**Multihazard Loss Estimation Methodology**

**Open HAZUS®MH**

**Whitepaper**

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For:

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**Executive Summary**

HAZUS’ mission is to combine science and technology to support FEMA’s mission of “…leading and supporting the Nation in a risk-based, comprehensive emergency management system of preparedness, protection, response, recovery, and mitigation.” HAZUS is maintained and operated with the Risk Mapping, Assessment, and Planning (Risk MAP) program and supports its vision to “…deliver quality data that increases public awareness and leads to action that reduces risk to life and property.”

**I. Introduction**

The purpose of this whitepaper is to define the functionality, external interfaces, performance, attributes, and design constraints of Open HAZUS. It is based on a Product Requirements Assessment (PRA) focused on the major capabilities and features needed by its stakeholders. This document will not define additional capabilities but focuses on the provision of the capabilities as defined in the PRA. Because Open HAZUS will be distributed for free by the federal government, other topics, such as pricing, competition analysis, marketing issues, are not relevant and are not addressed.

**I.1 Background**

**I.1.1 The current status of HAZUS-MH**

Hazard US (HAZUS) is a software suite within the risk mapping, assessment and planning section (Risk MAP) of the Federal Insurance and Mitigation Administration (FIMA) of the Federal Emergency Management Agency (FEMA) that is one of over 20 top-level units of the Department of Homeland Security (DHS). FEMA started HAZUS in 1992 as a request from the National Academy of Sciences based on the finding that no nationally consistent natural hazards loss estimation methodology was available that met the needs of the emergency management community for quantitative risk assessment. The earthquake risk assessment methodology and modeling was established in 1997 with the help of the National Institute of Building Sciences utilizing GIS-based software applications. HAZUS exclusively modeled earthquakes until 2004, when it expanded to include flood and wind loss estimation capability models. With the top scientific and engineering minds working on it, HAZUS continues to improve the speed of its software, level of analysis, community involvement, and functionality.

HAZUS provides a cost-effective method of identifying and addressing the impacts associated with a natural disaster. It allows the user community to develop policies for preparation, protection, response, recovery, and mitigation for natural hazards and decrease the risk of future loss and damages within the community. HAZUS is also used in the development of Disaster Mitigation Act (DMA) and Hazard Mitigation plans to provide critical information for decision makers. The default datasets and parameters included with HAZUS, detailed analysis, and expert knowledge provide an effective risk assessment tool. The overall objective of the existing HAZUS project is to implement a nationally applicable set of standardized multi-hazard methodologies for estimating potential wind, flood, and earthquake losses on a regional basis. The multi-hazard HAZUS is intended to be used by local, state, and regional officials for risk assessment, planning and stimulating mitigation efforts to reduce losses from hurricanes, severe floods, and earthquakes and preparing for emergency response and recovery following these events. Local, state, and federal authorities and policies are driving the need for the HAZUS-MH software package as specified in NEHRP, NHRAP, and NWHRP (Reference needed) and exemplified by the need to provide risk assessments for state-owned infrastructure. Depending on the capability built in for each hazard, HAZUS-MH is also be used to prepare a real time (rapid loss) estimate following an event. HAZUS-MH has shown to be capable of integrated multi-hazard loss estimation with the following major features:

* Models for earthquakes, floods, hurricanes and tsunamis
* Capability to run both deterministic and probabilistic scenarios
* A single, integrated set of functions for study region creation for all three models
* Geographic Information System (GIS) functions
* Capability to receive user-supplied input for all three models to generate more refined loss estimations
* Varying degrees of real-time analysis for each hazard
* State-of-the-art software, fully documented with metadata for all databases

**I.1.2 Changing administrative environment**

Parallel to the development of HAZUS-MH, FEMA’s Risk MAP program has undergone organizational changes that result in new regulatory requirements, e.g., for flood risk reporting. Another application of the HAZUS-MH software is the allocation of NEHRP allocation of grants based on risk assessments developed using HAZUS-MH. Crisis Action Teams (CAT) and the FEMA Preparedness Program now are active users of a software suite that was not designed for near real-time applications. As a result, the current user interface, which was designed for user with specialized skills is not serving this not anticipated community. Similarly, the MSC is now using HAZUS-MH to better support community risk cases – a task for which this software, in its current incarnation is ill-prepared for.

In an age of increasing extreme weather events, applied researchers in a range of social and natural sciences are dealing with the complexities of long-term planning of settlement patterns, protective infrastructure, public health, etc., widening the scope of the academic communities interested in working with HAZUS-MH and, in turn, providing input to further modelling efforts related to HAZUS-MH.

**I.1.2 Changing software environment**

HAZUS-MH is distributed free of charge. However, it is designed to run as an extension to the commercial GIS software ArcGIS Desktop, developed and distributed by ESRI, Inc. This software costs approximately $6,500 per seat, which is cost-prohibitive for many potential users. ESRI is phasing out its development of ArcGIS Desktop in favour of a more modern architecture called GIS Pro. HAZUS-MH is so tightly integrated with the dynamic link libraries of ArcGIS Desktop that a switch to ArcGIS Pro would require a complete overhaul / rewrite of HAZUS-MH. While there are other reasons to pursue “open” solutions (see section 1.2), this outside forcing precipitates the need to redesign HAZUS-MH to be independent of external GIS viewers and provides the opportunity to pursue a new set of requirements in Chapter III.

**I.2 Purpose**

Parallel but independent of the push factor described in I.1.2, members of the HAZUS community have been discussing ways to improve HAZUS-MH and to broaden its scope (see I.3). These discussions center on the term “open”, which has different connotations for different audiences. The dependency on ESRI software was initially an advantage for HAZUS(-MH) because the technically well-versed users all have GIS experience and ESRI’s ArcGIS Desktop platform has been the most widely used GIS in the United States for many years. The functionality of HAZUS (-MH), however, does not necessitate a GIS at all. One interpretation of “open” hence is to think of Open HAZUS as toolbox of multi-hazard methodologies that may but do not have to use GIS to visualize the spatial distribution of the risks to which ever assets the user is interested in. As the community of stakeholders working with spatial data spreads beyond traditional GIS users, the range of potential users of Open HAZUS is likely to multiply.

The tight coupling of HAZUS-MH with ArcGIS Desktop put a significant burden on users who want to customize the software and extend its capabilities. Power users would benefit from two different aspects of an open software architecture for HAZUS. One is a highly modularized system that acts like the above-mentioned toolbox, where each tool is well documented and can be accessed via an Application Programmer’s Interface or API. The other aspect is “open” as in free and open source software (FOSS), which would make it even easier to customize HAZUS for many uses beyond its original scope. Especially the FOSS interpretation of “open” would increase a much requested transparency, allowing users to see what is happening under the hood and hence trust the model outcomes.

**I.3 Scope**

The above described purpose determines the requirements that Open HAZUS has to support.

① Loss estimation tool. While Open HAZUS may develop into a universal natural hazards support tool system, its core application that takes precedence over all other potential demands is to fit the mission of FEMA, and here particularly the Risk MAP program. Any rewrite of HAZUS-MH will have to fulfil its current set of capabilities (except modelling of hazards).

② Data/results-sharing platform. A first expansion of these capabilities is for Open HAZUS to link seamlessly with MIP and act as a viewing platform for level 0 and level 1 authoritative results. This includes a standardized way of storing and accessing metadata, including the lineage of how the data was created – even if this happened outside of Open HAZUS. The standards requirements for metadata, as defined by FGDC and OGC, have to be adhered to.

③ Support import and integration of authoritative hazard data. In the spirit of openness, as outlined in section I.2, Open HAZUS must be able to integrate authoritative data from the USGS, as well as OLD engineering data. Parallel to that, stakeholders should be able to upload user-defined hazard data with standardized QA/QC measures to a sandbox, where it can be accessed by authority-granting FEMA personnel who may add that data to a public domain repository with FEMA’s stamp of approval after it has passed internal quality control.

④ Modularization. One of the advantages of a thorough overhaul of the HAZUS software architecture is the possibility to create a library of modules that encapsulate individual processing steps. Experienced users and developers should then be able to create their own workflows, adapting them to agency and application needs.

⑤ User-friendly GUI. The current user interface is to a large degree driven by the GIS software that HAZUS-MH is an extension of. With its separation from GIS, Open HAZUS’ user experience can be improved significantly. Whereas HAZUS-MH was always conceived as a desktop- (workstation) based software, Open HAZUS should be open to serve stakeholders in a web-based, desktop-based, and even mobile environment. Not all functions will be available in all environments, but the transition should be seamless from a UI/UX perspective.

