Iowa Climate Change Adaptation and Resilience Pilot

Stage 1: Climate Change Science and Risk Assessments
Executive Summary

This report provides a baseline of climate change information for community planners in Iowa and discusses relevant climate data that may be used in estimating future hazards in support of the following goal:

> *Working in Iowa, identify barriers to and incentives for considering regional effects of climate change in hazard mitigation and other community planning processes.*

This goal is addressed within the context of a practical resource that provides government officials in Iowa with requested information that is expressed in non-technical terminology to address the questions of (1) how is the climate changing in Iowa, and (2) what do changes in climate mean to these two communities in Iowa.

The points of entry of climate information may vary by community and hazard program. This suggests evaluation of policies, educational materials, and climate information would benefit from sustained dialogue between planners and climate information producers to understand how to evaluate emerging risks and identify approaches consistent with a variety of entry points.

Insurance and mitigation grant programs have different requirements for the use of climate data that imply different questions should be addressed by climate information. Flood insurance programs must base premiums on current rather than future hazard risk. With this constraint, the use of climate projections may be best focused on outreach campaigns to encourage flood insurance program participation, and this argues for programs that can develop community-specific educational materials describing climate change impacts on floods. In contrast, hazard mitigation plans are required to estimate the likelihood that a hazard will occur in the future, and this requires discussion with community and hazard mitigation planners on the appropriate methods to assess potential future flood magnitude and damage.

In this report, climate projections are selected by their ability to provide either a range of state-level responses to future emissions scenarios or locally specific information. A set of 112 climate projections from the Bias Corrected and Downscaled WCRP CMIP3 Climate Projections archive (http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/dcpInterface.html) is useful for illustrating the range of changing statewide annual temperature and precipitation. Projections for the communities themselves require different measures, such as consecutive days of heavy rainfall, so that the projection data set simulations from specialized stochastic techniques, leading to a smaller number of projections. However, these data contained larger spatial variability, which is consistent with historical observations. Taken together, the two data sets provided an initial inspection of potential future ranges arising from uncertainty in future emissions scenario as well as from the inherent variability of rainfall patterns.

Translating these projections of meteorological information into flood hazard faces three primary knowledge barriers in the use of climate projections in flood hazard planning.

- Traditional measures of rainfall extremes relate to only about half of flood events. This means it is difficult to confidently infer from projected increases in heavy rainfall what the future risk of floods might be.
- Standard methods to compute future inundation maps have not been developed, and this prevents estimates of potential future damages and economic loss.
- The intrinsic variability of rainfall itself may present a barrier in that uncertainty of this magnitude is not addressed by approaches to estimate current risk based upon historical reports.

Some of the recent trends and future projections planners found relevant for the two communities are summarized below.

- The current climate normal is much wetter with milder temperature than much of the 136-year record. The projected climate norm for 2045—2065 has an increase in annual temperature ranging 2.5—7.2^{O}F and annual precipitation ranging -15% to +10%, with primarily an increase of precipitation in the spring and wider range of precipitation change in the summer.
- The most prominent change in climate in recent years is an increase in frequency of very wet years (years with precipitation exceeding 40”). Since 1940 (the midpoint of the data series), very wet years have occurred 9 times and prior to 1940 they have occurred 2 times. In contrast, dry years have similar frequency before and after 1940 (7 versus 6).
- Streamflow has increased 20-50% since 1940, and this suggests that should future rainfall increase by 10% a resultant increase of 20% or more could occur in streamflow.
- The frequency of days in which rainfall exceeds 1.25” has increased since 1940 in both Ames and Cedar Rapids. The number of such days had not exceeded 10 in any given year prior to the 1950s but has done so 5 times in Ames and 4 times in Cedar Rapids since the 1950s. Projected changes by mid 21st Century from one downscaled data set (A2 Scenario only) of rainfall for Ames shows percentage change of annual precipitation from 1961-2000 norm that ranges 5 to 30% and change in number of days with precipitation > 1.25” that ranges 5 to 18. At Iowa City, the ranges are -1 to -15% and -1 to -5 days, respectively.

Overview

Climate change means past weather conditions may no longer be predictive of future conditions, and it is necessary to reevaluate the use of climate information in community planning and hazard mitigation. The American Planning Association recognizes that events of record may be exceeded in the future due to climate change, urging, in its policy guide to planning and climate change, the use of climate scenarios in community planning (American Planning Association 2008). Climate scenarios may be defined in a number of ways as discussed below; however, salient to this report is that approaches are lacking for translating climate scenarios into hazard information (for example, floods are not a direct output of climate simulations). This report provides a baseline of climate change information for community planners in Iowa and discusses relevant climate data that may be used in estimating future hazards in support of the following goal:

Working in Iowa, identify barriers to and incentives for considering regional effects of climate change in hazard mitigation and other community planning processes.

- *Use predictive models and future data for risk assessment, risk management, and scenario planning*
- *Develop smart planning solutions that reduce risks and enhance community resilience*
- *Integrate these smart planning solutions into existing planning frameworks*
- *Consider broader changes to existing planning frameworks*

The intended audience of this report includes federal, state, and local planning entities. Climate information relevant to hazards is provided for the entire state as well as two communities, Story County and Coralville, both of which recently have completed hazard mitigation plans. The document is not meant to be a comprehensive review of potential climate model datasets or climate impacts for the Midwest. Instead, it is meant to be a practical resource by providing information specific to the problems of hazard mitigation of these two communities. By reading this report, government officials in Iowa should have the information needed and expressed in non-technical terminology to address the questions of (1) how is the climate changing in Iowa, and (2) what do changes in climate mean to these two communities in Iowa.

A critical point underlying this report is an understanding that climate model projections are not suitable for use as climate forecasts. A forecast requires future knowledge of climate drivers, such as human greenhouse gas emissions, solar variability, and volcanic eruptions. It is not possible to predict these drivers; that is, sources for climate predictability are themselves unpredictable. Even with this limitation, it is possible to examine the potential for emerging vulnerabilities as climate changes. An approach suitable for vulnerability analysis is to consider climate scenarios -- postulated sequences of future climate drivers – that predict climate conditions under a range of specified but possible changes in climate drivers (Nakićenović et al. 2000). A description of global climate scenarios used to generate the climate model projections described in this report is provided in Appendix A and summarized in the ***Data Sources*** section.

