21	525		1.0	630	$6,230,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1976	Belle	9	225		1.0	270	$570,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1978	Amelia	36	900		1.0	1,080	$190,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1979	Claudette	3	75		1.0	90	$1,710,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1979	David	1	25		1.0	30	$980,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1979	David	1	25		1.0	30	$1,570,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1979	Frederic	17	425		1.0	510	$12,640,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1980	Allen	2	50		1.0	60	$2,060,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1981	Dennis	0	0		1.0	0	$140,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1983	Alicia	22	550		1.0	660	$9,670,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1984	Diana	4	100		1.0	120	$370,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1985	Bob	0	0		1.0	0	$120,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1985	Danny	0	0		1.0	0	$160,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1985	Elena	9	225	1,000,000	1.0	500,270	$4,340,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1985	Gloria	1	25		1.0	30	$520,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1985	Gloria	6	150		1.0	180	$2,490,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1985	Juan	11	275		1.0	330	$4,560,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1985	Kate	2	50		1.0	60	$1,270,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1988	Gilbert	5	125		1.0	150	$200,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1989	Allison	4	100		1.0	120	$1,680,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1989	Chantal	1	25		1.0	30	$280,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1989	Hugo	51	1,275	25,000	1.0	14,030	$18,320,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1989	Jerry	1	25		1.0	30	$210,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1990	Marco	13	325		1.0	390	$210,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1991	Bob	16	400	1,200	1.0	1,080	$3,620,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1992	Andrew	26	650	250,055	1.0	125,808	$66,770,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1993	Emily	2	50		1.0	60	$100,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1994	Alberto	20	500	20,022	1.0	10,611	$1,290,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1994	Beryl	3	75		1.0	90	$180,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1994	Gordon	16	400		1.0	480	$1,230,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1995	Erin	3	75	6,000	1.0	3,090	$820,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1995	Erin	3	75		1.0	90	$830,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1995	Jerry	0	0		1.0	0	$110,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1995	Opal	23	575	78,000	1.0	39,690	$7,490,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1996	Bertha	3	75		1.0	90	$610,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1996	Fran	32	800	4,000	1.0	2,960	$7,260,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1996	Josephine	1	25		1.0	30	$310,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1997	Danny	4	100		1.0	120	$200,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1998	Bonnie	4	100	17,000	1.0	8,620	$1,440,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS

Record Type	Event Group	NLE	Place	State	Event Start	Comments/Identifiers	SNRA Fatalities	SNRA Inj/Ill	SNRA Displaced	EFF	SNRA Psych.Distress	SNRA Direct Economic Damage	Event End	Observation Period Start	Observation Period End	Observation Period (years)	Incident Likelihood	Source
Incident	Natural	Hurricane			1998	Earl	0	0		1.0	0	$150,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1998	Frances	3	75		1.0	90	$970,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1998	Georges	14	350	5,127	1.0	2,984	$4,100,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1999	Dennis	2	50		1.0	60	$270,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1999	Floyd	50	1,250	3,000,010	1.0	1,501,505	$7,700,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1999	Irene	9	225		1.0	270	$1,430,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2001	Allison	43	1,075	172,000	1.0	87,290	$8,330,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2001	Gabrielle	2	50		1.0	60	$390,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2002	Isidore	2	50	13,200	1.0	6,660	$480,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2002	Lili	6	150		1.0	180	$1,210,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2003	Claudette	1	25		1.0	30	$250,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2003	Isabel	22	550	225,000	1.0	113,160	$4,820,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2004	Charley	0	0	545	1.0	273	$120,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2004	Charley	16	400	30,000	1.0	15,480	$18,520,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2004	Frances	11	275	5,000,000	1.0	2,500,330	$12,310,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2004	Gaston	0	0		1.0	0	$160,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2004	Ivan	25	625		1.0	750	$18,480,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2004	Jeanne	8	200	40,000	1.0	20,240	$9,350,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2005	Cindy	0	0		1.0	0	$360,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2005	Dennis	2	50		1.0	60	$2,670,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2005	Katrina	1,200	30,000	500,000	1.0	286,000	$92,050,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2005	Rita	8	200	300,000	1.0	150,240	$11,330,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2005	Wilma	16	400	30,000	1.0	15,480	$26,210,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2006	Ernesto	0	0	140	1.0	70	$550,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2008	Dolly	2	50		1.0	60	$1,080,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2008	Fay	1	25	400	1.0	230	$590,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2008	Gustav	7	175	2,100,000	1.0	1,050,210	$4,220,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2008	Hanna	0	0		1.0	0	$170,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2008	Ike	31	775	200,000	1.0	100,930	$19,600,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2010	Hermine	12	300		1.0	360	$250,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Wildfire	Oakland	CA	10/20/1991	Oakland Hills Fire	25	150		1.0	275	$2,803,063,000	10/20/1991	1/1/1990	12/31/2009	20.00	0.0500	See RSS
Incident	Natural	Wildfire	Sacramento	CA	10/26/1993		0	89		1.0	89	$514,587,000	10/31/1993	1/1/1990	12/31/2009	20.00	0.0500	See RSS
Incident	Natural	Wildfire	Los Angeles	CA	10/27/1993	Old Topanga Fire	6	187		1.0	217	$2,221,587,000	11/4/1993	1/1/1990	12/31/2009	20.00	0.0500	See RSS
Incident	Natural	Wildfire	Central Florida	FL	5/31/1998		0	150		1.0	150	$261,731,000	7/30/1998	1/1/1990	12/31/2009	20.00	0.0500	See RSS
Incident	Natural	Wildfire	Central Florida	FL	7/1/1998		0	65	40,124	1.0	20,127	$523,462,000	7/10/1998	1/1/1990	12/31/2009	20.00	0.0500	See RSS
Incident	Natural	Wildfire	Chelan	WA	8/2/1998		0	0		1.0	0	$123,978,000	8/30/1998	1/1/1990	12/31/2009	20.00	0.0500	See RSS
Incident	Natural	Wildfire	Los Alamos	NM	5/4/2000	Cerro Grande	0	0	25,400	1.0	12,700	$1,966,720,000	5/31/2000	1/1/1990	12/31/2009	20.00	0.0500	See RSS
Incident	Natural	Wildfire	Tehama	CA	9/29/2000		0	0		1.0	0	$717,197,000	9/30/2000	1/1/1990	12/31/2009	20.00	0.0500	See RSS
Incident	Natural	Wildfire	Pima	AZ	6/17/2003	Rodeo-Chediski Fire	0	0	1,269	1.0	635	$161,404,000	7/15/2003	1/1/1990	12/31/2009	20.00	0.0500	See RSS
Incident	Natural	Wildfire	San Diego	CA	10/25/2003	Cedar Fire	22	157	27,104	1.0	13,819	$2,572,317,000	11/5/2003	1/1/1990	12/31/2009	20.00	0.0500	See RSS
Incident	Natural	Wildfire	Carson	TX	3/12/2006		12	8		1.0	68	$107,289,000	3/18/2006	1/1/1990	12/31/2009	20.00	0.0500	See RSS
Incident	Natural	Wildfire	Wheeler	TX	4/11/2006		0	2		1.0	2	$103,553,000	4/13/2006	1/1/1990	12/31/2009	20.00	0.0500	See RSS
Incident	Natural	Wildfire	Alpine	CA	6/24/2007	Alpine Fire	0	3	768	1.0	387	$544,127,000	6/30/2007	1/1/1990	12/31/2009	20.00	0.0500	See RSS
Incident	Natural	Wildfire	San Diego County	CA	10/21/2007		10	132	640,064	1.0	320,214	$748,175,000	10/31/2007	1/1/1990	12/31/2009	20.00	0.0500	See RSS
Incident	Natural	Wildfire	Sacramento	CA	11/15/2008		0	0	55,000	1.0	27,500	$156,960,000	11/19/2008	1/1/1990	12/31/2009	20.00	0.0500	See RSS
Incident	Accidental	Food Contamination			1998	1998 Lysteria-Hot Dog	42	212		1.0	422			1/1/1998	12/31/2008	11.00	0.0909	See RSS
Incident	Accidental	Food Contamination			2004	2004 Salmonella-Roma Tomato	0	12,570		1.0	12,570			1/1/1998	12/31/2008	11.00	0.0909	See RSS
Incident	Accidental	Food Contamination			2006	2006 E. Coli-Spinach	10	6,212		1.0	6,262	$67,400,000		1/1/1998	12/31/2008	11.00	0.0909	See RSS
Incident	Accidental	Food Contamination			2006	2006 Salmonella-Peanut Butter	18	20,950		1.0	21,040			1/1/1998	12/31/2008	11.00	0.0909	See RSS
Incident	Accidental	Food Contamination			2007	2007 Salmonella-Pot Pie	6	11,749		1.0	11,779			1/1/1998	12/31/2008	11.00	0.0909	See RSS
Incident	Accidental	Food Contamination			2008	2008 Salmonella- Jalapeno/Serrano Peppers	4	44,976		1.0	44,996			1/1/1998	12/31/2008	11.00	0.0909	See RSS
Incident	Accidental	Food Contamination			2008	2008 Salmonella-Peanut Butter	18	20,979		1.0	21,069			1/1/1998	12/31/2008	11.00	0.0909	See RSS
Incident	Accidental	Chemical Accident	Pensacola	FL	12/13/1994	Fertilizer Manufacturing, Ammonia	4	27	2,000	1.1	1,152	$327,678,968		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Alberton	MT	4/11/1996	Rail Transport, Chlorine	1	787	0	1.1	871	$19,675,515		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Lancaster	OH	8/26/1997	Farm Supplies, Ammonia	5	0	0	1.1	28	$212,500		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Sacaton	AZ	11/3/1997	Apiculture, Ammonia	1	1	0	1.1	7	$118,592		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Orlando	FL	2/23/1998	Sewage Treatment, Chlorine	9	1	0	1.1	51	$389,100		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Centralia	KS	4/22/1998	Farm Supplies Wholesaler, Ammonia	12	0	0	1.1	66	$510,000		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Tacoma	WA	10/10/1998	Refrigerated Warehouse, Ammonia	5	0	0	1.1	28	$15,714,379		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Franklinton	LA	10/26/1998	Corn Farming, Ammonia	25	0	0	1.1	138	$1,062,500		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Green River	WY	1/5/2000	Ice Manufacturing, Ammonia	1	2	0	1.1	8	$55,700		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Jefferson	OK	5/17/2000	Chemical Manufacturing, HCl	15	0	0	1.1	83	$637,895		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Hammond	LA	4/2/2001	Milk Manufacturing, Ammonia	1	12	0	1.1	19	$7,541,017		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Newberg	OR	7/14/2001	Petrochemical Manufacturing, Chlorine	3	51	0	1.1	73	$608,918		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Mesquite	NM	10/16/2001	Corn Farming, Ammonia	1	2	0	1.1	8	$811,270		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Minot	ND	1/18/2002	Rail Transport, Ammonia	1	0	0	1.1	6	$42,500		1/1/1994	12/31/2010	17.00	0.0588	See RSS