⑥ Secure/private data integration. An estimated ten percent of HAZUS stakeholders are working with PCII and PII data that require secure storage, access and communication mechanisms. Conversely, the far majority of Open HAZUS stakeholders will be better served by web services. As Open HAZUS is built around the latter, the needs of secure or private data integration on desktop and mobile computers must be addressed without impacting the UI/UX design of the majority.

⑦ Improve HAZUS-provided inventory data. A significant obstacle to a more wide-spread use of HAZUS-MH is the amount of effort it takes to create inventory data. In recognition of this impediment, FEMA has, in cooperation with DHS’s HIFLD support team developed an incomparable resource of some 16 GB of level 0 data and the Comprehensive Data Management System, CDMS. While it is a good start for authorities who do not have the personnel resources to develop their own inventories, the demands have outgrown census tract-level analyses and with the availability of building-level data, expectations have grown for CDS to provide a centralized national building data set. Analog to ② and ③, and with the move to a web service environment, users should be able to upload their own improved inventory data into access-limited sub-clouds. As with the flood data in ③, a process should be established that allows to merge higher quality inventories with the main repository.

⑧ User must not pay to use HAZUS. Open HAZUS as a methodology toolset should remain free, as is the access to core national datasets. Private for-profit entities may be charged a fee for usage that exceeds five percent of the Open HAZUS server load.

⑨ Must be thin client. For most stakeholders, i.e., those that are not working with private or secure data, most of the data and all the processing should occur on a (web) server. One of the main issues with HAZUS-MH is that software updates must be synchronized with updates for the operating system, the GIS software, and often conflict with other locally installed software. Many HAZUS-MH installations are therefore isolated from the rest of the enterprise workflow, requiring significant hardware and software resources and maintenance, and impacting the overall security of the installation. A thin client consists of a relatively small application that can be installed on a variety of platforms such as MS Windows, Mac OS, Linux, Chrome, iOS, Android, etc.

⑩ Ability to automize workflows. A number of model runs can take quite a while to be executed, especially if users want to run an ensemble of scenarios. It is therefore desirable to have the ability to run complete workflows in batch mode without any user interaction.

**I.4 Definitions, Acronyms, and Abbreviations**

AAL Average annualized loss

AAR After action report

AEBM Advanced Engineering Building Model

BFE Basic Flood Elevation

BIT Building Import Model

ADCIRC [ADvanced CIRculation model](http://adcirc.org/) for oceanic, coastal and estuarine waters, developed at UNC

CAS Chemical Abstracts Service registry number

CAT Crisis Action Team

CDMS Comprehensive Data Management System

CDS Customer and Data Services, section of FIMA’s Risk Management Division

CERT Community Emergency Response Team

CEMP Comprehensive Emergency Management Plan

COG Continuity of Government

COOP Continuity of Operations Plan

CISM Critical Incident Stress Management

CIKR Critical Infrastructure and Key Resources

CNMS [Coordinated Needs Management Strategy](https://www.fema.gov/media-library-data/1521832299221-9e218ec1310c357befe493e534482673/CNMS_Technical_Reference_Feb_2018.pdf)

DEM Digital Elevation Model

DHS (United States) Department of Homeland Security

EF Essential Facilities

FEMA Federal Emergency Management Agency, a unit of DHS

FGDC Federal Geographic Data Committee

FIMA Federal Insurance and Mitigation Administration, a unit of FEMA

FIRM Flood Insurance Rate Map

FIS Flood Insurance Study

FIT Flood Information Tool

GBS General Building Stock

GBT General Building Type

GIS Geographic Information System

H\*WIND Hurricane Surface Wind Database

H&H Hydrologic and Hydraulic (modelling studies)

HEC Hyrdoligic Engineering Center (of the U.S. Army Corps of Engineers)

HEC-RAS HEC’s river Analysis System that models the hydraulics of water flow through natural streams

HFT Hazard Factor Tables

HIFLD Homeland Infrastructure Foundation-Level Data

HPLF High Potential Loss Facilities

HVA Hazard Vulnerability Assessment

HSEEP Homeland Security Exercise and Evaluation Program

INCAST Inventory Collection and Survey Tool

LFD Letter of Final Determination

LOMR Letter of Map Revision

MAP Mapping, Assessment and Planning

MIP Mapping Information Platform (part of CDS Risk MAP)

MMI Modified Mercali Intensity

MSC Map Service Center; one of five units in CDS (see above)

NAVD North American Vertical Datum

NHC National Hurricane Center

NED National Elevation Dataset

NEHRP National Earthquake Hazards Reduction Program

NFIP National Flood Insurance Program

NHD National Hydrography Dataset (1:24,000)

NHRAP National Hazard Risk Assessment Program

NTHMP National Tsunami Hazard Mitigation Program

NWHRP National Wind Hazards Reduction Program

NWIRP National Windstorm Impact Reduction Program

NWM [National Water Model](http://water.noaa.gov/about/nwm)

OGC Open Geospatial Consortium

P4 Risk MAP Project Planning and Purchasing Portal

PCII Protected Critical Infrastructure Information

PESH Potential Earth Science Hazards

PGA Peak Ground Acceleration

PGD Permanent Ground Deformation

PGV Peak Ground Velocity

PII Personal Identifiable Information

PODs Points of Distribution

Risk MAP Risk Mapping, Assessment and Planning, a unit of FIMA

SFHA Special Flood Hazard Area

SLOSH Sea, Lake and Overland Surges from Hurricanes model developed by NOAA

SSI Sensitive Security information

SWAN Simulating Waves Nearshore wave model

TIGER Topologically Integrated Geographic Encoding and Referencing system

UDF User-Defined Facility

UI/UX User Interface / User Experience

USGS United States Geological Survey

WSEL Water Surface Elevation

**I.5 References**

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12. Risk Mapping, Assessments, Planning (Risk MAP) Program, FIMA Multi-Year Plan: Fiscal Years (2010 – 2014)
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14. TMAC Annual Report (December 2015)
15. TMAC Future Conditions Report (December 2015)

**II. Overall Description**

This section describes

**II.1 HAZUS Strategic Plan 2017-2021**

The HAZUS Strategic Plan (FY17-FY21) assists with the HAZUS and Risk MAP missions by identifying key goals and the supporting objectives required to achieve these goals. HAZUS provides stakeholders with a dependable view of the potential risks they face and thereby encourages hazard mitigation. Primary stakeholders include decision makers, such as state and local elected and appointed officials, who provide the leadership and resources to implement HAZUS as well as practitioners, who are directly responsible for mitigation planning and other emergency management tasks, such as state and local emergency managers and planners, and floodplain managers. As indicated in Table 2.1, the 2017 Strategic Plan identifies five goals, three of which are directly addressed by this whitepaper, while the other two form a necessary backcloth for a successful implementation.

As a result, Open HAZUS (in parallel to Web HAZUS) will have a single one-stop online resource that will allow HAZUS users easier and quicker access to relevant information. Standardized output will allow complicated technical model outputs to be easily digestible and better understood by the end user. This will also help bridge the gap between risk analysts and decision makers by making the results more immediately accessible by leadership. That online portal will make basic results discoverable and available for the appropriate model with updates scheduled at a set frequency, thereby considerably widening the user base of HAZUS.

Open HAZUS will have an easily searchable online repository for users to share inventory including User Defined Facilities (UDF), best practices, and results. This requires the development of a quality control process and committee to vet new data in collaboration with Production and Technical Services (PTS) Contractors, Cooperating Technical Partners (CTP), and FEMA CERC projects.

A truly Open HAZUS will make it a lot easier to solicit contributions from subject matter experts because they can now comment and improve upon methodologies that are available at source code or pseudo source code level. This will build the end user’s confidence in HAZUS results and increase the software’s accuracy. One of the main advantages of Open HAZUS will be the establishment of a community of users and developers that, like in many FOSS projects, handle a large share of helpdesk duties and act as a conduit between actual users and developers. The increased transparency and accountability should improve stakeholder confidence significantly.