The use of scenarios requires thoughtful consideration of how to incorporate climate projections in hazard risk assessment. The use of potential future hazards in the context of flood insurance and hazard mitigation programs is innovative. For example, the use of future projections to support flood insurance programs is constrained by principle that flood insurance programs base premiums on current rather than future risk.

The relative newness of translating and integrating climate scenarios into local hazard information means understanding of how they may be useful in community planning is itself an innovative topic. Recent evaluation of the use of climate information in management decisions indicates that it is more likely to be useable when it is placed within the context of decision processes (Lemos and Morehouse 2005). Together, these findings strongly indicate a need for dialogue between planners and climate information producers to understand how planning approaches based upon risk estimates may be adapted to consider climate scenarios.

Giving a planning context to climate information is complex, because community and hazard mitigation plans are multi-faceted decision processes. A questionnaire was designed to learn from participants of the pilot project what climate data they used and how it was applied within planning decisions (Appendix B). From this questionnaire and informal discussions with participants, we have developed a preliminary list of some considerations planners make when crafting mitigation plans.

- Planners must link hazard risk to inventories of built structures and natural/societal resources in order to estimate potential losses.
- Climate information, such as rainfall and temperature, must be interpreted in light of hazards, such as floods, and community responses, such as energy usage and citizen willingness to participate in conservation programs.
- Planners rely upon well-developed best practices for hazard risk assessment in order to assure the information they use is of highest quality.
- The suite of mitigation and planning activities potentially funded by grant programs focuses the scope of hazard risks that are addressed and mitigation tactics that are considered.
- Mitigation of hazards in one community may impact the hazard profile of another, and climate change may alter differently the hazard profile of multiple communities.
- The points of entry of climate information may vary by community: land use plan, zoning designations, municipal ordinances, incentives for development and conservation, hazard risk estimates, and awareness (government officials and citizens).
- Planners may have limited staffs, and it is important that historical climate data and climate change projections are available and accessible at minimal cost to human resources.

This report supports the goal statement of this pilot project by providing a baseline of climate change information relevant to hazards for Iowa, including examples of local climate projections, and discussing approaches for translating climate information into hazard information. This information feeds into a second stage in which planners and government officials discuss the opportunities for using these climate data in hazard mitigation in light of the considerations outlined above and others. The report first describes statewide information on temperature and precipitation change, and associated changes in natural hazards. This serves as a point of reference for discussion of climate projections. The remainder of the report is focused on hazards for Story County and Coralville and is divided into sections that summarize relevant climate change information for floods and severe weather. Other natural hazards either are considered a low threat in the hazard mitigation plans of the pilot communities or have very little research completed in regards to their potential changes as inferred from climate model projections.

Data and Information Sources

Relevant Background Documents

Dr. Eugene S. Takle (Director, ISU Climate Science Program) has written a statewide summary of recent climate changes and projections for the Iowa Climate Change Advisory Council: "Assessment of Potential Impacts of Climate Changes on Iowa Using Current Trends and Future Projections." It contains sections on precipitation, temperature, wind speed, solar radiation, cloud cover, streamflow, soil moisture, tile drainage, tropospheric ozone, carbon dioxide, soil carbon, and plant growth. It is available by request. Send email requests to gstakle@iastate.edu.

Dr. Sara C. Pryor (Indiana University) has edited a collection of papers on climate change in the Midwest in *Understanding Climate Change: Climate Variability, Predictability, and Change in the Midwestern United States.* It includes chapters on Midwestern summer cooling trends, increasing lengths of the frost-free season, streamflow in the Upper Mississippi basin, extreme rainfall and severe weather.

Cornelia F. Mutel (Iowa University) has collected a variety of perspectives on the 2008 Cedar Rapids flood in *A Watershed Year: Anatomy of the Iowa Floods of 2008*. The book includes chapters on factors that contributed to the magnitude of the flood, discussion of flood forecasts, and description of the role of climate variability.

Joseph Barsugli, Christopher J. Anderson, Joel B. Smith, and Jason M. Vogel have co-authored an overview paper for non-technical audiences that contains descriptions of global climate models and methods for translating their results into regional and local climate information entitled "Options for Improving Climate Modeling to Assist Water Utility Planning for Climate Change". The report is available online at www.wucaonline.org/assets/pdf/actions_whitepaper_120909.pdf.

Historical Climate Data

Historical temperature and precipitation data were obtained from the State Climatologist Office and the Iowa State University Iowa Environmental Mesonet (IEM) archive. The State Climatologist (http://www.iowaagriculture.gov/climatology.asp) has selected 33 weather stations within Iowa as a subset of all weather stations that data records exceeding 100 years with minimal evidence of impacts by changes in landscape and measurement technique. The period of record is 1873-2008. These stations are considered the highest quality climate data within the state and are used in this report to compute state average data.

The IEM maintains an archive of surface weather measurements from a collection of many measurement networks. Data used in this report come from the IEM Climodat tool (http://mesonet.agron.iastate.edu/climodat/index.phtml). It contains data from the National

Weather Service Cooperative observer network that is the basis for the State Climatologists dataset. Individual stations, rather than state averages, are selected from the IEM data archive, all of which are included in the state average data obtained from the State Climatologist.

FEMA Region VII maintains a list of data sources for hazards. A subset of this list containing resources directly relevant to the pilot communities is provided in Appendix C. The full list is available by contacting FEMA Region VII. Additional hazard information used by the communities in this pilot project includes storm damage estimates archived by the National Climatic Data Center, FEMA Flood Insurance Rate Maps, Presidential Disaster declarations, and streamgauge measurements available from the United States Geological Survey.