Record Type	Event Group	NLE	Place	State	Event Start	Comments/Identifiers	SNRA Fatalities	SNRA Inj/Ill	SNRA Displaced	EFF	SNRA Psych.Distress	SNRA Direct Economic Damage	Event End	Observation Period Start	Observation Period End	Observation Period (years)	Incident Likelihood	Source
Incident	Accidental	Chemical Accident	Soddy Daisy	TN	4/11/2003	Syrup Manufacturing, Ammonia	1	0	0	1.1	6	$7,448,305		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Lakewood	CO	4/21/2003	Farm Supplies Wholesaler, Ammonia	1	6	0	1.1	12	$82,223		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Pampa	TX	7/13/2003	Seafood Processing, Ammonia	1	3	0	1.1	9	$62,300		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Paynesville	MN	11/4/2003	Farm Raw Material Wholesaler, Ammonia	1	1	0	1.1	7	$49,100		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Illiopolis	IL	4/23/2004	Plastic Manufacturing, Vinyl acetate monomer	5	6	0	1.1	34	$252,100		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Seymour	IN	5/25/2004	Farm Supplies Wholesaler, Ammonia	10	0	0	1.1	55	$425,000		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Macdona	TX	6/28/2004	Rail Transport, Chlorine	3	66	0	1.1	89	$563,100		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Graniteville	SC	1/6/2005	Rail Transport, Chlorine	9	631	5,400	1.1	3,714	$13,848,553		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Sanford	FL	1/8/2005	Highway Transport, CO2 (refrigerated liquid)	2	0	0	1.1	11	$85,000		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Ebensburg	PA	8/28/2006	Animal Slaughtering, Ammonia	10	4	0	1.1	59	$451,400		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Westlake	LA	6/27/2007	Pigment Manufacturing, Titanium tetrachloride	1	1	0	1.1	7	$243,585		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Hollywood	FL	5/20/2008	Water Transport, Argon (refrigerated liquid)	3	0	0	1.1	17	$127,500		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Swansea	SC	7/15/2009	Highway Transport, Ammonia	1	7	0	1.1	13	$89,427		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Cincinnati	OH	11/16/2009	Farm Supplies Wholesaler, Ammonia	2	0	0	1.1	11	$85,000		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Dam Failure		NY	1/1/1960	Electric Light Pond Dam	1			1.0	5			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		CT	3/6/1963	Mohegan Park Dam	6	6		1.0	36			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		UT	6/16/1963	Little Deer Creek Dam	1			1.0	5			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		CA	12/14/1963	Baldwin Hills Dam	5			1.0	25			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		MT	6/8/1964	Swift Dam	19			1.0	95			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		CO	6/17/1965	Cripple Creek Dam No. 3, domino failure Dam No. 2	1			1.0	5			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		MA	3/24/1968	Lee Lake Dam	2			1.0	10			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		IA	7/17/1968	Virden Creek Dam	1			1.0	5			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		WV	2/26/1972	Buffalo Creek Coal Waste Dam	125	1,000		1.0	1,625			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		AK	4/1/1972	Lake "O" Hills	1			1.0	5			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		SD	6/9/1972	Canyon Lake Dam	165	3,000		1.0	3,825			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		SC	9/18/1975	Lakeside Dam	1			1.0	5			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		NC	2/22/1976	Bear Wallow Dam	4			1.0	20			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		ID	6/5/1976	Teton Dam	11	800		1.0	855			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		PA	7/20/1977	Laurel Run Dam	40			1.0	200			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		GA	11/6/1977	Kelly Barnes Dam	39			1.0	195			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		KY	12/18/1981	Eastover Mining Co. Dam	1			1.0	5			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		CO	7/15/1982	Lawn Lake Dam + Cascade Lake Dam	3			1.0	15			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		UT	6/23/1983	D.M.A.D. Dam	1			1.0	5			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		TX	3/29/1989	Nix Lake Dam	1			1.0	5			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		NC	9/15/1989	Evans Dam + Lockwood Dam	2			1.0	10			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		SC	10/10/1990	Kendall Lake Dam	4			1.0	20			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		VA	6/22/1995	Timberlake Dam	2			1.0	10			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		NH	3/13/1996	Bergeron Pond Dam	1	2		1.0	7			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		ND	6/12/2000	Mike Olson Dam (Grand Forks Co. Comm. No.1 Dam)	2			1.0	10			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		HI	3/14/2006	Ka Loko Dam	7			1.0	35			1/1/1960	12/31/2009	50.00	0.0200	See RSS

Animal Disease, Human Pandemic, Tsunami, and Volcanic Eruption represent single scenarios: they are represented by the best estimate of their annual frequency and associated consequences. The remaining data in this table consist of the raw data from which the quantitative estimates for the remaining natural and accidental hazards were derived, as presented in the corresponding risk summary sheets. Accidental Radiological Substance Release is not included in this table.

For each incident, a point likelihood is calculated as 1/(event observation period) – that is, if the observation period from which the source data were reported covered the 18.5 years from 1/1/1970 to 7/1/1988, the point frequency for the incident would be 1/18.5 = 0.054. This is done to permit aggregation, subdivision, selection of different thresholds, and other manipulations on the source data.

EFF = Event Familiarity Factor, used in the SNRA Psychological Distress metric (Appendix G).

See RSS = See event Risk Summary Sheet (Appendix J) for data sources.

Blanks indicate no data, not zero.

APPENDIX L: TORNADOES

The Tornado National-level Event was added to the SNRA data set in calendar year 2012, subsequent to the communication of the 2011 SNRA data and findings to FEMA which informed the National Preparedness Goal.

Tornadoes

On average, there are 1,300 tornadoes that strike the United States each year, of which an average of 140 (or approximately 10%) are significant (rated as EF2 or higher on the enhanced Fujita scale (EF scale)).[1] Tornadoes are more common in the United States than in any other country because of the interactions between cold fronts coming from Canada that collide with warm fronts that hit the central United States via the Gulf of Mexico. This collision generally centers over the central and southeastern portions of the United States, and there is a higher frequency of tornadoes that strike these regions. Nevertheless, tornadoes occurred in all 50 states, the District of Columbia,[2] and Puerto Rico between 1996 and 2011.

For the purposes of the SNRA, only tornado events that resulted in $100 million or more in direct economic damage were analyzed. It is common for more than one tornado to spawn from a storm cell, so tornadoes that met a temporal and spatial threshold were aggregated into tornado events. Data from 1996 to 2011 was used to aggregate tornadoes into tornado events in the SNRA because it provided the most complete record of fatalities, injuries and direct economic consequences. Using the aggregation methodology, there were 46 tornado events analyzed for the SNRA that occurred from 1996-2011, of which 44 were outbreaks that included more than one tornado.

There are several important trends to note when considering tornado events. First, technology has played an increasingly important role in preparing for, mitigating, and responding to tornadoes. Through radar advancements, scientists have lengthened the average lead time before a storm. Tornado warnings can then be disseminated via multiple methods, including radio, television, the Internet, social media and mobile devices. Nevertheless, despite better communication and detection capabilities, tornadoes still pose a significant threat to the United States. One trend noted in the research is the geographic shift of tornado prevalence toward the Southeastern states. This is important because the mid-Southeastern states (such as Alabama, Arkansas, Mississippi, and Tennessee)[3] are more densely populated than traditional tornado alley areas like the rural regions of Oklahoma or Texas. The increased population density, and in particular mobile home density, could result in an increase in fatalities, injuries and economic consequences in the future.[4]

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[1] This is based on the number of tornadoes per year from 1996 – 2011. All calculations are taken from the NOAA National Weather Storm Service Storm Prediction Center (SPC) database. NOAA NWS SPC (2012). *SPC Tornado, Hail, and Wind Database Format Specification.* Retrieved June 22, 2012 from http://www.spc.noaa.gov/wcm/#data.

[2] On September 24, 2001, a tornado originated in Virginia and passed through Washington, DC.

[3] Parisi, T. (2008, February 8). *Deadly Storms Underscore New Research Finding*. Retrieved September 12, 2012, from NIU News: Media Relations and Internal Communications: http://www.niu.edu/PubAffairs/RELEASES/2008/feb/tornado.shtml.

[4] Dixon, P.G., Mercer, A.E., Choi, J. & Allen, J.S. (2011, April). Tornado Risk Analysis: Is Dixie Alley an Extension of Tornado Alley? *Bulletin of the American Meteorological Society*, 92, 433-441.

Tornado

A tornado event (either a single tornado or a cluster of tornadoes that form during a single storm system) occurs in the United States resulting in direct economic losses of or greater than $100 Million. The methodology for determining clusters can be found below.

Data Summary[1,2]

Description	Metric	Low	Best	High
Fatalities	Number of Fatalities[3]	0	22	316
Injuries	Number of Injuries or Illnesses[3]	0	247	3125
Direct Economic Loss	U.S. Dollars[3]	$103 Million[4]	$450 Million	$4.7 Billion
Frequency of Events	Number per Unit of Time[5]	0.63 per Annum	2.9 per Annum	7 per Annum

Event Description

The most destructive and deadly tornadoes occur from supercells – which are rotating thunderstorms with a well-defined radar circulation called a mesocyclone (supercells can also produce damaging hail, severe non-tornadic winds, unusually frequent lightning, and flash floods).[6] Although tornadoes appear throughout the world, the continental United States is subjected to more tornado events than any other country. On average, there are 1,300 tornadoes that hit the United States each year, of which an average of 140 (or approximately 10%) are significant (rated as EF2 or higher on the enhanced Fujita scale).[7] Tornadoes are more common in the United States than in any other country because of the interactions between cold fronts coming from Canada that collide with warm fronts that hit the central United States via the Gulf of Mexico. This collision generally centers over the central and southeastern portions of the United States, and there is a higher frequency of tornadoes that strike these regions. Nevertheless, tornadoes occurred in all 50 states, the District of Columbia[8] and Puerto Rico between 1996 and 2011.

For the purposes of the Strategic National Risk Assessment, the SNRA team analyzed tornado events that resulted in $100 million or more in economic damage. From 1996 to 2011, there were 46 tornado events that met this criterion. Of these 46 events, 44 were outbreaks that included more than one tornado. These outbreaks were determined using a clustering method to aggregate the fatality, injury and economic consequences of tornadoes that occurred within one day and 150 miles of at least one other tornado.