*Table 2.1*

|  |  |  |
| --- | --- | --- |
| ***Goal*** | ***Objective*** | ***Open HAZUS*** |
| Enable HAZUS access and usability for a broader group of users | * Consolidate HAZUS online resources into a single portal | 🗹 |
| * Standardize and simplify HAZUS results | 🗹 |
| * Provide nationwide basic results for earthquake, flood, and hurricane online | 🗹 |
| * Create and maintain online repository of HAZUS results and products driven by user submitted content | 🗹 |
| Ensure HAZUS software is reliable, scalable, and up-to-date | * Increase HAZUS stability | 🗹 |
| * Integrate subject matter experts in the development process to maintain modeling accuracy |  |
| Continue to update methodologies with the latest established science | * Perform routine assessment of methodologies to ensure they reflect the latest science |  |
| * Perform post-event studies comparing HAZUS modeling against real world results to assess methodology accuracy |  |
| * Create national resource for developing standardized risk assessments | 🗹 |
| Further engage the community | * Ensure training is robust, applicable, and timely leveraging real-world scenarios |  |
| * Perform routine stakeholder analysis | 🗹 |
| * Increase transparency by communicating the development and release schedules, modeling changes, and other HAZUS updates | 🗹 |
| Establish governance structure for the updating, maintenance, and implementation of all HAZUS elements | * Charter and convene a Change Control Board |  |
| * Develop performance metrics |  |
| * Draft a data management plan | 🗹 |
| * Coordinate supporting documentation and training materials with software releases |  |

**II.2 Assumptions and Dependencies**

Requirements of this Open HAZUS whitepaper are affected by the following:

* Project funding and schedule
* Changes in project requirements
* Availability of high-resolution demographic and inventory data (e.g. U.S. Census)
* Availability of required features in the HAZUS application shell
* Availability of building stock data, damage functions, and loss modeling functions required to perform the loss estimations
* Operate with a common low-level RDBMS access

Key assumptions behind this Open HAZUS whitepaper are described below.

* Proposed HAZUS software architecture supports the following requirements:
* There is a common interface to items such as the menu, study region builder, BIT, and InCAST.
* NiyamIT is responsible for system integration and shall coordinate and support all tasks associated with integrating the hazard models with the overall Open HAZUS software.

The following requirements are considered to be desirable but not necessary for the first version of Open HAZUS:

* Allowing users to define their own custom building types.
* Revising damage functions.
* Optimizing average annualized loss.
* Enabling HAZUS on newer versions of ArcGIS as well as Windows Operating Systems.
* Optimizing Fire Following Earthquake.
* Data updates when available.

**III. Stakeholder Analysis**

This section describes

**Hurricane Workshops**

**Flood Workshops**

**Tsunami Workshops**

**Disaster Operations Workshops**

**Basic HAZUS Workshops**

**CDMS Workshops**

**III.1 User Descriptions**

HAZUS is designed for use by federal, state, and local emergency planners, and hazard mitigation officers. These planners will use the tool for both long-range and short-term emergency response planning.

This section describes intended users of the HAZUS flood model and their operating environment. These profiles are based primarily on interviews conducted with potential users and input received from a user group that was established to work with the software development team.

**III.1.1 User Profiles**

At the local level, the HAZUS flood model will be used to address floodplain management issues such as land use planning, buy-out programs, and building code development and enforcement. As users replace default data with accurate locally available data, additional applications, such as performing benefit/cost analyses for proposed flood mitigation measures, will emerge. It is anticipated that users at the state and federal levels will use the program to meet their programmatic needs and policy decisions.

Each user profile is discussed below.

**III.1.2 Local Floodplain Coordinators/Managers**

The majority of potential users of the HAZUS flood model are local floodplain coordinators who may be at the city, township, or county levels. These users are interested in identifying areas in their jurisdictions that are subject to flooding for a variety of return periods and the inventory (all types) that are subject to that inundation. Specific application requirements will vary, depending on the size and technical sophistication of the jurisdiction, but user interviews conducted as part of this project indicate these to be key foreseen applications.

For example, local users are interested in identifying flood-prone areas, assessing the implications of existing land uses, and evaluating the effectiveness of potential mitigation measures to prevent future losses. Some mitigation measures mentioned include development regulation, acquisition and relocation programs, and elevating vulnerable structures.

These users are also interested in the ability to effectively communicate flood risk issues to the general public and disseminate information about floodplain management and the existing threat to the community.

The general conclusion drawn from the interviews was that local users will likely replace at least some default data with their own. Most claimed to have better elevation models and building inventories and are interested in a having a portfolio capability for their repetitive loss structures.

**III.1.3 State Users**

At the state level, likely users will be state floodplain managers and hazard mitigation officers. These users are more interested in performing regional flood vulnerability assessments of watersheds in states where repetitive losses are a continuing problem. These users are also likely to be interested in conducting benefit/cost analyses of proposed land uses and zoning regulations to reduce the impact of flooding losses to their states. Because state users are likely to perform the analysis on larger areas, they will be less likely to replace the default data because of the cost involved in data collection, although a possible exception may be elevation data. State users may also perform the HAZUS flood analysis for local users who cannot perform their own analysis (most likely small communities or unincorporated areas).

**III.1.4 Federal Users**

Federal user requirements vary greatly from agency to agency. Currently, the project team has identified the Federal Emergency Management Agency (FEMA) and the US Army Core of Engineers (USACE) as the primary federal users.

FEMA has identified the need to develop national flood loss estimates to meet their obligations to Congress. Developing a loss estimation tool that uses a consistent default inventory and methodology will solve this problem. Using Level 1 data supplemented with other flood-related studies should ensure a continual and consistent capability for FEMA.

USACE has identified the need for a software model with a default building inventory that would satisfy the need for preliminary loss estimation associated with flood projects (structural and non-structural). USACE has expressed interest in the inventory and watershed capabilities of the HAZUS flood model.

Other potential federal users include the U.S. Bureau of Land Management, the U.S. Fish and Wildlife Service, and the U.S. Department of Agriculture. No effort to establish requirements for them has been made because their level of usage is expected to be minimal.

**III.1.5 Special District Users**

Special districts, including flood control districts and stormwater services, are part of the HAZUS Flood User Group. Their requirements have paralleled other users at the local and regional levels.

**III.1.6 Consultants and Private Sector Users**

A special set of users include the consultant and private sector users who perform project analysis for local, state and federal clients or are supporting other organizations and other private clients. The cottage industry for flood loss estimation has expanded following the HAZUS Flood Model release. Specific application requirements vary greatly depending on the goals of the user, but generally they closely reflect those of the local floodplain coordinator discussed above.

The private sector users may fall into the following classifications:

* Consultants hired by government agencies to define potential flood losses for the development of mitigation programs or other policy related decisions. This includes consultants assisting agencies in examining the impact of land use planning decisions.
* Companies investigating their exposure to local flood hazards. This includes national companies that use the model to examine their facilities over the entire US.
* Risk managers assisting national or local companies in their Business Continuity Planning.
* Corporations assisting FEMA with floodplain mapping and other floodplain management activities.

This list is not meant to be an exhaustive examination of potential uses within the private sector but should give some idea of potential applications.

**III.1.7 Levels of Expertise**

Users can be broken into two groups: those who are performing the study, and those who are using the results of the study. For some studies these two groups will consist of the same people, but generally this will not be the case. However, the more interaction that occurs between these two groups, the better the study will be. End users of the loss estimation study need to be involved from the beginning to make results more usable. Those who are performing the study must, at minimum, have a basic understanding of the respective hazards and their consequences. In many cases, the results will be presented to audiences (i.e., city councils and other governing bodies) that have little technical knowledge of the hazard loss problem.

It is assumed that a loss study will be performed by a team consisting of severe storm/earthquake/tsunami experts, structural engineers or architects, economists, sociologists, emergency planners and a representative from the group who will be reviewing/using the loss estimates. These individuals are needed to develop hazard scenarios, develop and classify building inventories, provide and interpret economic data, provide information about the local population, and provide input as to what types of loss estimates are needed to fulfill the goals of the loss study. It is important to have an interdisciplinary team as, for example, hurricanes frequently also produce coastal and/or inland flooding or tsunamis are the result of an earthquake.

It should be noted that the involvement of the ultimate user of the study on the team is very important. End users of the loss estimation study (i.e., decision makers) need to be involved from the beginning to make results more usable. If a local or state agency is performing the study, some of the expertise can be found in-house. Experts are generally found in several departments: building permits, public works, planning, public health, engineering, seismic and tsunami science, information technologies, finance, historical preservation, natural resources, and land records. Although internal expertise may be most readily available, participation of individuals from academic institutions, citizen organizations, and private industry cannot be underestimated.

Although a loss study can be performed with a minimum of expertise using only the defaults provided by the computer program, the results of such a study should be interpreted with caution, as default values have a great deal of uncertainty associated with them. If the loss estimation team does not include individuals with expertise in the areas described above, then it is likely that one or more outside consultants may be required.

Unless scenarios have already been developed and documented for the study region, the user may require the expertise of a meteorologist or wind engineer when defining deterministic scenarios. Even if a scenario event has been documented, it may be defined using storm parameters that are different than those used in HAZUS. In this case, an expert will be needed to review the scenario and describe it in one of the formats supported by the hazard model. A scenario event that is defined without an in-depth understanding of hurricanes affecting the region may not be appropriate for the loss study.