Climate Projection Data: Global Climate Model Data

Global climate models (GCMs), driven by scenarios of global greenhouse gas emissions, provide the dataset from which projections of future local climate conditions are derived. Because future emissions of greenhouse gases are unpredictable – it depends on human choices, for example – a suite of possible future greenhouse gas emissions has been established and reported in the Special Report on Emissions Scenarios (Nakićenović et. al. 2000). The emissions rates are derived from a matrix of possible outcomes about how global regions interrelate, how

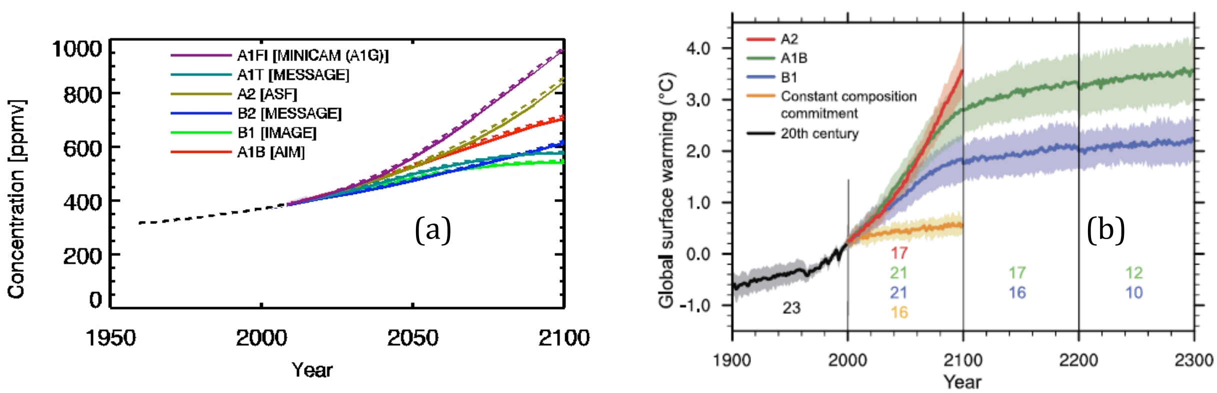

Figure 1. (a) Carbon dioxide concentration of global greenhouse gas emissions scenarios (http://www.ipcc-data.org/ddc_co2.html). (b) Average and range (given by shading) of global temperature change simulated by GCMs given emissions scenarios for the 21st Century.

new technologies diffuse, how regional economic activities evolve, how protection of local and regional environments is implemented, and how demographic structure changes. The outcomes are summarized in four scenario families (A2, A1, B1, B2). The assumptions of the scenario families are provided in Appendix A.

The GCM data used in this report are the output from driving GCMs with three emissions scenarios A2, A1B, and B1 that were chosen to represent the range of possible scenarios from the four scenario families (Figure 1a). The A2 scenario produces an increase of greenhouse gas emissions at rates similar to today. By the end of 2100, the global average carbon dioxide concentration in the A2 scenario is roughly 2.5-times the 2000 level. The A1B scenario reduces the rate of greenhouse gas emissions by mid-century, and the carbon dioxide concentration by

2100 is just under twice the 2000 level. The B1 scenario supposes rapid changes in technology and global collaboration to reduce greenhouse gas emissions immediately. The carbon dioxide concentration level in the B1 scenario stabilizes just under 1.5-times the 2000 levels. Carbon dioxide concentrations for these three scenarios and the global surface temperature projection from GCMs resulting from A2, A1B1, and B1 are given in Figure 1.

The realism of GCM simulations is established by means of a 20th Century scenario (20C) derived from observational estimates for solar variability, volcanic eruptions, and greenhouse gas emission inventories. Figure 2 shows the evolution of 20C global surface temperature from both GCM simulations and weather station measurements. The average global temperature of the GCM simulations (red line) replicates two warming periods in measurements (black line), one in the first 25 years and another in the final 25 years of the 20th Century. This result illustrates the potential utility of GCMs for prediction of future conditions when given precise estimates of future drivers, but they should not be considered a measure of expected accuracy of GCM projections of future conditions since precise estimates of future drivers are not available. This cautionary note is underscored by results from an alternative 20th Century scenario (20PI) in which greenhouse gas concentrations were held constant at pre-industrials levels. The average global surface temperature from GCM simulations (blue line) given 20PI diverges from measurements in the last quarter of the 20th Century. This provides evidence of the influence greenhouse gas increases has had on global surface temperature, and it illustrates the potential error in prediction should climate predictions employ inaccurate estimates of future climate drivers. Experiments to assess accuracy of long-range climate predictions (from years to decades) have been initiated recently, and results should be reported over the next 1 to 3 years.

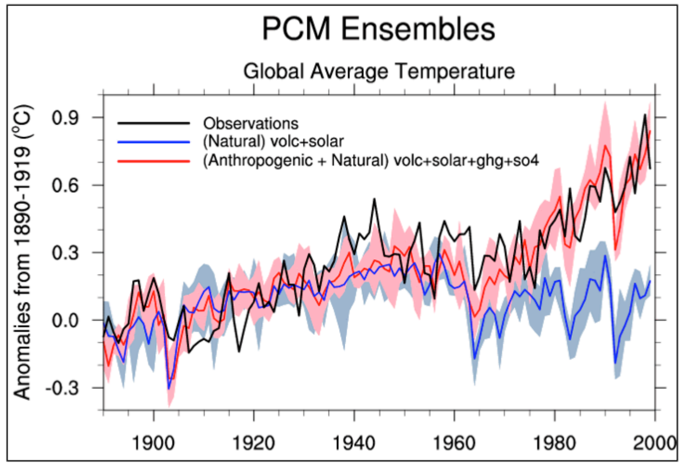

Figure 2. Global average temperature from measurements (black line), 20th Century scenario with solar cycles, volcanic activity, and greenhouse gas increases (red line; pink shading represents the range of GCM results), alternative 20th Century scenario lacking greenhouse gas increases (blue line, shading represents range of GCM results).

Regional and Local Climate Model Data

Community planning considers the impact of hazards over areas much smaller than resolved in global climate model data, which typically has a horizontal grid with data points spaced 1-2^{O} latitude apart. This disconnect in spatial detail means another layer of climate models must be used to translate global climate model data into local hazard data. The process of translating GCM data into local climate data is called downscaling, a name given because spatial detail is added by the technique (i.e. fine scale data is generated from coarse scale data). One consequence of downscaling is an increase in variability of projections within a region simply because variability of climate over short distances can be large. GCMs are incapable of simulating such details and, therefore, have fields with less variation. The approaches for downscaling are numerous, and the research community has not established a preferred generalized approach. The choice of which dataset is most appropriate is often based primarily upon the climate information needs of the data user, and the availability of the datasets that are often produced for the purposes of research studies rather than mass distribution. In this case, two datasets generated from downscaling methods that were designed to retain statistical consistency between GCM and historical data were chosen based upon two considerations: the ability to examine downscaled results from a large number of GCM projections and the ability to provide data at specific station locations, enabling direct comparison with historical station datasets that community planners have used.