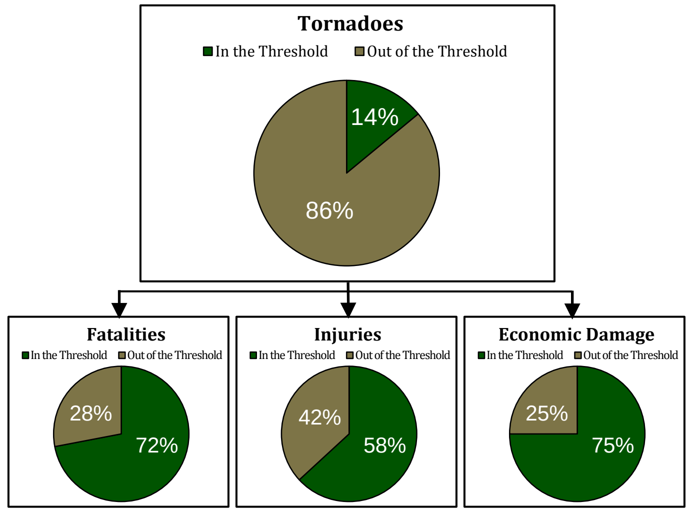
The economic threshold highlights 46 events during the time frame. Figure 1 outlines data on the tornado events that met the criteria of the $100 million threshold.

Methodology

Note that the tornadoes captured by this threshold represent only 14% of all tornadoes in the data set. However, those 14% of tornadoes are responsible for 72% of all fatalities, 58% of all injuries and 75% of all economic damage from all tornadoes during the 1996 – 2011 timeframe (see Figure 1).

When appropriate (i.e., when temporal and spatial criteria were met) individual tornadoes were clustered into multi-tornadic outbreak events. This was done because DHS is responsible for responding to a single destructive event, without separating out damage that comes from different tornadoes. The SNRA team chose to cluster tornadoes using spatial and temporal clustering, as this facilitated analysis on the aggregated total of fatalities, injuries and economic damage caused by tornadoes in a storm system, not just an individual storm. Through the use of this threshold, the SNRA team was able to capture the most damaging and dangerous storms from the data set.

Figure 1. Percentage of tornadoes in the data set that meet the threshold and the proportion of associated consequences within and outside of the threshold



In order to cluster the tornadoes, the team created a model that clusters tornado events if certain criteria are met. The data set has been programmed to cluster tornadoes if they meet the following two conditions: 1) the events fall within a one day window[9,10] and 2) the events are located within 150 miles of another event.[11]

It is important to note that the SNRA team elected to not make the Enhanced Fujita (EF) Scale (formerly known as the Fujita (F) Scale) rating a threshold for clustering. A powerful storm (EF4 – EF5) could hit a forest or a field, causing relatively little damage. At the same time, a weak storm (EF0 – EF2) could cause significant economic damage or loss of life if it struck a densely populated area. Due to the inconsistency, the SNRA team felt it was important to include all tornadoes regardless of the EF scale rankings in the data set.

During this risk assessment, temporally and spatially associated events were identified as "tornado clusters." There are two main reasons why the SNRA team created a model to cluster tornadoes as opposed to relying on external sources:

- A specific definition of a tornado cluster (also referred to as a tornado outbreak) is not available for guidance in the meteorological literature. There is an ongoing debate in the field regarding the definition of an outbreak, as storm systems can spawn tornadoes over a broad array of time and space.[12] Without a concrete definition, the SNRA team determined that it needed to create the clustering model internally.
- Since the historical data in the data set is arranged by individual tornadoes, and it does not group tornadoes by storm system, the entire data set had to be clustered before tornado clusters could be identified. Without the historical data on storm cells and their production of tornadoes, the decision was made to infer when tornadoes were associated with one another through the time and distance conditions.

The specific spatial and temporal parameters in the clustering algorithm were calibrated using publically available news and weather reports published on days of tornado outbreaks. Before clustering the data, the SNRA team checked its main data source, the National Weather Service's (NWS) Storm Prediction Center (SPC) database, for consistency. Several adjustments were incorporated in the SNRA data set:

[1] The data reported in this table represent historical U.S. tornado data. The SNRA project team used historical data from the Storm Prediction Center (SPC) online database. The SPC is a division of the National Weather Service (NWS), which is a part of the National Oceanographic and Atmospheric Administration (NOAA).
[2] Social displacement, psychological distress, and environmental impacts of tornado outbreaks were not assessed for the Tornado event. Expert elicitations and research for these metrics were completed during the main project phase of the SNRA (summer-fall 2011) before the tornado event was added in 2012. These measures will be assessed in the next iteration of the SNRA.
[3] Low, best, and high estimates for fatalities, injuries and illnesses, and direct economic loss come from the low, average, and high values of the set of events meeting a $100 million threshold of direct economic cost. This set came from the National Weather Service's Storm Prediction Center database on tornadoes ranging from 1996 - 2011. For further details see Assumptions sections below.
[4] This is the low estimate when the $100 million threshold is applied.
[5] Frequency estimates correspond to the inverse of the number of years of the longest interval between accident events (low), the mean frequency of the accident events (best), and the greatest number of accidents within one year (high) of the set described in note 3 above.
[6] (Edwards, The Online Tornado FAQ, 2012)
[7] This is based on number of tornadoes per year from 1996 – 2011. All calculations are taken from the SPC database.
[8] On September 24, 2001, a tornado originated in Virginia and passed through Washington DC. The individual entry for DC was removed during data consolidation. The tornado ID number is 11594 (entry in the NOAA SPC database is 2001 – 451).

[9] All units of time have been converted to central standard time (CST).
[10] The day window accounts for a 47 hour and 59 minute span of time. For example, a day window would associate a tornado that struck at 00:00 on January 1, 2011 and one that struck at 23:59 on January 2, 2011.
[11] An event was spatially associated with a previous event if it comes within 150 miles of the path taken by the previous event.
[12] Available definitions that are spatially precise may be nebulous in time, or vice versa. Moreover, many historical attempts to define the term "tornado outbreak" have failed to account for the spatial outliers, far removed from tornado clusters but within the same time domain. (Edwards, Thompson, Crosble, & Hart, 2004)

- The database contained multiple reports for the same tornado. This occurred when a single tornado would cross state lines. The reports were consolidated to reflect an accurate picture of the path and damage of the single tornado. The partial reports were eliminated prior to running the data through the clustering model.
- In 1996, NOAA began to track the economic damage caused by a storm by millions of dollars. Previously, the data had been semi-quantitatively binned by the order of magnitude of the losses. In order to ensure accuracy and consistency, the SNRA team decided to use data from 1996 – 2011.
- The SNRA team combined the Property Damage field and the Crop Damage field to create a Total Damage Field. This historic data was used as an estimate of Total Direct Economic Losses. However, it does not include losses due to business interruptions, medical costs, or loss in spending due to fatalities. These other types of direct economic impacts due to tornadoes were assumed to be small relative to property and crop losses.

To create the clustering model, a program was written by the SNRA team using MATLAB. The base of the program was previous work that was done to support research into clusters of floods for the SNRA. The following parameters were built into the model and used to define the criteria for each cluster:

- **Spatial** – Distance window of 150 miles from any point along the tornado path[13]
- **Temporal** – Time window of 1 day
- Year span: 1996 – 2011

The steps performed by the clustering algorithm proceeded as follows:

- Step 1: The areas of each tornado are calculated by finding all points within 150 miles from starting point A, ending point B, and midpoint C.[14]
- Step 2: Starting with a single tornado, the algorithm clusters any matching tornadoes with the original tornado based on whether the matching tornadoes meet the spatial and temporal criteria.
- Step 3: The algorithm loops over the newly identified tornado cluster (the original tornado and matching tornadoes) to find any other tornadoes that now match any portion of the cluster based on the spatial and temporal criteria.
- Step 4: New clusters are created as the data loops over the data set.
- Step 5: The data loop continues until all tornadoes are sorted into a cluster.[15]
- Step 6: The clusters are analyzed by the SNRA team.

The final data set that was put into the clustering model included individual tornadoes that occurred in the United States[16] from 1996 to 2011. The SNRA team analyzed 20,755 tornadoes that occurred during this timeframe. Using the clustering methodology, the final number of tornado clusters was 4,597. Of these clusters, 2,206 clusters represented more than one tornado while the remainders were individual tornadoes that did not cluster with any other tornadoes in the data set. Once the clusters were formed, they were extracted and analyzed in Microsoft Excel using advanced database tools. In Microsoft Excel, the $100 million threshold was applied. Of the 2,206 clusters established, 46 clusters were analyzed as SNRA level events (see the above Data Summary, Table 1 and Figure 1 for analysis).

Assumptions

The SNRA team used the following assumptions to estimate consequences caused by a tornado event:

- For the purposes of this assessment, tornado clusters are determined through spatial and temporal clustering. The distance threshold is 150 miles and the time threshold is one day. All economic estimates were inflation-adjusted to 2011 dollars.
- The decision to analyze tornado events from 1996 to 2011 was made because the historical data consistently measured the direct economic costs of tornadoes from 1996 to the present.[19]

Table 1. Results for Tornado Events Resulting in $100 Million or More in Economic Damage

Number of Events	46
Number of Tornadoes	2813
Number of Fatalities	1025
Number of Injuries	11,367
Total Economic Damage	$20.7 billion[17]
Proportion of Tornadoes Above the Threshold from the Entire Data Set	14%
Proportion of Fatalities Represented From Entire Data Set	72%
Proportion of Injuries Represented From Entire Data Set	58%
Proportion of Economic Damage Represented From Entire Data Set	75%
Number of Outbreaks (More than One Tornado per Event)	44
Number of Individual Storms	2
Average Number of Storms per Outbreak	64[18]

- The direct economic damages include losses to both property and crops.[20]
- Social displacement, psychological distress, and environmental impacts will be assessed in the next iteration of the SNRA.[21]

Event Background

Individual Storms:

Single tornadoes have the potential to cause a large loss of life. On May 22, 2011, the deadliest single tornado to strike the United States since 1947 tore through Joplin, MO (population 50,000). The tornado was rated as a strong EF5, and there was extensive loss of life, injuries, economic loss and psychological consequences. NOAA's SPC registered 158 fatalities and 1,150 injuries that were directly related to the single tornado. The final economic cost of the Joplin tornado was found to be $2.8 billion.[22,23] As a result of the tornado, the governor of Missouri issued a State of Emergency due to the loss of critical infrastructure in the city and the need to rapidly deploy federal, state and local resources in response to the disaster. The Joplin tornado was the most significant tornado in a tornado outbreak which spanned May 20 to May 26, 2011. This storm system crossed the Midwest and into the Ohio River Valley, spawning 188 tornadoes across 21 states, in total. This outbreak caused 173 fatalities, 1,545 injuries and $2.84 billion worth of damage.[24]

The Joplin Tornado is also significant because of the damage done to critical infrastructure. City officials as well as local, state and federal emergency managers had to work to restore basic utilities and healthcare capabilities to the city while also clearing debris.[25] FEMA reported that it had provided an estimated $174 million in federal assistance provided through various programs to aid the recovery.[26]

The Joplin Tornado was the most significant tornado to strike the United States from 1996 – 2011, but it is worth noting that severe storms (defined as EF4 – EF5) are rare. Out of 20,755 individual storms analyzed by the SNRA team from 1996 – 2011, there were only 112 other severe tornadoes (0.54% of the total number of tornadoes).[27] These 112 severe storms were responsible for a significant share of damage. From 1996 to 2011, severe storms resulted in 45% of the total amount of damage. They were also responsible for 52% of the total number of fatalities and 41% of the total number of injuries. This suggests that even though the frequency per year is low, the risk of severe storms is high.