If the user intends to modify the defaults data or parameters, it is likely that he will need input from someone with expertise in the field. For example, if the user wishes to change default percentages of model building types for the region, he will need the input of a structural engineer who has knowledge of design and construction practices of the region. Modifications to defaults in the economic loss models will require input from an economist.

**III.1.8 Key User Features**

During development of the methodology, it became clear that user input would significantly increase acceptance of the flood model specifically. Interviews of users covering all levels and functions identified key features that would facilitate the user’s job and help identify how they would define success in the flood model. The sections below provide an overview of key points identified by users; however, no products currently exist that will meet these needs.

*Identification of Flood-prone Areas*: Many floodplain managers stated that identifying areas subject to flooding is a key concern. Most felt their existing Flood Insurance Rate Maps (FIRM) (including the Q3s) were out of date or did not reflect recent development that leads to increased urban runoff and subsequent increases in flood elevations.

Floodplain managers want a tool that uses a consistent methodology to allow them to compare new flood studies with existing studies to project changes or areas of concern. They also want a tool to allow them to perform “what if?” analyses to determine the impact of scenario events or increased water volumes above the 100-year or design flood levels.

*Prioritization of Repetitive Loss Structures for Future Mitigation Projects*: A high priority of both FEMA and the FIA is to identify structures that have suffered repetitive losses. Because this responsibility will likely fall on local officials, interviewed users ranked this capability very high. Currently, no tool exists to allow users to conduct a spatial analysis of the cause of these losses and to identify and prioritize cost-effective mitigation measures. A tool that can provide this capability is deemed highly desirable by interviewed users.

*Building Standards and Floodplain Management Regulations*: Associated with the prioritization of repetitive loss structures is the requirement to manage existing and future development within and near the floodplain. Closely associated with proper land use planning, developing building standards and regulations to control and restrict development in and near floodplains is a key concern.

Providing a methodology to identify the effects of standards and regulations is a key benefit. Most users felt that a scientific approach would help them approach local elected officials when requesting approval of standards and regulations. Additionally, users felt that tools such as HAZUS would provide officials with back-up information to assist in their effective decision making.

*Flood Warning*: While this requirement is self-explanatory, no tools currently exist that can be used in real time or near real time to identify the potential impacts for projected flood elevations. Users want a tool that can help the emergency management community project areas of inundation and provide warning so that residents can perform flood prevention/proofing, remove or move contents, and evacuate as necessary.

*Flood Loss Estimation Analysis and Benefit/Cost Analysis*: Existing tools to estimate flood losses (such as USACE-HEC) are complex and require a minimum level of technical expertise to use. The application of such tools is most often related to demonstrating the benefit/cost of specific flood control projects.

Users have identified the need for a tool to conduct a lower-level analysis that can assist them in rapidly demonstrating the benefit/cost of various project mitigation measures in order to prioritize them. It is important that the tool produce loss estimates at resolutions smaller than census tract (i.e., the census block). For users with better local elevation and flood and building information, the ability to import such data into the model was also deemed important.

*Prioritization of Census Blocks/Watersheds for Future Mitigation Outreach and Projects*: Floodplain managers need a tool that allows them to view the entire watershed of concern and identify areas that should be targeted for public outreach campaigns. These campaigns usually include promoting residential mitigation efforts, purchasing flood insurance, and, in some cases, participating in voluntary buy-out programs.

*Flood Protection Measures*: Many jurisdictions nationwide have either levees or upstream storage basins as flood protection, and other jurisdictions regularly consider the installation of these protective measures. These jurisdictions need a simple tool to allow them to examine the benefits of such measures and to identify or highlight potential impacts throughout the watershed. Those communities already protected by such measures may wish to examine potential impacts resulting from the failure of the protection. Some may even wish to examine the impact of removing the protective measures.

Private corporations could perform an analysis to determine if the installation of flood protection measures at various critical sites is cost effective or whether relocation may be a better flood protection approach.

**III.1.9 User Environment**

The user environment will vary depending on the size, structure, and function of the jurisdictions for which they work. In some agencies, floodplain management, land use planning, and the enforcement of building codes and regulations are highly centralized and managed by only a few people. In other agencies, these functions are decentralized and extensive coordination is required to effectively manage them. Still other agencies rely on consulting companies to provide these services.

Local jurisdictions have primary responsibility for managing development within the floodplain and complying with state and federal regulations; however, it is difficult to specifically identify the number of people involved in completing a task. The numbers vary with specific projects and the political nature of land use planning and management decisions. Regulations require each jurisdiction to assign the responsibility of floodplain management to a single person.

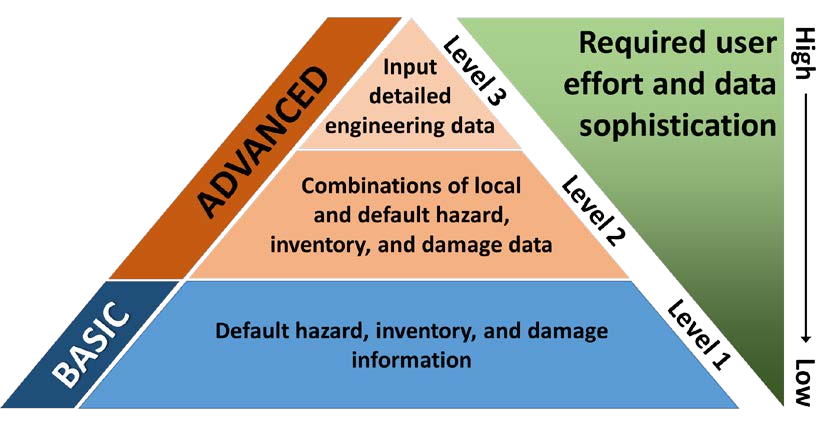
Whether this person will actually perform a HAZUS flood analysis will depend on the jurisdiction’s organizational structure. In the HAZUS training programs, FEMA has taken the approach of recommending that loss estimation be handled by a team of people within an agency. This type of coordination is designed to bring all resources necessary to modify databases, review development patterns and trends, general planning, etc.

The flood model supports a wide variety of project cycles. Users interested in flood estimation during an event will obviously prefer fast, accurate results, but the more typical application will allow the user to obtain locally specific data, input that data into the model, and produce results. A typical analysis—including the compiling of data (e.g., digital elevation models, flood study cross sections and elevations, and surveys of structures)—may take several months.

Users currently have several models that help them analyze floodplains. Examples include HEC-2, HEC-RAS, and SLOSH. Most of these software packages identify stream or coastal inundation, flow direction, rates, and other physical flooding characteristics. None help the user develop direct estimates of losses to the exposed building inventory, vehicles, or agriculture products. While the HEC-FDA allows some functionality in this area, it does not have a comprehensive graphical (GIS) component.

**III.2 Levels of Analysis**

To provide flexibility, losses are estimated based on the accuracy of input data. Basic analysis can be based on default data and parameter data provided within HAZUS. Advanced analysis can be estimated using more accurate data that is specific to the region, hazard, population, etc. thus improving inventories and/or parameters with user-supplied data. The advanced level also incorporates data from third-party studies. The appropriate level of analysis must be determined to meet the needs and resources of the user.



*Figure 3.8. Levels of HAZUS analysis.*

**III.2.1 Analysis Based on Default Information**

A Basic Level 1 analysis is the simplest type of analysis requiring minimum effort by the user. It is based primarily on the default general building stock (GBS), essential facility and demographic databases built into the model. These databases are derived from national-level data sources for building square footage, building value, population characteristics, costs of building repair, and economic data. Default data sets of surface roughness and tree coverage derived from national land-use data are also used for hurricanes. Direct economic and social losses associated with the general building stock are computed, as well as estimates of essential facility functionality, short-term shelter requirement, and debris.

The user is not expected to have extensive technical knowledge. Other than defining the study region, specifying the hazard (probabilistic or scenario), and making decisions concerning the extent and format of the output, an analysis based on default data requires minimal effort from the user. This level of analysis is suitable primarily for preliminary evaluations and crude comparisons among different regions.