A set of 112 climate projections was obtained from the Bias Corrected and Downscaled WCRP CMIP3 Climate Projections archive (http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/dcpInterface.html). The data were generated from empirical relationships between local data and GCM data produced by simulations that were given emissions scenarios A2, A1B, and B1. The data are available on a 1/8th-degree grid across the entire continental United States and are valid for the period 1950—2100. One disadvantage is the data set includes only monthly temperature and precipitation. The advantage of this data set is that it contains the largest number of projections available with resolution somewhat comparable to station measurements. This means the range of future values of monthly temperature and precipitation may be calculated and compared to station data, providing an indication of whether future conditions lie outside of the present range.

A second downscaled dataset was obtained to evaluate projections of daily precipitation to provide context for discussion of potential changes in floods. Similar to the dataset of monthly temperature and precipitation, the downscaling methodology establishes empirical relationships between measurements and GCM output (Schoof et al. 2010). The approach is applied to 10 GCM projections given the A2 scenario, and, therefore, represents a smaller range of potential future changes. Another key difference is the use of station measurements rather than 1/8th degree grid of interpolated measurements. This preserves a higher degree of spatial variability and permits comparisons at specific locations.

Climate Change Information: Statewide

Summary of Historical Statewide Climate Data

- The current climate normal is much wetter with milder temperature than much of the 136-year record. The current statewide annual average temperature is 48.3^{O}F and annual precipitation is 34.0” (Figure 3). Most of the statewide precipitation increase has come in the first half of the year and increases are larger in eastern Iowa.

- The most prominent change in climate in recent years is an increase in frequency of very wet years (years with precipitation exceeding 40”). Very wet years have occurred 9 times since 1940 (the midpoint of the data record) after occurring only 2 times prior to 1940.
- Annual statewide temperature has decreased slightly since the 1930s, and the increase in very wet years is directly related to the reduction of very hot years (10 prior to 1940 and 5 since 1940). Statewide winter temperature has increased more than summer, and on average there are about 5 more frost-free days than in 1950.
- Statewide impacts on hazard risk associated with these changes include the following.
    - Streamflow has increased 20-50% since 1940, and soils have been nearer saturation during spring more often in recent years compared to past years, increasing the risk of spring and summer river flood and expansive soils.
    - Flash flood risk has increased.
    - Thaw-freeze cycles are more frequent, raising risk to damage from expansive soil.
    - Surface wind speeds (at the standard measurement height of 10 m) have been reported to be declining over the last 30 years. This may mean incidence of poor air quality has become more likely.

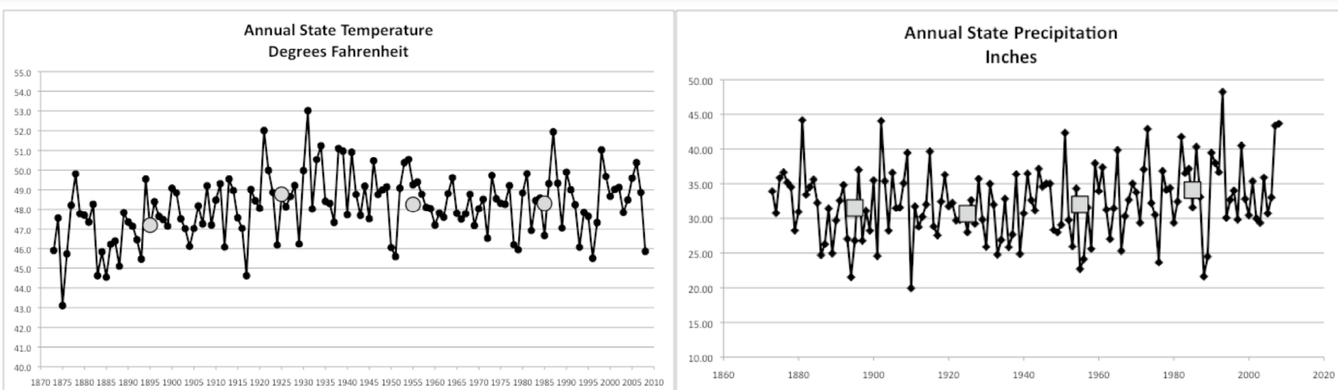

Figure 3. Statewide annual temperature and precipitation computed from State Climatologist 33-station data set. Grey-shaded boxes are 30-year average for 1881-1910, 1911-1940, 1941-1970, and 1971-2000.

Summary of Projected Statewide Climate Data

- Climate conditions for 2010—2025 are expected to be similar to the statistics of the recent 10-20 years. The reason for this is that the effect of the current climate cycle is projected to be larger than of increases in greenhouse gases for the next 10-15 years.
- The projected climate norm for 2045—2065 has the following range of plausible conditions (Figure 4).
    - The projected range of increase in annual temperature range is 2.5—7.2^{O}F. The high end is associated with precipitation conditions slightly wetter than the 1930s. This suggests dry

periods will be much, much warmer than the 1930s; while, wet periods will be slightly warmer than present. Thus, the risk of extreme heat is projected to increase.

- The range of change of annual precipitation is -15% to +10%, with primarily an increase of precipitation in the spring and wider range of precipitation change in the summer. This means the projections likely indicate an increase of risk for river flood, flash flood, and expansive soils, especially during the spring and early summer.
- The projection of drought risk is complicated in that risk for extreme heat is projected to increase, but the projected rainfall remains higher than historical drought periods.

Discussion of Historical Statewide Climate Data

The most reliable historical climate data are temperature and precipitation measurements made by cooperative observers for the National Weather Service (NWS COOP). The observers are trained by the NWS and follow standardized measurement procedures. The general public often hears reports of climate normal, and these reports are derived primarily from the NWS COOP data set, but it is infrequently reported that the standard for defining climate norms is dynamic, which is addressed below. State average precipitation and temperature are shown in Figure 3. While average measurements do not necessarily correspond directly with hazards, these data are standard summary climate measures and are presented here to provide context for comparison with climate projection data.