However, even significant storms (rated EF2 to EF3) are responsible for a large portion of the damage from tornadoes, mainly because there are significantly more EF2 and EF3 storms. From 1996 to 2011, 10% of all tornadoes were rated as EF2 to 3 (compared to 0.54% of severe storms at EF4 to 5). The 2,144 EF2 and EF3 tornadoes were responsible for 37% of the total amount of damage. The significant storms caused 43% of the total number of fatalities and 48% of the total number of injuries. Even though the majority of tornadoes are weak (there were 18,499 EF0 and EF1

[13] To judge the distance, the SNRA project team used several data fields from the SPC database. First, using the starting and ending latitude and longitude, one can establish the exact origin and termination points of the tornado. For the purposes of the analysis, the algorithm uses the midpoint C of a straight line between the starting point A and terminating point B. If two tornadoes were within 150 miles AND one day of each other at points A, B, or C, they would be clustered.
[14] The average path length of a tornado in the data set is 3 miles and the average maximum width is 113 yards. Due to the short average path length and width, the starting, ending and midpoint were assumed to be sufficient points of measurement from which the 150 mile distance is determined.
[15] Note that a single tornado can be its own cluster if no other tornadoes in the data set meet the spatial and temporal criteria.
[16] Geographically, the data set spanned all 50 U.S. states as well as Puerto Rico and the District of Columbia.
[17] The economic damage of the tornadoes in the threshold totaled $20,721,128,120.
[18] The average number is found by dividing the total number of tornadoes that were part of an outbreak (2811) by the number of outbreaks (44).
[19] Prior to 1996, the SPC database used a logarithmic scale to provide a range of estimated loss. According to the information sheet that accompanies the database, it was "a categorization of tornado damage by dollar amount (0 or blank-unknown; 1<$50, 2=$50-$500, 3=$500-$5,000, 4=$5,000-$50,000; 5=$50,000-$500,000, 6=$500,000-$5,000,000, 7=$5,000,000-$50,000,000, 8=$50,000,000-$500,000,000, 9=$5,000,000,000.)" (NOAA NWS SPC, 2012)
[20] The SPC began separating crop and property damage in 2007. Where available, the fields have been combined to reflect the direct economic damages.
[21] The Tornado national-level event was added to the SNRA in calendar year 2012, subsequent to the main project phase of the SNRA in summer-fall 2011 when the expert elicitations and research for the social displacement, psychological distress, and environmental impact measures were completed. These measures will be assessed for all events in the next iteration of the SNRA.
[22] (Storm Prediction Center Warning Coordination Meteorologist, 2011)
[23] (The Associated Press, 2012)
[24] (Storm Prediction Center Warning Coordination Meteorologist, 2011)
[25] (State Emergency Management Agency, 2011)
[26] (FEMA, 2011)
[27] From 1996 – 2011, there were 99 EF 4 tornadoes (or 0.48% of the data set) and 13 EF 5 tornadoes (or 0.06% of the data set).

tornadoes, or 89% of all tornadoes in the data set), the majority of the damage from tornadoes comes from significant and severe storms.

Tornado Clusters:

While powerful storms like the Joplin tornado do pose a significant threat, they very rarely appear alone.[28] By clustering tornadoes, the SNRA team was able to gain a clearer picture of the regional impact of storm systems that hit vulnerable areas. This clustering method illuminated information from serious outbreaks, such as the outbreak that occurred from April 22 – 28, 2011. In April 2011, the United States was hit by an unprecedented number of tornadoes. There were 752[29] tornadoes reported during the month of April alone, and this significantly outpaced the previous record of 540[30] tornadoes in May 2003. From April 22 – 28, there were 382 tornadoes that struck 21 states, resulting in 316 fatalities, 3125 injuries and $4.7 billion in damage. The most significant and deadly tornadoes struck Alabama, Mississippi and Tennessee from April 26 – April 28. Of the 316 fatalities, 234 were in Alabama, 32 were in Tennessee, 31 were in Mississippi, 15 were in Georgia, and 4 were in Virginia.

This outbreak ranks with the 1974 Super Tornado Outbreak [as the most severe outbreak to strike the United States since 1950, when the data was consistently measured] and resulted in more deaths than the 1965 Palm Sunday Outbreak.[31] According to the service assessment released by the NWS:

> The deadliest part of the outbreak was the afternoon and evening of April 27, when a total of 122 tornadoes resulted in 313 deaths across central and northern Mississippi, central and northern Alabama, eastern Tennessee, southwestern Virginia, and northern Georgia… there were 15 violent (Enhanced Fujita Scale 4 or 5) tornadoes reported. Eight of the tornadoes had path lengths in excess of 50 miles.[32]

The service assessment conducted in-depth research into why the fatality numbers were so high during this outbreak. Contributing factors to the high number of casualties included:

- A large number of rare, long-track, violent tornadoes
- Tornado tracks intersecting densely populated areas
- Damage to warning dissemination sources
- Individuals in the affected areas who did not respond to warnings until confirmed by more than one communication source
- People in the paths of the storms who waited for visual confirmation before taking protective action
- The rapid pace of the storms, which moved at 45-70 mph, giving people who waited for secondary confirmation a smaller window of time in which to take shelter
- Residences that did not have adequate storm shelters[33]

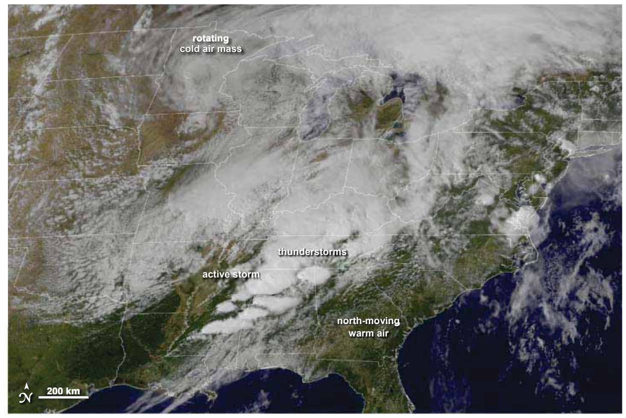
The large number of severe tornadoes played a crucial role in the high fatality rate. As Kevin Simmons and Daniel Sutter explain,

> …insuring residents receive a warning and take shelter in an interior bathroom or closet will not prevent fatalities because these rooms often fail to protect residents from an EF4 or EF5 tornado. In addition, the longer a tornado remains on the ground, more structures and people are placed at risk. To address this threat, engineers have developed safe rooms and underground shelters capable of protecting residents from even the strongest tornadoes. When a significant event occurs, there is enhanced interest and some political pressure to increase the use of shelters. However, violent tornadoes are just too rare to make hardening millions of homes in tornado-prone states cost effective.[34]

According to the data clustered by the SNRA model, there were 12 EF4 tornadoes and 4 EF5 tornadoes during the outbreak, or 4% of the 382 tornadoes in the outbreak.[35] These violent tornadoes were responsible for 277 fatalities (or 88% of fatalities), 2675 injuries (or 86% of injuries), and $4.2 billion in damage (or 90% of damage).

The prevalence of severe storms during this outbreak led to widespread damage. The combination of high fatalities along with the damage to critical infrastructure such as the electricity grid prompted governors in several states (Alabama, Arkansas, Kentucky, Mississippi, Missouri, Tennessee and Oklahoma) to declare a State of Emergency.

Figure 2 - The Southern U.S. on 27 April 2011 (NASA Earth Observatory, 2011)



Additional Relevant Information

The Enhanced Fujita (EF) Scale:

In 2007, NOAA began to classify tornado damage using the Enhanced Fujita scale (EF scale). The previous Fujita (F) scale "did not include damage indicators (DIs) and did not provide a method to correlate construction quality with the observed variability in damage resulting from similar wind speeds. Therefore, in 2004 the EF Scale ratings were adopted and provide a more rigorous and defensible metric for the severity of tornadoes."[36] The EF scale allows for a

> ...more precise and robust way to assess tornado damage than the original [Fujita scale]. It classifies F0-F5 damage as calibrated by engineers and meteorologists across 28 different types of damage indicators (mainly various kinds of buildings, but also a few other structures as well as trees). The idea is that … a tornado scale needs to take into account the typical strengths and weaknesses of different types of construction. This is because the same wind does different things to different kinds of structures. In the EF scale, there are different, customized standards for assigning any given F rating to a well built, well anchored wood-frame house compared to a garage, school, skyscraper, unanchored house, barn, factory, utility pole or other type of structure.[37]

Table 4 – Fujita Scale Conversion (Mitigation Assessment Team Report, 2012)

Fujita Scale Converted to EF Scale			
F0	45–78	EF0	65–85
F1	79–117	EF1	86–110
F2	118–161	EF2	111–135
F3	162–209	EF3	136–165
F4	210–261	EF4	166–200
F5	262–317	EF5	Over 200
mph = miles per hour; EF = Enhanced Fujita			

At this point in time, NOAA has not gone back to reassess the previous Fujita scale classifications for tornadoes, making the assumption that the Fujita scale data is aligned as closely as possible with the EF scale. The SNRA team agreed with this assertion.

Geographic Shifts in Tornado Prevalence

"Tornado Alley" has long been a colloquial term to describe the most tornado prone regions in the United States, which can "shift dramatically across the space between the Rocky and Appalachian Mountains."[38] Tornadoes have occurred in every state as well as the District of Columbia and Puerto Rico since 1996, and during the 1996 – 2011 timeframe, there were on average 406 tornadoes per state. The District of Columbia had the lowest number of tornadoes with only one tornado reportedly passing through DC, while Texas had the highest proportion of tornadoes with 2,282. This is in large part due to its juxtaposition between the Great Plains and the Gulf of Mexico, as well as its large geographic size.

Meteorologists are researching an eastward shift in the number of tornadoes.[39] Walker Ashley, a meteorologist at Northern Illinois University, notes that the increased number of tornadoes in the mid-south states (particularly Alabama, Tennessee, Mississippi and Arkansas) from 1996 into the 2000s pose a threat to residents of those states. He argues that

[28] In fact, as noted above, the Joplin tornado appeared as part of a cluster. The SNRA project team chose to highlight it because of its infamy and its severe consequences.
[29] Based on data from the SPC database. NOAA released the tornado count of 751 tornadoes for the month of April 2011 in its Special Report, but there was a discrepancy between the number of tornadoes (752 in SPC database and 751 in the special report). Therefore, the SNRA team used the SPC database figures. (National Climatic Data Center, 2011)
[30] Based on data from the SPC database. NOAA released the tornado count of 542 tornadoes for the month of May 2003 in its Special Report, but there was a discrepancy between the number of tornadoes (540 in SPC database and 542 in the special report). Therefore, the SNRA team used the SPC database figures. (National Climatic Data Center, 2011)
[31] (National Weather Service, 2011)
[32] (National Weather Service, 2011)
[33] (National Weather Service, 2011)
[34] (Simmons & Sutter, 2012)
[35] There were 382 tornadoes clustered in this outbreak. 4% of the storms were violent (EF4 – EF5).
[36] (Mitigation Assessment Team Report, 2012)
[37] (Edwards, Thompson, Crosble, & Hart, 2004)
[38] (Dixon, Mercer, Choi, & Allen, 2011)
[39] This eastward shift into the mid-southern states is subjectively defined as "Dixie Alley." See Dixon, Mercer, Choi, & Allen, 2011.