**III.2.2 Analysis with User-Supplied Inventory**

Level 2 analysis improves Level 1 results by considering additional data that are readily available or can be easily converted or computed to meet methodology requirements. In Level 2, the user may need to determine parameters from published reports or maps as input to the model. It requires more extensive inventory data and effort by the user than a Basic Level 1 Analysis. The purpose of this type of analysis is to provide the user with the best estimates of hazard input data that can be obtained using the standardized methods of analysis included in the methodology. For example, user-supplied flood depth grids should be used over the internal HAZUS hydrology and hydraulics model. It is likely that the user will need to employ consultants to assist in the implementation of certain methods. For example, a local geotechnical engineer would likely be required to define soil and ground conditions. Improved results are highly dependent on the quality and quantity of improved inventories. The significance of the improved results also relies on the user’s analysis priorities. The following inventory improvements impact the accuracy of analysis provided by the respective hazard models, as well as applications of the results:

* Use of locally available data or estimates concerning the square footage, count, and replacement values of buildings in different occupancy classes.
* Use of local expertise to modify the databases concerning percentages of model building types associated with different occupancy classes.
* Preparation of a detailed inventory for all essential facilities and facilities housing hazardous materials.
* Collection of detailed inventory and cost data to improve evaluating exposure of various transportation and utility lifelines.
* Collection of detailed population and transportation data to improve the evacuation results.
* Use of locally available data concerning construction costs or other economic parameters.
* Development of maps of tree coverage. These maps would be used for evaluation of the effects of these local conditions upon damage and losses.
* Synthesis of data for evaluating the economy of the study region used in assessing indirect economic impacts.

Depending upon the size of the region and the number of these features selected by the user, months may be required to assemble the required input. The effort put into preparing the inventory of the building stock can range from minimal to extensive, depending upon the desire to reduce uncertainty in computed results.

**III.2.3 Analysis with Advanced Data**

A Level 3 analysis requires effort by the user to develop and update information concerning the underlying engineering and loss analysis parameters in HAZUS. This type of analysis incorporates results from engineering and economic studies carried out using methods and software not included within the methodology. At this level, one or more technical subject matter experts are required to acquire data, perform detailed analyses, assess damage/loss, and assist the user in gathering extensive inventory data. There are no standardized Level 3 analysis approaches. It is anticipated that at this level there will be extensive participation by local utilities and owners of special facilities. Users must understand where, within the HAZUS software, to change the underlying engineering and loss parameters used for an analysis. The quality and detail of the results will depend on the level of effort. For example, local terrain (i.e., surface roughness) has a significant effect on the magnitude of the actual surface level wind speeds applied to buildings. Surface roughness lengths depend on vegetation height and density, building heights and densities, and other obstructions upwind from the point of interest. The default surface roughness lengths provided with the hurricane model are derived from state and national land-use databases and have been validated through extensive comparisons with aerial photography. However, land use conditions change over time and locations with the same land-use category may, in fact, have substantially different surface roughness. If you are considering supplying your own terrain data, we strongly recommend that you consult with a wind engineering expert. It is important to recognize that the surface roughness values are averaged over each census tract and are assumed to be independent of wind direction.

**III.2.4 Anticipated breakdown of Open HAZUS users**

Once Open HAZUS is available in form of web services with a substantial building-level inventory and widely accessible high-resolution depth grids, we anticipate that:

50% will just want to work with model results, i.e., view reports

5% will want to remain on the desktop to benefit from local environment capabilities

45% will want to replicate and improve upon current HAZUS capabilities with all its cloud advantages

This 45% is predicated on a substantial improvement of the inventories down to the building level and the wide-spread availability of depth grids.

**III.3 Typical Workflows**

While the overall workflow of HAZUS-MH follows the same general logic, there are some differences based on hazard type. The common logic is represented by the following seven steps:

1. Hazard-specific building stock definition
2. Database aggregation
3. Scenario definition
4. Building damage and loss function display
5. Loss category selection
6. Loss estimation
7. Results display

The following sections highlight the differences between models as a function of hazard type.

**III.3.1 Flood Model Workflows**

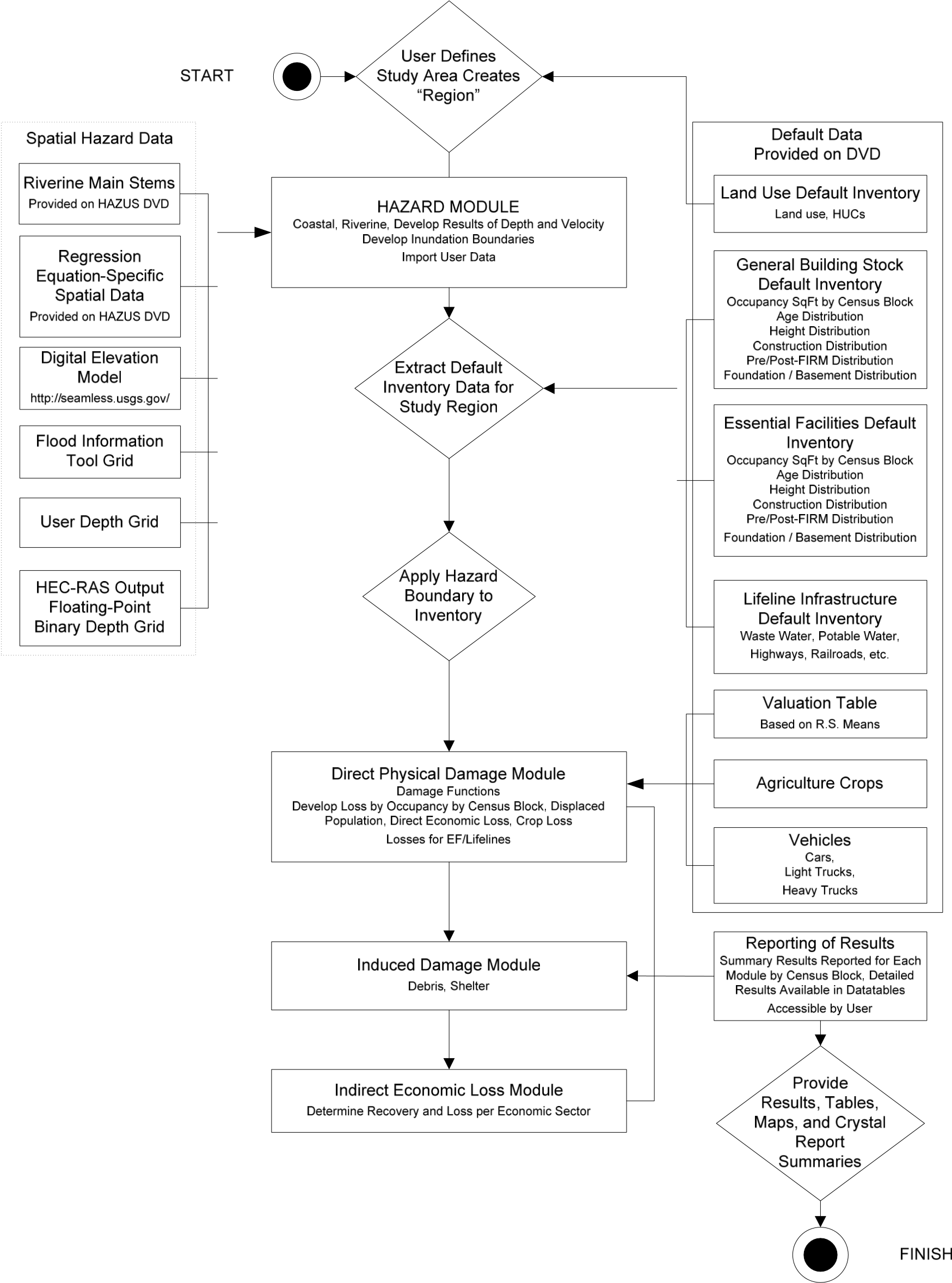
The steps used in the Flood Model are as follows:

* Select the area to be studied. The region of interest is created based on census tract, census block, county, state/territory, community, or watershed. The area generally includes a city, county, or group of municipalities. It is generally desirable to select an area that is under the jurisdiction of an existing regional planning group.
* Specify the hazard. In the Flood Model, the hazard can be specified as riverine, coastal, or a combination of riverine and coastal.
* Provide additional information describing the building inventory, or Essential Facilities, if available.
* Using formulas embedded in HAZUS, HAZUS computes expected building losses, expected contents losses, and expected loss-of-use for different classes of buildings.

HAZUS uses the above results to compute estimates of direct economic loss and short-term shelter needs.