What is defined to be the climate norm is itself a dynamic standard. The World Meteorological Organization definition for computing the climate norm is to use measurements from the prior 30-year period ending at the most recent decade. The current 30-year averaging period is 1971—2000, and it will soon change to 1981—2010. Thirty-year averages are shown in Figure 3 for 1881—1910, 1911—1940, 1941—1970, and 1971—2000. Fluctuations of the 30-year average are evident with a range of 47.2 to 48.8^{O}F for temperature and 30.7 to 34.0” for precipitation. The most recent 30-year period is the wettest (34.0”) of the 4 periods, and its temperature (48.3^{O}F) is near the center of the range. This means Iowa’s weather is much wetter with milder temperature than much of the past 136 years.

Changes of climate may be evident through either a gradual change of annual data occurring over many years (e.g., long-term trend toward wetter conditions) or changes in frequency of unusual events (e.g., increase frequency of heavy rainfall). In Iowa’s temperature and precipitation record, year-to-year fluctuations are much larger than the long-term gradual change in annual data (Figure 3). This means long-term trend of annual data is essentially negligible, even if it is noticeable in annual temperature during 1873—1930.

A different story emerges when examining frequency of unusual years. A definition of very wet and dry years in Iowa is a year in which precipitation exceeds 40” or is less than 25”, respectively. Since 1940 (the midpoint of the data series), very wet years have occurred 9 times and prior to 1940 they have occurred 2 times. In contrast, dry years have similar frequency before and after 1940 (7 versus 6). A hot year in the time series of Iowa’s temperature is one in which annual temperature exceeds 50^{O}F, and a cold year as one in which annual temperature is less than 46^{O}F. The frequency of hot years is much less since 1940 (5 versus 10), and cold years have occurred with similar frequency before and after 1940 (7 versus 6).

The increase in frequency of heavy rainfall is a change noted across the entire United States. However, rainfall changes are largest across the northern United States, where it is widely regarded in the scientific community as one of the more remarkable changes in the United States Climate (CCSP 2008). What is unique about Iowa is the capacity of its soil to hold large amounts of water. As a result, years of unusual rainfall and temperature are related to one another. Hot years occur more frequently during extended periods of low rainfall (such as the 1930s), and this interplay between rainfall and temperature partly explains the recent absence of very hot years.

There are statewide changes in hazard risk associated with recent changes in temperature and precipitation and many of these are summarized in the document prepared for the Iowa Climate Change Advisory Council by Dr. Takle:

- Most of the statewide precipitation increase has come in the first half of the year and increases are larger in eastern Iowa. This means soils are nearer saturation during spring more often in recent years compared to past years, increasing the risk of river and flash flood and expansive soils, especially in the spring and early summer months.
- Surface wind speeds (at the standard measurement height of 10 m) have declined over the last 30 years. This may mean incidence of poor air quality has become more likely.
- Statewide winter temperatures have increased more than summer, and on average of there are about 5 more frost-free days than in 1950. This means thaw-freeze cycles are more frequent.

Discussion of Statewide Climate Projection Data

Climate projections provide plausible future conditions of temperature and precipitation, given a scenario of future greenhouse gas emissions. The impact of the current climate cycle on future conditions is expected to be more important than that of increases in greenhouse gases for the next 10-15 years. During this period, the climate norm is expected to be similar to the current climate norm.

The future period 2040—2069 should be much less impacted by the current climate cycle. Projected changes between the climate norms of 2040—2069 and 1970—1999 for statewide annual temperature and precipitation are shown in Figure 4.

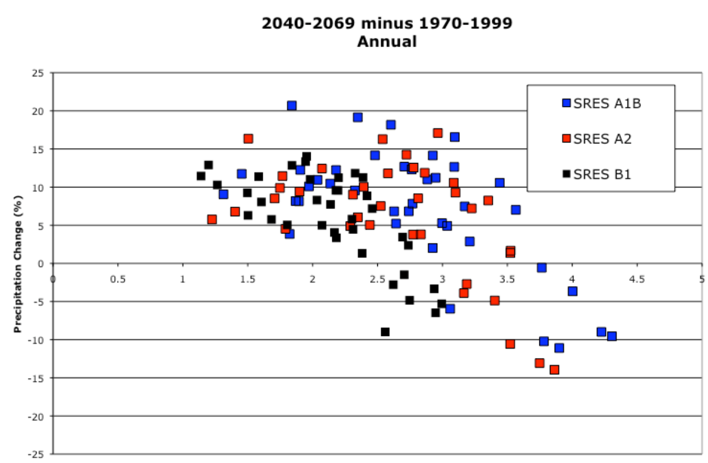

Figure 4. Difference of climate norms between 2040—2069 and 1979—1999 expressed as temperature difference (^{O}C) and precipitation percentage change for each of 121 climate projections.

The range of warming by mid-century is 2.5—7.2^{O}F, which is greater than the 1.6^{O}F difference in norms during the 20th Century. The range of precipitation change is -10% to +15%. The top end of this range is comparable to the 10% increase of the climate norm during the 20th Century (30.7" to 34.0").

The relationship between higher temperature and drier conditions is evident in the climate projections. This implies that periods of dry conditions, similar to the 1930s, are likely to be much warmer than the 1930s; whereas, periods of wet conditions are expected to be only slightly warmer than present.

The change in seasonality of precipitation is projected to continue into the mid 21st Century. Rainfall increases are projected in the springtime, but in summertime the range of projections includes both drier and wetter conditions. This means climate projections point to continued wet soils and increases in streamflow, particularly in spring and early summer. Since the percentage change of the projections is similar to the percentage increase of the 20th Century, it is reasonable to expect streamflow to increase at least 20%. This means the risks of river flood, flash flood, and expansive soils are likely to be higher.

The projection of greater range of summer dry and wet conditions has implications for drought and heat waves. Summer dry conditions are projected to cause conditions warmer than the 1930s, implying a significantly higher risk for extreme heat. A more complicated picture emerges for drought as a projection of 10% precipitation decrease still means precipitation exceeds that of the 1930s.