"while the 'tornado alley' region of the Great Plains boasts the most frequent occurrence of tornadoes, most tornado fatalities occur in the nation's mid-South region, which includes parts of Arkansas, Tennessee, Alabama and Mississippi."[40] There are a number of factors that make the mid-southern states vulnerable to tornadoes:[41]

- Mobile home density. The NIU meteorologist Walker Ashley noted 44 percent of all fatalities during tornadoes occur in mobile homes, compared to 25 percent in permanent houses. The southeast United States has the highest percentage of mobile-home stock compared with any other region east of the Continental Divide. "Mobile homes make up 30 to 40 percent of the housing stock in some counties in the deep South," Ashley said. "By far, mobile homes are the most vulnerable structures in a tornadic situation."
- Nighttime tornadoes. The southeast United States has a higher likelihood of killer nighttime tornadoes. Most states within this region have greater percentages of tornado fatalities occurring at night than other states. "I just completed another study that shows tornadoes from the midnight to sunrise period are 2.5 times as likely to kill as daytime events," Ashley said. Further, nocturnal tornadoes are more difficult to spot, and people are more likely to be asleep when warnings are issued.
- Forested areas. Whereas regions within the Great Plains by definition are lacking in tree cover, the mid-South region is more forested, leading to reduced visibility both for the public and spotters.[42]
- Early season storms. Storms that occur before the national peak in the severe storm season, which spans May and June, may catch people off guard during a tornado event.
- Complacency. In contrast to other parts of the country, the South lacks a focused "tornado season," which can lead to complacency. "In the South, people think tornado alley is where you get tornadoes," Ashley said. "That sort of perception also leads to complacency, which in turn leads to higher fatality rates." He points out that Oklahoma is known worldwide for the frequency of its tornadoes. Yet the state has fewer fatalities than Arkansas, Alabama and Mississippi.[43]

Advanced Warning Systems

Technology has played an increasingly important role in preparing for, mitigating to, and responding to tornado disasters. The increased use of radar has caused a surge in the number of tornadoes identified by the NWS. Today, the Doppler radar is widely used, and NOAA estimates that it provides on average an 11 minute lead time on tornado formation and can predict with a high level of accuracy where a tornado will strike.[44] Scientists are currently developing the next generation of weather radars by "adapting phased array technology, currently used on Navy ships, for use in weather forecasting. Phased array technology is expected to lengthen the average lead time for tornado warnings from 12 minutes to 20 minutes."[45]

According to the NWS, there are several steps of identification before information is disseminated to the public. When there are favorable conditions "for severe weather to develop, a severe thunderstorm or tornado **WATCH** is issued. Weather Service personnel use information from weather radar, spotters, and other sources to issue severe thunderstorm and tornado **WARNINGS** for areas where severe weather is imminent."[46] Once the conditions justify the issuance of a tornado watch or a tornado warning, information is disseminated to "local radio and television stations and are broadcast over local NOAA Weather Radio stations serving the warned areas. These warnings are also relayed to local emergency management and public safety officials who can activate local warning systems to alert communities."[47]

Due to the advancement in technology, affected individuals may receive tornado watch and warning information via the radio, television, cellular phones, internet and/or social media sites. The modernization of warning dissemination is taking place in both the public sector (with FEMA and NWS leading the initiative for tornadoes) and the private sector (with local news and media outlets enhancing dissemination capabilities).[48]

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[40] (Parisi, 2008)
[41] The following factors are based on analysis done prior to 2008.
[42] Storm spotters play an important role in identifying tornadoes. Over 30 years ago, the National Weather Service (NWS) developed SKYWARN, a program that "encourages communities to develop a network of trained storm spotters who provide detailed reports of dangerous weather conditions to their local emergency management agency and to the NWS." (National Weather Service, 2012)
[43] (Parisi, 2008)
[44] (NOAA National Severe Storms Laboratory, 2012)
[45] (NOAA National Severe Storms Laboratory, 2012)
[46] (National Weather Service, 2012)
[47] (National Weather Service, 2012)
[48] (Coleman, Knupp, Spann, Elliott, & Peters, 2011)

APPENDIX M: DATA SOURCES IN THE CLASSIFIED SNRA

The 2011 SNRA natural hazard and technological hazard data was derived completely from unclassified data, with substantial reliance on historical records. Data within the assessment which addresses only natural hazards and technological hazards has been treated as unclassified. The following paragraphs describe the derivation of the For Official Use Only and classified SNRA data which may be found in the full (classified) SNRA Technical Report.

Consequences

For the adversarial/human-caused events, some consequence estimates were unclassified but marked For Official Use Only (U//FOUO) in accordance with DHS practice, while other consequence estimates were classified by derivation.

- For the conventional attack events (Armed Assault, Explosives, and Aircraft as a Weapon) fatality and injury/illness estimates were derived from unclassified historical data, as detailed in the corresponding risk summary sheets (Appendix J). Following DHS practice these analyst-calculated estimates were marked as (U//FOUO). Direct economic consequence estimates were calculated from (U//FOUO) models and data using the Risk Assessment Process for Informed Decision-Making (RAPID) engine.[1]
- Fatality, injury/illness, and economic consequence data for the CBRN events were uniformly obtained from the DHS Directorate of Science & Technology (S&T) 2011 Integrated Terrorism Risk Assessment (ITRA). While these estimates are unclassified in their original form, the CBRN data provided by S&T to the SNRA team utilized weighted average consequences, which incorporate frequencies (the modelled relative likelihood that an attack, given occurrence, will result in consequences of a given magnitude). This calculation elevated the CBRN consequence estimates provided to the SNRA project to the SECRET//NOFORN classification level of the incorporated frequency data.

Social displacement and environmental impact estimates were unclassified for all events.

Frequency

Quantitative estimates of the frequency with which an adversarial/human-caused event may be initiated and successfully executed were used as measures of the likelihood of SNRA events.

Due to the short timeline imposed by the PPD-8 Implementation Plan, the 2011 SNRA project team made a concerted effort to rely on previously conducted analyses wherever possible. Appropriate prior analysis had been accomplished for many of the adversarial/human-caused events. For these events, all frequency and consequence data derive directly from previously conducted analysis.

Five SNRA adversarial/human-caused events are discussed as a unit below because the data within the SNRA was uniformly obtained from the DHS/ Science & Technology (S&T) 2011 Integrated Terrorism Risk Assessment (ITRA).

[1] The Risk Assessment Process for Informed Decision Making (RAPID) 2010 is a strategic level, DHS-wide process to assess risk and inform strategic planning priorities developed by the DHS Office of Risk Management & Analysis (National Protection & Programs Directorate). The RAPID engine is a suite of computational tools for calculating human and economic measures of risk and the relative effectiveness of different DHS programs in risk reduction. Like the SNRA it is a quantitative tool for calculating and comparing risks in the homeland security mission space with each other, but unlike the SNRA it is designed for additionally calculating the comparative effectiveness of different governmental programs in buying down risk.

SNRA Chemical, Biological, Radiological, and Nuclear Terrorism Attack Events
Events Covered • Biological Terrorism Attack (non-food) • Chemical/Biological Food Contamination Terrorism Attack • Chemical Terrorism Attack (non-food) • Nuclear Terrorism Attack • Radiological Terrorism Attack
Data Source DHS/Science & Technology (S&T) 2011 Integrated Terrorism Risk Assessment (ITRA)
Data Gathering Process[2] The Integrated CBRN Terrorism Risk Assessment elicitations were conducted throughout May and June 2010. Experts were formally elicited on five topics: absolute frequency of CBR initiation, relative frequency of CBR selection, absolute frequency of IND acquisition, frequency of CBRN interdictions, and CTRA and BTRA terrorist organization category capabilities. From this data, absolute frequency of acquisition for CBRN and the absolute frequency of attack with CBRN were calculated. Elicitation methods used were based on the approach described in NUREG-1150.[3] Elicitation experts followed the below steps in obtaining probabilities from intelligence analysts: 1. Pre-elicitation meeting: The group discussed the purpose and approach and scope of the planned elicitations 2. Intelink Terrorism Risk Assessment Frequency of Initiation Intellipedia discussion: Elicitees continued on-line discussion of event definitions and scope, to ensure shared definitions 3. Dissemination of elicitation materials: Elicitation materials were shared electronically to allow the group to review the elicitation process and event definitions 4. Study period/ individual formal elicitation meetings: Individual elicitations were conducted 5. Group review meeting: The full panel reviewed the final results and confirmed or updated responses 6. Dissemination of group review meeting follow-up document and reconciliation responses: The final results were circulated amongst the group for documentation purposes Resultant probabilities were based on analysts' knowledge of the field and prior exposure to intelligence reporting, but probabilities were not expressly linked to specific reporting. Probability distributions resulting from the elicitations were classified as SECRET//NOFORN.
Participating Organizations A combined panel of CBRN experts was convened for elicitation purposes, including analysts from: • National Counterterrorism Center • Defense Intelligence Agency • National Security Agency • Office of the Director of National Intelligence (ODNI) • DHS Office of Intelligence & Analysis Experts who were selected generally had significant expertise in at least one of the four CBRN terrorism threat areas, along with knowledge of the other threat areas.

[2] This process description is a summation of material contained in the DHS Science & Technology Directorate's 2011 Integrated CBRN Terrorism Risk Assessment, Chapter 3: Technical Approach (p. 3-149 – 3-155). (Reference is SECRET//NOFORN; Extracted information is UNCLASSIFIED.)

[3] NUREG-1150 is an elicitation methodology developed by the Nuclear Regulatory Commission (NRC) in 1991to formalize the process by which subject matter experts may provide probabilistic assessments in areas where data is sparse.

Two of the adversarial/human-caused events had previously been assessed within the DHS National Protection and Programs Directorate's (NPPD) Risk Assessment Process for Informed Decision-making (RAPID), which provided a quantitative assessment of strategic risk facing the nation. These events are discussed as a unit below.