**III.3.1.1 Riverine Flood Level-1 Analysis for General Building Stock**

1. Open a Region
2. Select Flood Hazard Type (riverine vs coastal[[1]](#footnote-1))
3. Chose DEM
4. Develop (synthetic) Stream Network (from DEM)
   1. Define Drainage Area
5. Create a Scenario
   1. Select River Reaches (subset of the above stream network)
   2. If coastal hazard, select shorelines and breaklines
      1. Identify vertical datum
      2. Include optional wave setup
6. Run Hydrologic Analysis
   1. Simulate levees
   2. Determine impact of flood velocity and flow regulation measures
7. Delineate Floodplain (Hydraulic Analysis)
   1. Chose Analysis Type
      1. Single return period (choice of period span)
8. Compute Losses within the Floodplain
   1. Select GBS Damage and Loss Options
      1. Select or modify building depth-damage functions
      2. Restoration functions
   2. Define parameters for
      1. Fire, Debris, Casualties, Shelter, Agriculture, (in-)Direct Econcomic, and Lifelines
   3. Flood Warning (USACE Day curve)
   4. Annualized loss
   5. Combined Wind and Flood (if the user has run the Hurricane model first)



*Figure 3.1.  
Flood Model Schematic consisting of two basic analytical processes:  
① hazard analysis and ② loss estimation analysis*

**III.3.2 Hurricane Model Workflows**

Several steps are typically performed in assessing and mitigating the impacts of a natural hazard such as a hurricane. The methodology encompasses inventory collection, hazard identification, and impact assessment. In a simplified form, the steps are:

* Select the area to be studied. This may be a city, a county or a group of municipalities. It is generally desirable to select an area that is under the jurisdiction of an existing regional planning group.
* Specify the hazard. In the Hurricane Model the hazard can be specified as either a single historical or user-defined storm scenario or as a complete probabilistic analysis. When a single event scenario is chosen, the option of developing coastal storm surge and wave estimates is available. These results can be fed into the HAZUS Flood Model to produce combined wind and surge loss estimates for the General Building Stock.
* Provide additional information describing the building inventory, essential facilities, tree coverage, and surface roughness, if available.
* Using formulas embedded in HAZUS, damage probabilities, expected building losses, expected contents losses, and expected loss-of-use are computed for different classes of buildings.
* The above results are used to compute estimates of direct economic loss and short-term shelter needs.

Using formulas embedded in HAZUS, the expected amounts and types of debris are estimated.

**III.1.2.1 Developing data for a complete loss estimation study**

1. Developing a Regional Inventory
   1. Locations of government facilities such as military installations and government offices
   2. Tax assessor’s files
   3. School district or university system facilities
   4. Databases of fire stations or police stations
   5. Databases of historical buildings
   6. Databases of churches and other religious facilities
   7. Postal facilities (ATC-26, 1992)
   8. Hospitals (The AHA Guide of the American Hospital Association; ATC-23A, 1991)
   9. Public and private utility facility databases
   10. Department of transportation bridge inventory
   11. Dun and Bradstreet database of business establishments
   12. Insurance Services Office’s files of large buildings that is used for fire assessment real estate databases
2. Standardizing and Classifying Data
   1. Collecting Inventory Data
      1. General Building Stock
         1. Square footage
         2. Building count
         3. Dollar exposure
      2. Essential facilities
      3. High Potential Loss Facilities
      4. User Defined Facilities
      5. Transportation Systems
      6. Utility Systems
      7. Hazardous Materials
      8. Demographics
3. Building or Modifying Inventory Databases
   1. Importing Features and Files
      1. Importing site-specific data files
      2. Import Database Utility
   2. Adding Records to Site-Specific Databases
      1. Adding features
      2. Adding, editing, deleting records to attribute table
4. Inventory Requirements
5. Relationship between Building Types and Occupancy Classes
   1. Defining Specific Occupancy to General Building Type Mapping Schemes
   2. Defining Specific Building Type Mapping Schemes
   3. Defining Wind Building Characteristics Distributions
   4. Applying Mitigation to the General Building Stock
   5. Defining Wind-Related Building Characteristics for Essential Facilities

**III.1.3.2 Running HAZUS Hurricane with user-supplied data**

1. Define the Study Region
2. Define the Inventory Data
3. Define the Hurricane Hazard
   1. Probabilistic
   2. Deterministic
      1. Define storm track
      2. Import storm track
      3. Selecting a historic storm
      4. Import from H\*Wind file
      5. Import Hurrevac storm advisory
   3. Review the Currently Defined Hazard
4. Review the Damage, Loss and Debris Functions
   1. Building damage
   2. Building and contents loss
   3. Loss of use
   4. Debris
5. Setting the Analysis Parameters
   1. Defining Tree Coverage Data
   2. Defining Terrain Data
   3. Defining Shelter Parameters
      1. Development of input for displaced households
      2. Fraction of dwelling units likely to be vacated if damaged
      3. Percentage of HH affected by utility outages likely to seek alternative shelter
      4. Development of input for shelter needs
         1. Number of people in the census tract
         2. Number of households in census tract
         3. Income breakdown of households in census tract
         4. Ethnicity of households in census tract
         5. Percentage of homeowners and renters in the census tract
         6. Age breakdown of households in census tract
   4. Defining the Buildings Economic Parameters
      1. Types of direct economic loss
      2. Development of input for building losses
         1. Building replacement values by census tract for all occupancies
         2. Contents values by census tract for all occupancies
         3. Annual gross sales or production in $ per square foot for agricultural, commercial and industrial occupancies
         4. Business inventory as a percentage of gross annual sales for agricultural, commercial and industrial occupancies
         5. Business inventory damage as a function of damage state for agricultural, commercial and industrial occupancies
         6. Building cleanup and repair time in days as a function of wind building type
         7. Rental costs
         8. Disruption costs
         9. Percent of buildings that are owner occupied for each occupancy class
         10. Capital-related income and wage income in $/day per square foot for each occupancy
      3. Building replacement costs
      4. Building contents
      5. Business inventory
      6. Repair and cleanup times
      7. Relocation expenses
      8. Capital-related expenses
   5. Selecting Analysis Options and Running an Analysis
      1. Storm surge options

**III.3.3 Earthquake Model Workflows**

Steps in assessing and mitigating losses due to natural hazards shows the steps that are typically performed in assessing and mitigating the impacts of a natural hazard such as an earthquake. The methodology incorporates inventory collection, hazard identification, and the natural hazards impact assessment. In a simplified form, the steps include:

* Select the area to be studied. The region of interest is created based on Census Tract, Census Block, county, or state. The area generally includes a city, county, or group of municipalities. It is generally desirable to select an area that is under the jurisdiction of an existing regional planning group.
* Specify the magnitude and location of the scenario earthquake. In developing the scenario earthquake, consideration should be given to the potential fault locations.
* Provide additional information describing local soil and geological conditions, if available. Soil characteristics include site classification according to the National Earthquake Hazard Reduction Program (NEHRP) and susceptibility to landslides.
* Using formulas embedded in HAZUS, probability distributions are computed for damage to different classes of buildings, facilities, and lifeline system components. Loss-of-function is also estimated.
* The damage and functionality information is used to compute estimates of direct economic loss, casualties and shelter needs. In addition, the indirect economic impacts on the regional economy are estimated for the years following the earthquake.
* An estimate of the number of ignitions and the extent of fire spread is computed. The amount and type of debris are estimated. If an inundation map is provided, exposure to flooding can also be estimated.

Several steps are required to convert the land use areas to building inventory:

* Land use must be converted to building type
* Land use area must be converted to square feet of building

**III.3.3.1 Running HAZUS Earthquake with user-supplied data**

1. Define Study Region
2. Define Hazard
   1. Scenario earthquake (deterministic hazard),
      1. Historical epicenter event
      2. Source event (selecting source from HAZUS faults database)
      3. Arbitrary event
   2. Probabilistic seismic hazard analysis (for eight return periods)
      1. Annualized loss calculation
   3. User-supplied map of ground motion
      1. User supplies digitized peak ground acceleration, and
      2. Spectral acceleration contour maps
      3. Potential ground displacement (PGD) due to lateral spreading from landslide
      4. Potential ground displacement (PGD) due to settlement from liquefaction
      5. Potential ground displacement (PGD) due to surface fault rupture
   4. Include (soil) site effects
   5. Include ground failure
3. Direct Physical Damage Analysis
   1. Structural vs non-structural
   2. Definition of (five) damage states
      1. Fragility curves (default values)
      2. Fragility curves (user-defined)
   3. Calculating damage state probabilities
   4. Modifying capacity curves
   5. Restoration time
4. Induced Physical Damage
   1. Inundation
      1. Tsunami
      2. Seiche
      3. Dam or levee failure
   2. Fire
      1. Fire parameters
      2. Number of simulations
   3. Hazardous materials option
   4. Debris estimate
5. Direct Social and Economic Loss
   1. Casualties
   2. Displaced households
   3. Direct economic loss
      1. Development of input for building losses
      2. Replacement costs
      3. Business inventories
      4. Cleanup and repair time
      5. Relocation expenses
      6. Capital-related expenses
6. Indirect Economic Loss
   1. For each of ten sectors
   2. Run loss model with a synthetic economy
   3. Run loss model with IMPLAN
7. Dealing with Uncertainty

**III.3.4 Tsunami Model Workflows**

Several steps are typically performed in assessing and mitigating the impacts of a tsunami. In a simplified form, the steps include:

1. Select the area to be studied. The region of interest is created based on Census block, Census tract, county, NFIP community, or state. The area could include a city, county, or group of municipalities. It is generally desirable to select an area that is under the jurisdiction of an existing regional planning group.
2. Specify the hazard. In the Tsunami Model, the hazard can be specified as a Near Source or Distant Source tsunami. When a Near Source scenario is selected, the option of running a combined earthquake and tsunami damage scenario is available. The results of the earthquake shake damage can be fed into the HAZUS Tsunami Model to produce combined earthquake and tsunami loss estimates for the General Building Stock (GBS) and User-Defined Facilities (UDF).
3. Select an analysis level (Runup-ony, depth & velocity, depth & momentum flux)
4. Chose and mask DEM
5. Provide additional information describing the building inventory, essential facilities, and demographics, if available.
6. Using formulas embedded in HAZUS, damage probabilities, expected building losses, expected contents losses, and expected loss-of-use are computed for different classes of buildings.
7. The results of the previous step are used to compute estimates of direct economic loss, evacuation times, and casualties.