Climate Change Information for Hazards: River Flood and Flash Flood

Summary of Historical Data

- The Ames hazard mitigation plan used FIRM and a city-approved flood plain study to identify the 100-yr floodplain (regulatory floodplain) from past discharge records. Recent damage estimates were tallied from NCDC storm damage reports and estimated losses were computed by incorporating floodplain maps into HAZUS-MH. Based on these data, the community determined the future probability of a flood event is similar to recent history such that one is likely to occur within the next 25 years.
- The Story County multi-jurisdiction hazard mitigation plan reviewed FIRMs, descriptions from residents and media reports, library historical data, past disaster declarations, and USGS maps. Historical frequency (based upon past 25 years) and future probability (likelihood of recurrence in one year, ten years, and 100 years) were similar in Cambridge (at least one chance in next 10 years), Maxwell (nearly 100% chance in next year), Nevada (nearly 100% chance in next year), Slater (nearly 100% chance in next year), Story City (nearly 100% chance in next year), Zearing (at least in one chance in next 10 years), Unincorporated (nearly 100% chance in next year).
- Rainfall measurements that correspond closely to flood incidence have not been widely established. The reason for this is that flood incidence depends on the travel time of water within the river network feeding into a community. This means rainfall from two days and 100's of

miles away prior to a flood may be as important as rainfall the day of a flood within the community. The appropriate rainfall measurement is likely to be community dependent, though one study has identified for the Midwest a modest correlation between flood damage and frequency of two-day rainfall (Pielke and Downton 2000).

- Daily rainfall is the metric most readily available to planners participating in this pilot project. A relevant measure for planners is an engineering design criterion for water quality management of storm water for which storm infiltration amount of 1.25” is required. The frequency of days in which rainfall > 1.25” occurs has increased since 1940 in both Ames and Cedar Rapids, consistent with a statistically significant increasing trend of very high daily rainfall rates across the Midwest region (CCSP 2008). The number of such days had not exceeded 10 in any given year prior to the 1950s but has done so 5 times in Ames and 4 times in Cedar Rapids since the 1950s (Figure 5).

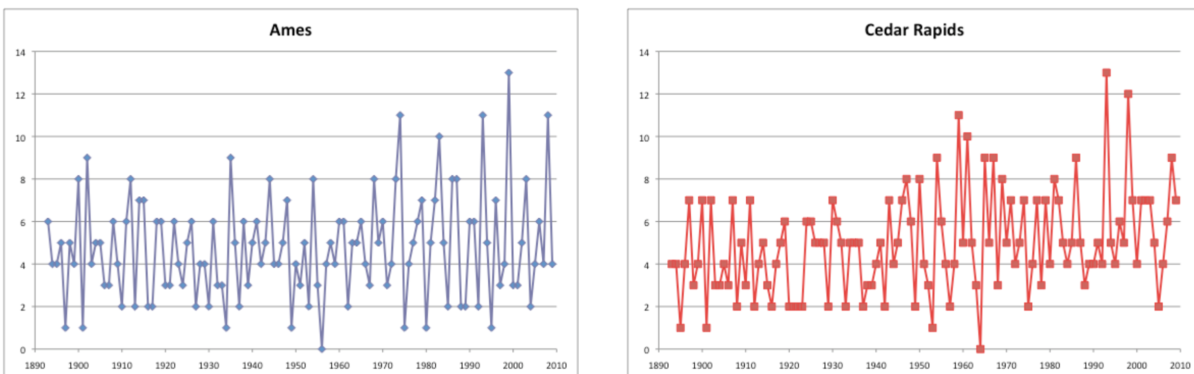

Figure 5. Number of days exceeding 1.25” at weather stations in Ames and Cedar Rapids.

Summary of Climate Projection Data

- Recent rainfall measurements in the community and neighboring communities are likely the best guidance of expected rainfall statistics for the next 10-15 years.
- Climate projections of daily rainfall are highly experimental datasets. They generally contain greater spatial variability, i.e., larger range of values, than GCMs, due in part to local climate variability they include that is not resolved in GCMs as well as the variety of approaches that may be used to generate them. Projected changes by mid 21st Century from one downscaled data set (A2 Scenario only) of rainfall for Ames shows percentage change of annual precipitation from 1961-2000 norm that ranges 5 to 30% and change in number of days with precipitation > 1.25” that ranges 5 to 18 (Figure 6). At Iowa City, the ranges are -1 to -15% and -1 to -5 days, respectively.

Discussion of Historical Data

Rainfall is the climate measurement most closely related to flood incidence. However, research of 2008 Cedar Rapids flood by the Iowa Flood Center (IFC) has revealed the most useful rainfall measure for a particular community is determined by characteristics of the river system in which the community resides. This may explain why studies of various measures of rainfall have found that rainfall extremes in this region relate to about half of flood events and explain about half to two-thirds of annual variability in flood damage (Kunkel et al. 1993, Pielke and Downton 2000). The IFC results indicate the best rainfall measurement will need to be accumulated over a characteristic area for a characteristic time period that are both unique to each community. This means the most direct measure of flood risk available to planners at present is not rainfall but, instead, the historical record of flood elevation relative to existing structures as well as measurements from nearby stream gauges.

The hazard mitigation plans of Ames and Story County have used a variety of historical data sources to estimate past flood occurrence and losses and to extrapolate future flood probability and losses. These information sources include FIRMs, floodplain maps generated by engineering consultants, media reports, descriptions from residents and emergence management professionals, disaster declarations, and USGS stream gauge data and maps. Both mitigation plans concluded the likelihood of a flood in the future is similar to recent past.

Summary of Climate Projections

Climate projections that provide daily rainfall data at historical measurement sites are generally experimental research datasets. Generally, GCM rainfall processes poorly replicate real-world processes in the Midwest, such as nocturnal rainfall maximum and dependence between rainfall and night-time wind fields (Ghan et al. 1996). Projections are provided, therefore, from the stochastic downscaling technique of Schoof et al. (2010) that relates daily rainfall to broad scale weather conditions. These relationships are diagnosed from historical measurements and used to simulate rainfall frequency and amount given data from 10 GCMs that were driven by the A2 emissions scenario. While the results illustrate none of the variability due to consideration of emissions scenario, it more completely represents the spatial variability of rainfall in the Midwest.

It is widely reported that future climate conditions are expected to be supportive of increases in extremely high daily rainfall amounts. This is based upon an expectation of greater atmospheric moisture content, resulting from warmer ocean temperatures, particularly in the Gulf of Mexico and Caribbean Sea, and warmer atmospheric temperature.