SNRA Explosives and Aircraft-as-a-Weapon Events
Events Covered • Explosives Terrorism Attack • Aircraft as a Weapon
Data Source NPPD RAPID (2010)
Data Gathering Process The RAPID elicitations were conducted between October 2009 and January 2010. Eleven experts participated in the elicitation process. Following a modified NUREG-1150 expert elicitation process, RAPID II was able to obtain likelihood probabilities for the terrorism incident sets. Elicitation experts followed the below steps in obtaining probabilities from intelligence analysts: **1.** Identification of issues: Elicitation topics were identified in alignment with the analytic fault trees provided **2.** Selection of experts: RAPID team members identified appropriate experts within the intelligence community **3.** Individual elicitations performed: Using R Project, the RAPID team worked with experts to interactively create probability distributions which represent the likelihood that an adversary will initiate an attack, and, if initiated, the relative likelihood of different types of attacks **4.** Review by experts: Experts reviewed anonymous inputs of all participating experts, with the opportunity to make adjustments The resultant probability distributions identified the likelihood with which particular attack types would be initiated and the likelihood that a particular target class would be selected. Resultant probabilities were based on analysts' knowledge of the field and prior exposure to intelligence reporting, but probabilities were not expressly linked to specific reporting. Probability distributions resulting from the elicitations were classified as SECRET//NOFORN.
Participating Organizations All eleven experts were from the DHS Office of Intelligence & Analysis (I&A) or a DHS operational component. Experts were selected based on their knowledge of the research area.

Finally, the SNRA team conducted original subject matter elicitations for two adversarial/human-caused events. These elicitations were conducted separately but are treated as a unit here because the same elicitation protocol was used.

SNRA Armed Assault and Cyber Events
Events Covered • Armed Assault • Cyber Attack against Data • Cyber Attack against Physical Infrastructure
Data Source Original frequency elicitations conducted in August 2011 to support the SNRA
Data Gathering Process Following a modified NUREG-1150 expert elicitation process, SNRA was able to obtain likelihood probabilities for the terrorism incident sets. Elicitation experts followed the below steps in obtaining probabilities from intelligence analysts: **1.** Selection of experts: The SNRA team worked with staff within the ODNI to identify appropriate participants **2.** Identification of issues: On the day of the elicitation, the experts discussed and agreed upon the definition of the events. Note that for cyber, the broad categories of attacks against data and attacks against physical systems had been previously constructed **3.** Group elicitations performed: Using a binning structure, each member of the group provided their probability estimate. Some information was collected via an in-person group discussion, while some information was received in electronic form after the meeting **4.** Review by experts: Following the elicitation, the SNRA team compiled the inputs and provided final outcomes to participants for review and comment The resultant probability distributions identified the likelihood with which each event types would be initiated and the likelihood that a particular target class would be selected. Resultant probabilities were based on analysts' knowledge of the field and prior exposure to intelligence reporting, but probabilities were not expressly linked to specific reporting. Probability distributions resulting from the elicitations were classified as SECRET//NOFORN.
Participating Organizations Armed Assault • National Counterterrorism Center • Department of Homeland Security Intelligence & Analysis • Federal Bureau of Investigation Cyber Attacks (Infrastructure and Data) • Office of the Director for National Intelligence • Central Intelligence Agency • Federal Bureau of Investigation • National Security Agency • National Security Staff • Department of Homeland Security Cyber Security and Communications

Derivative Classification Sources for SNRA Data

The following references are derivative classification sources for the classified data of the 2011 SNRA, as noted in the data tables provided in Appendices B through D of the full (classified) SNRA Technical Report.

Armed Assault SME: Subject matter expert elicitation session with representatives from the DHS Office of Intelligence & Analysis (I&A), Federal Bureau of Investigation (FBI), and National Security Staff (NSS) (2011, July 26). Classification level of discussion was SECRET; Derived from: Multiple Sources; Declassify on: 20360726.

Cyber SME: Subject matter expert elicitation session with representatives from DHS National Protection and Programs Directorate Office of Cyber Security and Communications (CS&C), Office of the Director of National Intelligence (ODNI), Central Intelligence Agency (CIA), Federal Bureau of Investigation (FBI), National Security Staff (NSS), and National Security Agency (NSA) (2011, July 25). Classification level of discussion was SECRET; Derived from: Multiple Sources; Declassify on: 20360725.

ITRA: Email correspondence from Program Manager, Integrated CBRN Terrorism Risk Assessment (ITRA), DHS Science & Technology Directorate (2011, September 28). Data file: '(SNF) 20110926 Uncertainty (U).zip'. Extracted information is SECRET//NOFORN; Derived from: Multiple Sources; Declassify on: 25X2.

ITRA – Nuclear Econ Update: Email correspondence from Battelle Memorial Institute Support Contractor, Integrated CBRN Terrorism Risk Assessment (ITRA) Program, DHS Science & Technology Directorate (2012, July 20). Data file: '(U) Histogram Bins Rad and Bio_files are SNF.zip'. Extracted information is SECRET//NOFORN; Derived from: Multiple Sources; Declassify on: 20370720.

RAPID: DHS Office of Risk Management & Analysis (RMA) Risk Assessment Process for Informed Decision-making (RAPID) Database. Accessed July 12, 2011. Extracted information is SECRET//NOFORN; Derived from: Multiple Sources; Declassify on: 20360712.

Additional detail is given in Appendix I of the classified SNRA Technical Report. Derivative classifications for narrative statements are noted as footnotes in the body of the classified SNRA Technical Report.

APPENDIX N: COMPARATIVE RISK TABLE – LINEAR SHADING

As Table 1 is presented with logarithmic shading (proportional to powers of ten), the visual distinction between best estimate risks in or bounding the top order of magnitude (those marked by 'X') may not be visually clear. For this reason, Table 1 is replicated below, but with the intensity of shading represented on a linear scale.

Table N.1: Comparative Risk in the SNRA - Natural Hazard and Accidental Events

National-Level Event	Fatality	Injury/Illness	Direct Economic	Social Displacement	Psychological Distress	Environmental
	Best Estimate Risk					
Animal Disease			X			
Earthquake			X			
Flood			X	X		X
Human Pandemic Outbreak	X	X	X		X	
Hurricane			X	X	X	X
Wildfire			X	X		
Biological Food Contamination						
Chemical Substance Spill or Release						X
Dam Failure						
Radiological Substance Release						
Insufficient quantitative data to support comparisons to other events						
Space Weather						
Tsunami						
Volcanic Eruption						
Cyber Event affecting Data						
Cyber Event affecting Physical Infrastructure						
Risk estimates are classified						
Aircraft as a Weapon	See classified SNRA results					
Armed Assault						
Biological Terrorism Attack (non-food)						
Chemical/Biological Food Contamination Terrorism Attack						
Chemical Terrorism Attack (non-food)						
Explosives Terrorism Attack						
Nuclear Terrorism Attack						
Radiological Terrorism Attack						

How to read this table:

Best estimate risk is assessed to fall within or bound the top order of magnitude of fatality, injury/illness, direct economic, social displacement, or psychological distress risk or the highest risk bin (Figure 8) of best estimate environmental risk among the natural and accidental hazard events in the SNRA. The relative magnitude (on a linear scale) of the quantitatively based best estimate risks is indicated by background coloring in each cell. [X]

Insufficient quantitative risk data to support comparisons with other events. [grey box]

In this approach, the relative risk on each consequence axis is considered in isolation, rather than combined. Relative weightings between different consequence measures are subjective value judgments that may vary by decision context and decision maker.

The best estimate of risk for each SNRA event is used to identify highest-magnitude risks. However, there is considerable uncertainty, varying data quality, and substantial overlap in the risk estimates of the SNRA events, making it difficult to generate a rank-ordered list of events based solely on the SNRA risk results.

APPENDIX O: SNRA 2011 PUBLIC FINDINGS REPORT

The Strategic National Risk Assessment in Support of PPD 8: A Comprehensive Risk-Based Approach toward a Secure and Resilient Nation

December 2011

Overview

The Strategic National Risk Assessment (SNRA) was executed in support of Presidential Policy Directive 8 (PPD-8), which calls for creation of a National Preparedness Goal, a National Preparedness System, and a National Preparedness Report. Specifically, national preparedness is to be based on core capabilities that support "strengthening the security and resilience of the United States through systematic preparation for the threats that pose the greatest risk[1] to the security of the Nation, including acts of terrorism, cyber attacks, pandemics, and catastrophic natural disasters."

As part of the effort to develop the National Preparedness Goal and identify core capabilities, the Secretary of Homeland Security led an effort to conduct a strategic national risk assessment to help identify the types of incidents that pose the greatest threat to the Nation's homeland security. Representatives from the offices of the Director of National Intelligence and the Attorney General, as well as other members of the Federal interagency, supported this effort. The assessment was used:

- To identify high risk factors that supported development of the core capabilities and capability targets in the National Preparedness Goal;
- To support the development of collaborative thinking about strategic needs across prevention, protection, mitigation, response, and recovery requirements, and;
- To promote the ability for all levels of Government to share common understanding and awareness of National threats and hazards and resulting risks so that they are ready to act and can do so independently but collaboratively.

The subsequent pages provide an overview of the unclassified findings and the analytic approach used to conduct the SNRA. It should be emphasized, however, that although the initial version of the SNRA is a significant step toward the establishment of a new homeland security risk baseline, it contains data limitations and assumptions that will require additional study, review, and revision as the National Preparedness System is developed. These limitations are discussed below, and future iterations of the assessment are expected to reflect an enhanced methodology and improved data sets.

Strategic National Risk Assessment Scope

To inform homeland security preparedness and resilience activities, the SNRA evaluated the risk from known threats and hazards that have the potential to significantly impact the Nation's homeland security. These threats and hazards were grouped into a series of national-level events with the potential to test the Nation's preparedness.

[1] The DHS Lexicon defines risk as the potential for an unwanted outcome resulting from an incident, event, or occurrence, as determined by its likelihood and the associated consequences. Accessed at: http://www.dhs.gov/xlibrary/assets/dhs-risk-lexicon-2010.pdf

SNRA participants – including Federal agencies, DHS Components, and the intelligence community, among others – developed a list of national-level events (see Table 1) for assessment in the initial SNRA. The events are grouped into three categories: 1) natural hazards; 2) technological/ accidental hazards; and 3) adversarial, human-caused threats/hazards. For the purposes of the assessment, DHS identified thresholds of consequence necessary to create a national-level event. These thresholds were informed by subject matter expertise and available data. For some events, economic consequences were used as thresholds, while for others, fatalities or injuries/illnesses were deemed more appropriate as the threshold to determine a national-level incident. In no case, however, were economic and casualty thresholds treated as equivalent to one another (i.e., dollar values were not assigned to fatalities). Event descriptions in Table 1 that do not explicitly identify a threshold signify that no minimum consequence threshold was employed. This allows the assessment to include events for which the psychological impact of an event could cause it to become a national-level event even though it may result in a low number of casualties or a small economic loss. Only events that have a distinct beginning and end and those with an explicit nexus to homeland security missions were included. This approach excluded:

- Chronic societal concerns, such as immigration and border violations, and those that are generally not related to homeland security national preparedness, such as cancer or car accidents, and;
- Political, economic, environmental, and societal trends that may contribute to a changing risk environment but are not explicitly homeland security national-level events (e.g., demographic shifts, economic trends). These trends will be important to include in future iterations of a national risk assessment, however.