**III.3.4.1 Running a combine earthquake and tsunami model**

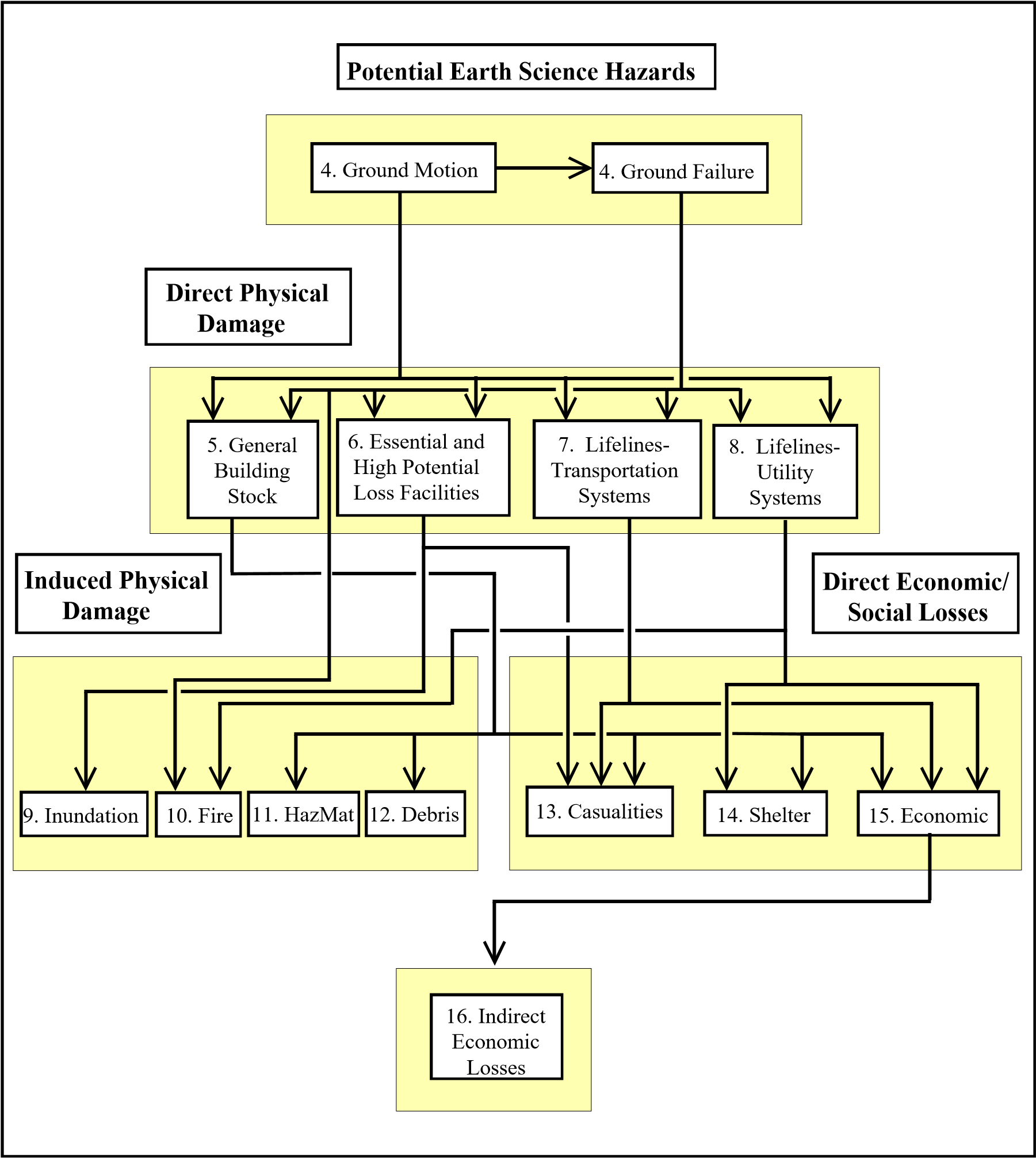
|  |  |
| --- | --- |
| ***Earthquake Model*** | ***Tsunami Model*** |
| * Define/Select Earthquake Scenario  (using same scenario source that creates the Tsunami hazard) * Run Analysis * Display Earthquake-Only Losses | * Select Tsunami Scenario * Define Tsunami Type as Near Source * Define Scenario – Level 2 or 3 * Run Tsunami Analysis * Define Casualty Level 2 * Display Combined Earthquake and Tsunami Losses |

**III.3.4.2 Pedestrian evacuation workflow example**

1. Create/set a portfolio for the study area
2. Preprocess data
   1. Preprocess DEM and LULC
   2. Preprocess hazard
   3. Validate safe zone
3. Create surfaces and maps
   1. Calculate distance path
   2. Create evacuation surface
   3. Determine max time value
   4. Create time map
4. Process vertical evacuation sites
   1. Process vertical evacuation sites
   2. Merge safe zones
5. Population processing

**IV Solution Framework**

The vision of earthquake loss estimation requires a methodology that is both flexible, accommodating the needs of a variety of different users and applications, and able to provide the uniformity of a standardized approach. The framework of the methodology includes each of the components shown in Figure 4.1. As indicated by arrows in the figure, modules are interdependent with output of some modules acting as input to others. In general, each of the components will be required for loss estimation.



*Figure 4.1. Flowchart of the HAZUS loss estimation methodology.*

However, the degree of sophistication and associated cost will vary greatly by user and application. It is therefore necessary and appropriate that components have multiple levels (multiple modules) of detail or precision when required to accommodate user needs. The approach is based on a hazard-load-resistance-damage-loss methodology developed from an individual risk framework (Li & Ellingwood 2009[[2]](#footnote-2)). The basic model components (hazard model, load model, resistance models, etc.) are developed separately. Each model component is, wherever possible, separately validated using full-scale data, model scale data, or experimental data. A first principles-based hazard-load-resistance-loss model is used, providing the capability to model the effects of building code changes and mitigation strategies on reduction in damage and loss. Furthermore, since economic damage (loss) is modeled separately from physical damage to a building, estimates of both building damage and loss are separately modeled and predicted.

**IV.1 Modularization**

Framing the hazard loss estimation methodology as a collection of modules permits adding new modules (or improving models/data of existing modules) without reworking the entire methodology. Improvements may be made to adapt modules to local or regional needs or to incorporate new models and data. The modular nature of the methodology permits a logical evolution of the methodology as research progresses and the state-of-the-art advances.

While HAZUS-MH has so far relied on GIS as the framework from within which individual modules are called, Open HAZUS is designed to be GIS-independent. After initial inventory specification, the program will run efficiently on a range of hardware platforms and operating systems. GIS technology may be used by a stakeholder for subsequent analysis beyond the scope of HAZUS but the mere mapping function will be provided by Open HAZUS-internal visualization tools that fall under the category of reporting.

The methodology utilizes a modular approach with different modules addressing different user needs. This approach avoids the need to decide on who is the designated user. The needs of most, if not all, users are accommodated by the flexibility of a modular approach.

The methodology incorporates available state-of-the-art models in the hazard loss estimation methodology. For example, in the earthquake model, ground shaking hazard and related damage functions are described in terms of spectral response rather than MMI. Modules include damage loss estimators not previously found in most studies, such as induced damage due to fire following earthquake and indirect economic loss. In the flood model, users can develop their depth grids based on their hydrologic and hydraulic models and use the most current depth damage functions.