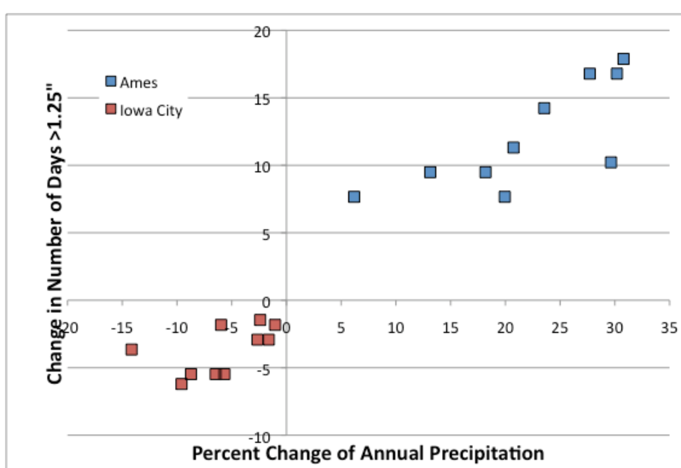

Figure 6. Projected change from 1961-2001 for 2046-2065 (A2 scenario only) of annual precipitation (percent change from present) and number of days with precipitation exceeding 1.25" for station locations

Figure 6 shows projected changes for station locations in Ames and Iowa City. It shows the range of variability in rainfall statistics that is typical of climate projections that replicate the spatial variability of rainfall in the Midwest. Results for Ames and Iowa City have opposite signs with projections showing increases for Ames and decreases for Iowa City of annual precipitation and number of days with precipitation > 1.25”. At the low end, the projected number of days with precipitation > 1.25” at Ames is a 50% increase above the maximum year in the historical record. In contrast, Iowa City shows a reduction to the frequency observed prior to the 1940s.

Statistics at both stations deviate from regional averages taken over more than 900 stations in the Midwest. Schoof et al. (2010) report over this region the rainfall amount of rainy days that occur with 5% frequency (about 18 per year) and 1% frequency (about 3-4 per year) both increase by 0.1” and 0.2”, respectively. In the Ames projection, they increase by 0.3” and 0.5”, and in the Iowa City projection, they decrease by 0.1” and 0.3”, respectively. Thus, the projection for high rainfall days in Ames is that their intensity will increase by about 10-20%; whereas, at Iowa City, their intensity is projected to decrease by 15-25%.

Opportunities/Barriers to Incorporating Climate Projections

The lack of clear correspondence between traditional rainfall measurements and flood incidence produces a strong barrier to using historical and future rainfall information in mitigation planning. The reason is that it prevents the rainfall measurements from being a predictor of inundation, and an inundation map is needed to estimate damages and economic loss.

A secondary barrier may be the intrinsic variability of rainfall itself. The ranges of downscaled results for Ames and Iowa City are very large, even before considering the differences between the two station locations. Part of the variability reflects the uncertainty inherent in relating rainfall to broad weather patterns. There are simply many situations in which subtle changes in broad weather patterns significantly alter the intensity and location of rainfall. This is why differences among the GCMs in weather characteristics such as low-level wind fields, atmospheric moisture, and position of storm tracks can produce large ranges in rainfall projections. However, it is not expected that future generations of GCMs will significantly reduce the range of results. Rather, the path forward should be more productive, particularly for identifying potential vulnerabilities, if the range is more completely filled in with a large number of local projections. This will better inform planners of extreme and moderate projections.

These barriers suggest two opportunities for researchers to improve the information available to planners. First, climate scientists should intercompare local projections from multiple downscaling techniques in order to be able to articulate whether daily rainfall projections are highly sensitive to the downscaling methodology. The optimal intercomparison would develop community-specific rainfall measures that accurately connect rainfall to the flood hazard associated with the community’s river system.

A second opportunity for incorporating climate projection information into flood hazard mitigation lies in approaches for computing future flood probability. The city of Ames provides an example of how a path forward might be developed. They have relied upon advanced hydrological modeling to better delineate a portion of their floodplain in the aftermath of the 1993 flood. Although their purpose was to better delineate floodplain boundaries, hydrological models may be used more broadly within land use and climate change scenarios. This is done to some extent already in the practice of design storms. Design storms are sometimes described as worst-case scenario rainfall events. The design storm rainfall is used to generate streamflow data that serve as input into flood inundation models to provide maps of areas inundated under the conditions of a worst-case scenario rainfall. This process should be adaptable so that it may incorporate rainfall data from climate projections and should produce what might be called future design storms. The approach may be generalized to incorporate not only alternative rainfall statistics but also alternative land use characteristics.

Climate Change Information for Hazards: Severe Weather

Summary of Historical Data

- The Ames Hazard Mitigation Plan uses reports of tornado, wind, and hail archived by NOAA since 1950 to count historical frequency of severe weather events, determine annual occurrence rates and losses, and estimate future occurrence and losses. From these reports, the likelihood of a severe weather event in the next 25 years is rated as "high" with a "low" impact on people and the economy.
- Recent reports of severe weather are far more numerous than prior to the 1970s, particularly for weak tornadoes and windstorms. Severe weather awareness campaigns and increasing public interest in storm chasing and filming extreme weather events are suspected to be primary factors in this increase. Thus, trends in severe weather reports due to changes in weather patterns are highly uncertain. Furthermore, the best estimates for severe weather frequency and intensity are from the past 20-25 years, when the public was more actively involved in reporting severe weather. Though, this record is too short at any one location to estimate the expected severe weather frequency, it is possible to aggregate reports over large regions to ascertain a regional risk for severe weather. A database available from the National Severe Storms Laboratory indicates….

Summary of Climate Projections

- Climate models do not directly simulate severe weather events. It is not possible to directly compare climate model output to historical severe weather records or to evaluate future severe weather intensity or frequency.
- An alternative is to examine weather conditions favorable for severe weather occurrence in observations and climate model simulations. Projections from a single downscaled simulation of a single GCM given a single emissions scenario (A2) indicates changes in severe weather frequency are more likely in the summer months, when the number of days favorable for wind and hail may increase.