Table 1: SNRA National-Level Events

Threat/ Hazard Group	Threat/Hazard Type	National-level Event Description
Natural	Animal Disease Outbreak	An unintentional introduction of the foot-and-mouth disease virus into the domestic livestock population in a U.S. state
	Earthquake	An earthquake occurs within the U.S. resulting in direct economic losses greater than $100 Million
	Flood	A flood occurs within the U.S. resulting in direct economic losses greater than $100 Million
	Human Pandemic Outbreak	A severe outbreak of pandemic influenza with a 25% gross clinical attack rate spreads across the U.S. populace
	Hurricane	A tropical storm or hurricane impacts the U.S. resulting in direct economic losses of greater than $100 Million
	Space Weather	The sun emits bursts of electromagnetic radiation and energetic particles causing utility outages and damage to infrastructure
	Tsunami	A tsunami with a wave of approximately 50 feet impacts the Pacific Coast of the U.S.

Threat/ Hazard Group	Threat/Hazard Type	National-level Event Description
	Volcanic Eruption	A volcano in the Pacific Northwest erupts impacting the surrounding areas with lava flows and ash and areas east with smoke and ash
	Wildfire	A wildfire occurs within the U.S. resulting in direct economic losses greater than $100 Million
Technological/ Accidental	Biological Food Contamination	Accidental conditions where introduction of a biological agent (e.g., *Salmonella*, *E. coli*, botulinum toxin) into the food supply results in 100 hospitalizations or greater and a multi-state response
	Chemical Substance Spill or Release	Accidental conditions where a release of a large volume of a chemical acutely toxic to human beings (a toxic inhalation hazard, or TIH) from a chemical plant, storage facility, or transportation mode results in either one or more offsite fatalities, or one or more fatalities (either on- or offsite) with offsite evacuations/shelter-in-place
	Dam Failure	Accidental conditions where dam failure and inundation results in one fatality or greater
	Radiological Substance Release	Accidental conditions where reactor core damage causes release of radiation
Adversarial/ Human-Caused	Aircraft as a Weapon	A hostile non-state actor(s) crashes a commercial or general aviation aircraft into a physical target within the U.S.
	Armed Assault	A hostile non-state actor(s) uses assault tactics to conduct strikes on vulnerable target(s) within the U.S. resulting in at least one fatality or injury
	Biological Terrorism Attack (non-food)	A hostile non-state actor(s) acquires, weaponizes, and releases a biological agent against an outdoor, indoor, or water target, directed at a concentration of people within the U.S.
	Chemical/Biological Food Contamination Terrorism Attack	A hostile non-state actor(s) acquires, weaponizes, and disperses a biological or chemical agent into food supplies within the U.S. supply chain
	Chemical Terrorism Attack (non-food)	A hostile non-state actor(s) acquires, weaponizes, and releases a chemical agent against an outdoor, indoor, or water target, directed at a concentration of people using an aerosol, ingestion, or dermal route of exposure
	Cyber Attack against Data	A cyber attack which seriously compromises the integrity or availability of data (the information contained in a computer system) or data processes resulting in economic losses of a Billion dollars or greater

Threat/ Hazard Group	Threat/Hazard Type	National-level Event Description
	Cyber Attack against Physical Infrastructure	An incident in which a cyber attack is used as a vector to achieve effects which are "beyond the computer" (i.e., kinetic or other effects) resulting in one fatality or greater or economic losses of $100 Million or greater
	Explosives Terrorism Attack	A hostile non-state actor(s) deploys a man-portable improvised explosive device (IED), Vehicle-borne IED, or Vessel IED in the U.S. against a concentration of people, and/or structures such as critical commercial or government facilities, transportation targets, or critical infrastructure sites, etc., resulting in at least one fatality or injury
	Nuclear Terrorism Attack	A hostile non-state actor(s) acquires an improvised nuclear weapon through manufacture from fissile material, purchase, or theft and detonates it within a major U.S. population center
	Radiological Terrorism Attack	A hostile non-state actor(s) acquires radiological materials and disperses them through explosive or other means (e.g., a radiological dispersal device or RDD) or creates a radiation exposure device (RED)

The SNRA participants identified the events listed in Table 1 as those with the potential to pose the greatest risk to the security of the Nation and formed the analytic basis of the SNRA. In some cases, tornados may also become national-level events that pose significant risk. Table 1 is not a complete list of risks that exist and will be reconsidered in future iterations of the assessment. Additional threats and hazards, such as droughts, heat waves, winter storms, rain storms, and different types of technological/accidental or human-caused hazards, can also pose a risk to jurisdictions across the country and should be considered, as appropriate, in preparedness planning. Non-influenza diseases with pandemic potential and other animal diseases should also be considered. In addition, assessment participants identified a number of events for possible inclusion in future iterations of the SNRA, including electric grid failure, plant disease outbreak, and transportation system failure.

Overarching Themes to an All-Hazards Approach

The results of the SNRA are largely classified and include a comparison of risks for potential incidents in terms of the likelihood (calculated as a frequency—i.e. number of events per year) and consequences of threats and hazards, as well as an analysis of the uncertainty associated with those incidents.[2] The assessment finds that a wide range of threats and hazards pose a significant risk to the Nation, affirming the need for an all-threats/hazards, capability-based approach to preparedness planning. Overarching themes include:

- Natural hazards, including hurricanes, earthquakes, tornadoes, wildfires, and floods, present a significant and varied risk across the country.
- A virulent strain of pandemic influenza could kill hundreds of thousands of Americans, affect millions more, and result in economic loss. Additional human and animal infectious diseases, including those previously undiscovered, may present significant risks.

[2] The full results of the SNRA are classified.

- Technological and accidental hazards, such as dam failures or chemical substance spills or releases, have the potential to cause extensive fatalities and have severe economic impacts, and the likelihood of occurrence may increase due to aging infrastructure.
- Terrorist organizations or affiliates may seek to acquire, build, and use weapons of mass destruction. Conventional terrorist attacks, including those by "lone actors" employing explosives and armed attacks, present a continued risk to the Nation.
- Cyber attacks can have their own catastrophic consequences and can also initiate other hazards, such as power grid failures or financial system failures, which amplify the potential impact of cyber incidents.

These findings supported the development of the core capabilities, as well as the establishment of capability targets for the Goal. In addition to the above findings articulated in the National Preparedness Goal, the SNRA found that:

- Many events have the potential to occur more than once every 10 years, meaning that the Nation's preparedness will likely be tested in this decade.
- Although historic events provide a useful perspective on homeland security risks, the changing nature of society and the risk landscape means that the Nation must also be prepared for new hazards and threats or for events that result in greater consequences than have occurred in the past.
- Within an all-hazards preparedness context, particular events that present risk to the Nation—such as nuclear attacks or chemical releases—require additional specialized response activities.
- Some events, such as explosives attacks or earthquakes, generally cause more localized consequences, while other events, such as human pandemics, may cause consequences that are dispersed throughout the Nation, thus creating different types of impacts for preparedness planners to consider.

Analytic Approach

The SNRA drew data and information from a variety of sources, including existing Government models and assessments, historical records, structured analysis, and judgments of experts from different disciplines. The information was used to assess the risk of identified incidents as a function of frequency[3] and consequence—specifically, *With what frequency is it estimated that an event will occur, and what are the consequences of the incident(s) if it does occur*?

The SNRA examined the consequences associated with six categories of harm: loss of life, injuries and illnesses, direct economic costs, social displacement, psychological distress, and environmental impact. This multi-faceted view of potential consequences draws attention to the broad and often interdependent effects of incidents that require whole of community preparation and cooperation across the homeland security enterprise. For instance, community resilience relates to both mitigating human and economic consequences and addressing the psychological and social distress caused by the incident within the community. Similarly, other types of resilience involve withstanding environmental and infrastructure degradations to ensure that essential services continue to be delivered.

The SNRA relied on the best available quantitative estimates of frequency and consequence from existing Government assessments, peer-reviewed literature, and expert judgment. Where sufficient

[3] Frequency was used in the SNRA to capture likelihood because some events have the potential to occur more than once a year.

quantitative information was not available—such as data related to the frequency of high-consequence space weather—events were assessed qualitatively. The estimates of the frequency and consequences for each of the events considered were compared where appropriate. No effort was made to create a single "risk judgment" for any event type because it was deemed infeasible to aggregate all consequence types into a single metric. Instead, the assessment treated consequence categories separately (i.e., economic consequences are reported separately from fatality consequences). This allowed stakeholders to apply their own expert judgments to the findings and decide how those findings should inform core capability targets in the Goal.

All sources and estimates were documented to promote credibility, defensibility, and transparency within the assessment. Uncertainty in frequency and consequences was explicitly included in the analysis by representing low and high bounds in addition to best estimates. Examples of sources of uncertainty include incomplete knowledge of adversary capabilities and intent, variability in possible event severity and location, and lack of historical precedence.

Because the assessment was performed at a strategic national level, it provided the ability to draw rough comparisons of the assessed events—within an order of magnitude—to view the broad differences in risk across events. Given the uncertainty inherent in assessing risks at a national level and the lack of information about some of the events included—many of which are likely to occur very infrequently—the assessment was designed to avoid false precision. Instead, the assessment identifies only those differences in risk that are still significant despite the associated uncertainties.

Limitations

The analysis of available information—even if that analysis is imprecise and contains a wide degree of uncertainty—supports better decision making, as long as key limitations and assumptions are noted. Participants designed the SNRA to capture the best information the Nation has about homeland security risks to support the development of the National Preparedness Goal while recognizing the limitations of conducting such analysis in a shortened time frame.

- This is a strategic national risk assessment. As such, it does not present a full view of the risk facing local communities. To complement preparedness planning, it is necessary to consider national and regional risks, many of which differ from region to region.
- Given PPD-8's emphasis on contingency events with defined beginning and endpoints (e.g. hurricanes, terrorist attacks), the current SNRA does not explicitly assess persistent, steady-state risks like border violations, illegal immigration, drug trafficking, and intellectual property violations, which are important considerations for DHS and the homeland security enterprise.
- Information about the frequency and consequences of the events included in the SNRA is at varying stages of maturity, with additional work required in some areas to ensure that event data can be appropriately compared. Where substantial additional research is warranted, events are discussed qualitatively and are not compared with other events.
- The SNRA methodology does not explicitly model the dynamic nature of some of the included hazards. For example, terrorists' evolving tactics in response to changes in defensive posture are not included.
- Experts consulted about psychological consequences emphasized caution in the application of the SNRA's measure of psychological distress, and stressed the need for additional research. The Department of Homeland Security and its partner organizations leveraged previously funded social and behavioral research to better understand how to anticipate,

prepare for, counteract, and mitigate the effects of terrorist acts, natural disasters, and technological accidents. Additional research is required to further explore psychosocial factors that enable resilience in individuals, organizations, and communities and at the societal level.

- For national-level events where historic data was used as the basis of analysis, the risk from low-likelihood, high-consequence incidents may not be adequately captured. This is particularly true for technological/accidental hazards. Further study is needed to better characterize these risks at the national strategic level.