The methodology permits users to select methods (modules) that produce varying degrees of precision. The methodology incorporates both deterministic and probabilistic descriptions. The performance of a building class under wind loading events is formulated probabilistically using the concepts of structural reliability. The probability of an individual failure mode, such as a window or door failure, is the probability that the wind load effect (e.g., aerodynamic pressure or impact energy) is greater than the resistance of the element. By performing many simulations on representative buildings within many classes of building construction, the damage probabilities for the key building components are estimated and the relationships between physical damage and wind hazard are developed. Similarly, losses are estimated using repair and restoration models for physical damage states. These concepts have been used to generate the fast-running damage and loss functions required in the HAZUS software tool.

Alternatively, the proposed methodology accepts user-supplied maps of depth grids, storm fields, or earthquake ground shaking.

The methodology includes standard methods for:

* + - * 1. Inventory data collection based on census tract areas
        2. Using database maps of soil type, ground motion, ground failure, etc.
        3. Using database maps of terrain elevations
        4. Classifying occupancy of buildings and facilities
        5. Classifying building structure type
        6. Describing damage states
        7. Developing building damage functions
        8. Grouping, ranking and analyzing lifelines
        9. Using technical terminology
        10. Providing output.

**IV.2 Advantages of the Open Character**

The hazard loss estimation methodology is an improvement over existing regional loss estimation methodologies because it more comprehensive and inter-disciplinary than single-hazard studies. Examples of these impacts are service outages for lifelines, estimates of fire ignitions and fire spread, potential for a serious hazardous materials release incident, and indirect economic effects. One important aspect in which Open HAZUS goes beyond the capabilities of HAZUS-MH is its ability to run scenario ensembles and to employ modern visualization techniques that help stakeholders sort through the vast amounts of data generated. The ability to ask “what if” questions – and get them answered – will be vastly improved, especially for organizations that do not have the computational facilities locally available that the web services-based solution of Open HAZUS provides.

Another advantage of Open HAZUS is the ability of stakeholders to add to the methodology, where it has so far been lacking. For instance, the methodology calculates potential exposure to flood (e.g., dam break) or fire (following earthquake) in terms of the fraction of a geographical area that may be flooded or burned but does not have methods for rigorous calculation of damage or loss due to flooding or fire. Consequently, these two potential contributors to the total loss are now obvious foci of community-developed modules for estimations of economic loss, casualties or loss of shelter.

**IV.3 Inventories as an Indispensable Aspect of Open**

A limiting factor in performing a study and quality of the inventory is the associated cost. The collection of inventories is without question the costliest part of performing the study. Furthermore, many municipalities have limited budgets for performing an earthquake loss estimation study. It is thus of utmost importance that as much data is readily accessible to accommodate different users with different levels of resources.

While most users will develop a local inventory that best reflects the characteristics of their region, such as building types and demographics, Open HAZUS is designed to provide reasonable estimates of losses based on a minimum of local input. We have a come a long way since the first releases of USGS or US Census data. Open data is more than a buzzword and has become the basis for many business processes, including those of governments. The quality and richness of user-generated geospatial data such as Open Street Map has been studies and proven time and time again (Sehra et al. 2014, Basiri et al. 2016, Barrington-Leigh & Millard-Ball 2017)[[3]](#footnote-3). Private entities like Google and Microsoft now provide web services with well documented APIs and monthly as well as needs-driven updates down to the building level (Microsoft 2018[[4]](#footnote-4)).

Some analyses require data that will for security reasons never be made public. For example, a stakeholder may wish to make detailed assessments of damage to and service outages for lifelines, which require cooperation and input from utilities and transportation agencies. Lifeline systems require an understanding of the interactions between components and the potential for alternative pathways when certain components fail. Thus, without cooperation of utilities, the user is limited in the quality of analysis that can be performed. Open HAZUS will need to provide options to either upload such data to a private/secure space alongside publicly accessible inventory data or (the 5% of Open HAZUS users dealing with PII data referred to in section III.2.4 of this whitepaper) to link to such data locally.

**IV.3.1 Requirements for the demographic data**

**IV.3.2 Requirements for the building and critical infrastructure data**

**IV.3.3 Requirements for the depth grids**

**IV.3.4 Requirements for results database**

**V Architecture**

HAZUS-MH was designed to work on top of ESRI’s ArcGIS Desktop platform. The workflow was hence spatially driven. HAZUS-MH functionality was accessed through three additional menus within the ArcMap user interface. With the decision for Open HAZUS to be GIS-independent, a number of constraints to the user interface and the necessary sequencing of processing steps will become obsolete. For instance, the definition of a study area is easily accomplished through a web service that displays a zoomable map of the world, pre-set to the extent of the United States. With much of the inventory data (including an expanded set of higher resolution GBS and demographic data) readily accessible on Open HAZUS servers (see section IV.3), the software architecture has become much more open and can be interpreted as a library of methods, similar to the original philosophy of the Unix operating system or the open source GIS GRASS.

The importance of having a Cloud-based repository of actionable data cannot be over-emphasized. Open (and web-based) HAZUS is only feasible if much of the burden of data generation, especially the computing extensive generation of depth grids, is off-loaded to the server side. The remaining steps of hazard definition, damage, loss, and impact estimation, as well as the generation of report elements are easily handled in form of web services. This in turn facilitates Open HAZUS to be a light-weight or thin client.

In terms of traditional ArcGIS users, Open HAZUS now becomes a toolbox with many toolsets and potentially hundreds of tools that are extendable by the user community. Like the (geo-)processing models in ArcGIS and QGIS, Open HAZUS users will be able to design their own workflows and customize Open HAZUS to their needs. FEMA CDS will provide a reference implementation that stakeholders may use out-of-the-box, but the assumption is that interested parties will create their own tools, models, and workflows.

The following pages will describe typical workflows and the tools or methods they consist of. They are organized by hazard and type of analysis, followed by a mapping of tools to types of users (viewers, editors, analysts).

**V.1 Hazard**

**V.1.1 Flood Modules**

**V.1.1.1 Inventory Creation**

The majority of Open HAZUS users are expected to work with inventory data that is provided on Open HAZUS servers. However, it could not be called open if there was not the facility to create specialized inventories that are tailored to fit the user’s needs. In addition to providing tools for building inventory data similar to the existing CDMS.

**V.1.1.1.1 Building and facilities**

**V.1.1.1.2 Transportation systems**

**V.1.1.1.3 Building and facilities**

**V.1.1.1.4 Lifeline utility systems**

**V.1.1.1.5 Agricultural products**

**V.1.1.1.6 Vehicles**

**V.1.1.1.7 Hazardous material facilities**

**V.1.1.1.8 Direct economic and social losses**

**V.1.1.1.9 Indirect economic losses**

**V.1.1.2 Flood Hazard Characterization**

**V.1.1.2.1 Riverine flood**

**V.1.1.2.1 Coastal flood**

**V.1.1.2.1 Combined flood**

**V.1.1.2.1 Other flood types**

**V.1.2 Wind Modules**

**V.1.2.1 Inventory Creation**

**V.1.2.1.1 Building and facilities**

**V.1.3 Earthquake Modules**

**V.1.3.1 Inventory Creation**

**V.1.3.1.1 Building and facilities**

**V.1.4 Tsunami Modules**

**V.1.4.1 Inventory Creation**

**V.1.4.1.1 Building and facilities**

**V.2 Analysis**

**V.3 Mapping of Modules to User Types**

1. The coastal option is only enabled if the user previously ran the Hurricane model [↑](#footnote-ref-1)
2. Li Y and B Ellingwood 2009. “Framework for multihazard risk assessment and mitigation for wood-frame residential construction.” *J. Struct. Eng.*, 10.1061/(ASCE)0733-9445(2009)**135**:2(159), 159–168. [↑](#footnote-ref-2)
3. Sehra S, Singh J and H Rai 2014. A Systematic Study of OpenStreetMap data Quality Assessment. *Proceedings of the Eleventh International Conference on Information Technology: New Generations*. Las Vegas, NV. Berlin (DE): FI-STAR Consortium. DOI 10.1109/ITNG.2014.115.

   Basiri A, Jackson M, Amirian P, Amir Pourabdollah, Sester M, Winstanley A, Moore T & L Zhang 2016. Quality assessment of OpenStreetMap data using trajectory mining, *Geo-spatial Information Science*, **19**:1, 56-68, DOI: 10.1080/10095020.2016.1151213.

   Barrington-Leigh C, & A Millard-Ball 2017. The world's user-generated road map is more than 80% complete. *PloS one*, **12**(8), e0180698. doi:10.1371/journal.pone.0180698 [↑](#footnote-ref-3)
4. https://github.com/Microsoft/USBuildingFootprints [↑](#footnote-ref-4)