Discussion of Historical Data

Historical reports of severe weather (tornadoes, wind, and hail) are filled with reporting inconsistencies (Brooks and Doswell 1998). Chief among the factors is the increasing willingness of the general public to provide reports since the 1970s. The national number of tornado reports has more than doubled; hail and windstorm reports have increased even more. Although the NOAA archive of severe weather reports extends back to the 1950s, reporting inconsistencies essentially render useless all but the past 25 years of reports at any particular location.

The short record combined with relative infrequence of severe weather means the time period of local datasets are too short to accurately estimate probability of severe weather. One approach to overcome short time periods is to aggregate reports over large areas. The National Severe Storms Laboratory (NSSL) has developed an averaging procedure that defines broad patterns of severe weather risk. Plots are available online at http://www.nssl.noaa.gov/hazard/totalthreat.html, and they show the historical frequency of potentially damaging tornadoes is 1 in 4 years.

A less precise approach is to build statistical relationships between weather variables and severe weather reports. This enables the development of a longer record of favorable conditions that should a thunderstorm form it would be likely to produce severe weather. The areas of relative risk for severe weather are consistent with the NSSL estimates of risk.

Discussion of Climate Projection Data

Climate models do not directly simulate severe weather events. Furthermore, GCMs may poorly replicate the conditions associated with severe weather. Instead, it is necessary to use downscaled data sets from using regional weather models that better represent weather spatial patterns of conditions related to thunderstorms and severe storms.

Detailed analysis for the late 21st Century of a single regional simulation indicates frequency of favorable severe weather conditions is most likely to be effected in summertime. Increases of atmospheric moisture and reductions in frequency of days with high wind speeds far above the surface could add 5-10 days on average for which conditions are favorable for hail and brief, but intense, windstorms (Trapp et al. 2009).

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Appendix A: Description of IPCC AR4 climate scenarios

The following information is taken from the IPCC Special Report on Emission Scenarios Summary for Policymakers (IPCC 2000).

The A1 storyline and scenario family describes a future world of very rapid economic growth, low population growth, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into four groups that describe alternative directions of technological change in the energy system.1

The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in high population growth. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.

The B1 storyline and scenario family describes a convergent world with the same low population growth as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with moderate population growth, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

Appendix B: Questionnaire provided to pilot project participants
Climate Change Information Questionnaire

List Your Profession:
List the agency for which you work:

(1) Describe the ways in which climate data are used in your current professional activities?

(2) If you do not use climate data directly (such as temperature and precipitation), please describe any environmental data you use that is derived from climate data. This may include data sets such as flood plain maps and heat indices.

(3) From what sources (organizations, websites, other media) do you obtain climate data currently used in your professional activities?

(4) How useful are these data for your needs?

(5) Are they readily accessible and in a format optimal for your use?

(6) Please explain how these data could be improved?

(7) Please describe the information from Dr. Takle's review that is most relevant to your professional activities. The document title is: **Assessment of Potential Impacts of Climate Changes on Iowa Using Current Trends and Future Projections.** It is available from the EPA Pilot project ftp site http://drop.io/IowaAdaptationPilot/Climate Change Iowa-13.doc.

(8) Please describe whether the information is presented in a way that is understandable to you and appropriate for outreach activities.

(9) Please describe what information might be added to Dr. Takle's review that is relevant to your professional activities.

(10) What is the best method to provide information and updates to you about expected climate change and the implications for communities?

Appendix C: List of historical climate data resources

http://www.nwo.usace.army.mil/html/op-e/EOCFloodsandDroughtResources.htm
http://www.usgs.gov/hazards/
http://webra.cas.sc.edu/hvri/products/sheldus.aspx
http://www.ncdc.noaa.gov/oa/ncdc.html
www.fema.gov/about/contact/regions.shtm
http://www.policymap.com/map
http://webra.cas.sc.edu/hvri/products/sovi.aspx
http://www.epa.gov/smartgrowth/
http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwEvent~Storms
http://www.nssl.noaa.gov/hazard/hazardmap.html
http://www.hprcc.unl.edu
http://www.ncdc.noaa.gov/oa/climate/regionalclimatecenters.html
http://www.colorado.edu/hazards
www.rma.usda.gov/data/cause.html
http://content.asce.org/ASCELeveeGuide.html
http://npdp.stanford.edu/index.html
http://www.fema.gov/library/viewRecord.do?id=3122
http://www.drought.gov/portal/server.pt/community/drought_gov/202
http://drought.unl.edu/plan/handbook/risk.pdf
http://earthquake.usgs.gov/earthquakes/states/
http://earthquake.usgs.gov/earthquakes/eqarchives/
http://earthquake.usgs.gov/
http://pubs.usgs.gov/fs/fs-131-02/fs-131-02.pdfhttp://earthquake.usgs.gov/earthquakes/states/?old=kansas/kansas_history.html
http://www.nws.noaa.gov/om/heat/index.shtml
http://www.nws.noaa.gov/om/windchill/index.shtml
http://www.nws.noaa.gov/om/brochures/heat_wave.html
http://www.crh.noaa.gov/pub/heat.htm
http://msc.fema.gov
www.fema.gov/plan/prevent/floodplain/index.shtm
http://www.fema.gov/plan/prevent/floodplain/data_tool.shtm
http://www.fema.gov/plan/ffmm.shtm
http://jfsp.nifc.gov/projects/01-1-6-08/01-1-6-08_final_report.pdf
http://www.ncdc.noaa.gov/oa/climate/severeweather/tornadoes.html#maps
http://www.nssl.noaa.gov/hazard/hazardmap.html
http://www.nssl.noaa.gov/primer/wind/wind_basics.html
http://library.thinkquest.org/05aug/01462/NaturalDisasters/blizzzard.htm
http://webra.cas.sc.edu/hvriapps/SOVI_Access/SOVI_search.aspx?Region=state&State=Iowa&Search=Submit+Query
http://www.agcensus.usda.gov/Publications/2007/Online_Highlights/County_Profiles/Iowa/index.asp
http://www.agcensus.usda.gov/Publications/2007/Full_Report/Volume_1,_Chapter_2_County_Level/Iowa/st19_2_008_008.pdf
http://www.extension.iastate.edu/newsrel/hail.html#flood
http://drought.unl.edu/risk/us/iowa.htm