Impacts and Future Uses

The SNRA was executed in support of PPD-8 implementation and has served as an integral part of the development of the National Preparedness Goal, assisting in integrating and coordinating identification of the core capabilities and establishing a risk-informed foundation for the National Preparedness System. Participants mapped the core capabilities identified in the Goal to the events assessed in the SNRA to identify any additional core capabilities that may need to be included. In addition, the SNRA can be used to inform discussions on priorities for capability investment decisions. Finally, the SNRA results will be used to drive other preparedness priorities at the national level.

In addition, conducting a Strategic National Risk Assessment will support the National Preparedness System by providing a consolidated list of "national level events" for consideration and augmentation for Threat and Hazard Identification and Risk Assessment processes at multiple jurisdiction levels.

Conclusion

Although the development of the SNRA is an important first step, further analysis through the execution of regional- and community-level risk assessments will help communities better understand their risks and form a foundation for their own security and resilience. The Nation's preparedness is dependent on a whole-of-community understanding of risk and comprehensive consequences at and across all levels of government. In conjunction with Federal, state, local, tribal, and territorial partners, the SNRA will be expanded and enhanced and will ultimately serve as a unifying national risk profile to facilitate preparedness efforts.

APPENDIX P: PRESIDENTIAL POLICY DIRECTIVE 8: NATIONAL PREPAREDNESS

March 30, 2011
PRESIDENTIAL POLICY DIRECTIVE/PPD-8
SUBJECT: National Preparedness

This directive is aimed at strengthening the security and resilience of the United States through systematic preparation for the threats that pose the greatest risk to the security of the Nation, including acts of terrorism, cyber attacks, pandemics, and catastrophic natural disasters. Our national preparedness is the shared responsibility of all levels of government, the private and nonprofit sectors, and individual citizens. Everyone can contribute to safeguarding the Nation from harm. As such, while this directive is intended to galvanize action by the Federal Government, it is also aimed at facilitating an integrated, all-of-Nation, capabilities-based approach to preparedness.

Therefore, I hereby direct the development of a national preparedness goal that identifies the core capabilities necessary for preparedness and a national preparedness system to guide activities that will enable the Nation to achieve the goal. The system will allow the Nation to track the progress of our ability to build and improve the capabilities necessary to prevent, protect against, mitigate the effects of, respond to, and recover from those threats that pose the greatest risk to the security of the Nation.

The Assistant to the President for Homeland Security and Counterterrorism shall coordinate the interagency development of an implementation plan for completing the national preparedness goal and national preparedness system. The implementation plan shall be submitted to me within 60 days from the date of this directive, and shall assign departmental responsibilities and delivery timelines for the development of the national planning frameworks and associated interagency operational plans described below.

National Preparedness Goal

Within 180 days from the date of this directive, the Secretary of Homeland Security shall develop and submit the national preparedness goal to me, through the Assistant to the President for Homeland Security and Counterterrorism. The Secretary shall coordinate this effort with other executive departments and agencies, and consult with State, local, tribal, and territorial governments, the private and nonprofit sectors, and the public.

The national preparedness goal shall be informed by the risk of specific threats and vulnerabilities – taking into account regional variations – and include concrete, measurable, and prioritized objectives to mitigate that risk. The national preparedness goal shall define the core capabilities necessary to prepare for the specific types of incidents that pose the greatest risk to the security of the Nation, and shall emphasize actions aimed at achieving an integrated, layered, and all-of-Nation preparedness approach that optimizes the use of available resources. The national preparedness goal shall reflect the policy direction outlined in the National Security Strategy (May 2010), applicable Presidential Policy Directives, Homeland Security Presidential Directives, National Security Presidential Directives, and national strategies, as well as guidance from the Interagency Policy Committee process. The goal shall be reviewed regularly to evaluate consistency with these policies, evolving conditions, and the National Incident Management System.

National Preparedness System

The national preparedness system shall be an integrated set of guidance, programs, and processes that will enable the Nation to meet the national preparedness goal. Within 240 days from the date of this directive, the Secretary of Homeland Security shall develop and submit a description of the national preparedness system to me, through the Assistant to the President for Homeland Security and Counterterrorism. The Secretary shall coordinate this effort with other executive departments and agencies, and consult with State, local, tribal, and territorial governments, the private and nonprofit sectors, and the public.

The national preparedness system shall be designed to help guide the domestic efforts of all levels of government, the private and nonprofit sectors, and the public to build and sustain the capabilities outlined in the national preparedness goal. The national preparedness system shall include guidance for planning, organization, equipment, training, and exercises to build and maintain domestic capabilities. It shall provide an all-of-Nation approach for building and sustaining a cycle of preparedness activities over time.

The national preparedness system shall include a series of integrated national planning frameworks, covering prevention, protection, mitigation, response, and recovery. The frameworks shall be built upon scalable, flexible, and adaptable coordinating structures to align key roles and responsibilities to deliver the necessary capabilities. The frameworks shall be coordinated under a unified system with a common terminology and approach, built around basic plans that support the all-hazards approach to preparedness and functional or incident annexes to describe any unique requirements for particular threats or scenarios, as needed. Each framework shall describe how actions taken in the framework are coordinated with relevant actions described in the other frameworks across the preparedness spectrum.

The national preparedness system shall include an interagency operational plan to support each national planning framework. Each interagency operational plan shall include a more detailed concept of operations; description of critical tasks and responsibilities; detailed resource, personnel, and sourcing requirements; and specific provisions for the rapid integration of resources and personnel.

All executive departments and agencies with roles in the national planning frameworks shall develop department-level operational plans to support the interagency operational plans, as needed. Each national planning framework shall include guidance to support corresponding planning for State, local, tribal, and territorial governments.

The national preparedness system shall include resource guidance, such as arrangements enabling the ability to share personnel. It shall provide equipment guidance aimed at nationwide interoperability; and shall provide guidance for national training and exercise programs, to facilitate our ability to build and sustain the capabilities defined in the national preparedness goal and evaluate progress toward meeting the goal.

The national preparedness system shall include recommendations and guidance to support preparedness planning for businesses, communities, families, and individuals.

The national preparedness system shall include a comprehensive approach to assess national preparedness that uses consistent methodology to measure the operational readiness of national capabilities at the time of assessment, with clear, objective and quantifiable performance measures, against the target capability levels identified in the national preparedness goal.

Building and Sustaining Preparedness

The Secretary of Homeland Security shall coordinate a comprehensive campaign to build and sustain national preparedness, including public outreach and community-based and private-sector programs to enhance national resilience, the provision of Federal financial assistance, preparedness efforts by the Federal Government, and national research and development efforts.

National Preparedness Report

Within 1 year from the date of this directive, the Secretary of Homeland Security shall submit the first national preparedness report based on the national preparedness goal to me, through the Assistant to the President for Homeland Security and Counterterrorism. The Secretary shall coordinate this effort with other executive departments and agencies and consult with State, local, tribal, and territorial governments, the private and nonprofit sectors, and the public. The Secretary shall submit the report annually in sufficient time to allow it to inform the preparation of my Administration's budget.

Roles and Responsibilities

The Assistant to the President for Homeland Security and Counterterrorism shall periodically review progress toward achieving the national preparedness goal.

The Secretary of Homeland Security is responsible for coordinating the domestic all-hazards preparedness efforts of all executive departments and agencies, in consultation with State, local, tribal, and territorial governments, nongovernmental organizations, private-sector partners, and the general public; and for developing the national preparedness goal.

The heads of all executive departments and agencies with roles in prevention, protection, mitigation, response, and recovery are responsible for national preparedness efforts, including department-specific operational plans, as needed, consistent with their statutory roles and responsibilities.

Nothing in this directive is intended to alter or impede the ability to carry out the authorities of executive departments and agencies to perform their responsibilities under law and consistent with applicable legal authorities and other Presidential guidance. This directive shall be implemented consistent with relevant authorities, including the Post-Katrina Emergency Management Reform Act of 2006 and its assignment of responsibilities with respect to the Administrator of the Federal Emergency Management Agency.

Nothing in this directive is intended to interfere with the authority of the Attorney General or Director of the Federal Bureau of Investigation with regard to the direction, conduct, control, planning, organization, equipment, training, exercises, or other activities concerning domestic counterterrorism, intelligence, and law enforcement activities.

Nothing in this directive shall limit the authority of the Secretary of Defense with regard to the command and control, planning, organization, equipment, training, exercises, employment, or other activities of Department of Defense forces, or the allocation of Department of Defense resources.

If resolution on a particular matter called for in this directive cannot be reached between or among executive departments and agencies, the matter shall be referred to me through the Assistant to the President for Homeland Security and Counterterrorism.

This directive replaces Homeland Security Presidential Directive (HSPD)-8 (National Preparedness), issued December 17, 2003, and HSPD-8 Annex I (National Planning), issued December 4, 2007, which are hereby rescinded, except for paragraph 44 of HSPD-8 Annex I.

Individual plans developed under HSPD-8 and Annex I remain in effect until rescinded or otherwise replaced.

Definitions

For the purposes of this directive:

(a) The term "national preparedness" refers to the actions taken to plan, organize, equip, train, and exercise to build and sustain the capabilities necessary to prevent, protect against, mitigate the effects of, respond to, and recover from those threats that pose the greatest risk to the security of the Nation.

(b) The term "security" refers to the protection of the Nation and its people, vital interests, and way of life.

(c) The term "resilience" refers to the ability to adapt to changing conditions and withstand and rapidly recover from disruption due to emergencies.

(d) The term "prevention" refers to those capabilities necessary to avoid, prevent, or stop a threatened or actual act of terrorism. Prevention capabilities include, but are not limited to, information sharing and warning; domestic counterterrorism; and preventing the acquisition or use of weapons of mass destruction (WMD). For purposes of the prevention framework called for in this directive, the term "prevention" refers to preventing imminent threats.

(e) The term "protection" refers to those capabilities necessary to secure the homeland against acts of terrorism and manmade or natural disasters. Protection capabilities include, but are not limited to, defense against WMD threats; defense of agriculture and food; critical infrastructure protection; protection of key leadership and events; border security; maritime security; transportation security; immigration security; and cybersecurity.

(f) The term "mitigation" refers to those capabilities necessary to reduce loss of life and property by lessening the impact of disasters. Mitigation capabilities include, but are not limited to, community-wide risk reduction projects; efforts to improve the resilience of critical infrastructure and key resource lifelines; risk reduction for specific vulnerabilities from natural hazards or acts of terrorism; and initiatives to reduce future risks after a disaster has occurred.

(g) The term "response" refers to those capabilities necessary to save lives, protect property and the environment, and meet basic human needs after an incident has occurred.

(h) The term "recovery" refers to those capabilities necessary to assist communities affected by an incident to recover effectively, including, but not limited to, rebuilding infrastructure systems; providing adequate interim and long-term housing for survivors; restoring health, social, and community services; promoting economic development; and restoring natural and cultural resources.

BARACK OBAMA

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