Aggregate Flood Hazard Risk Reduction Scoping Project

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Background

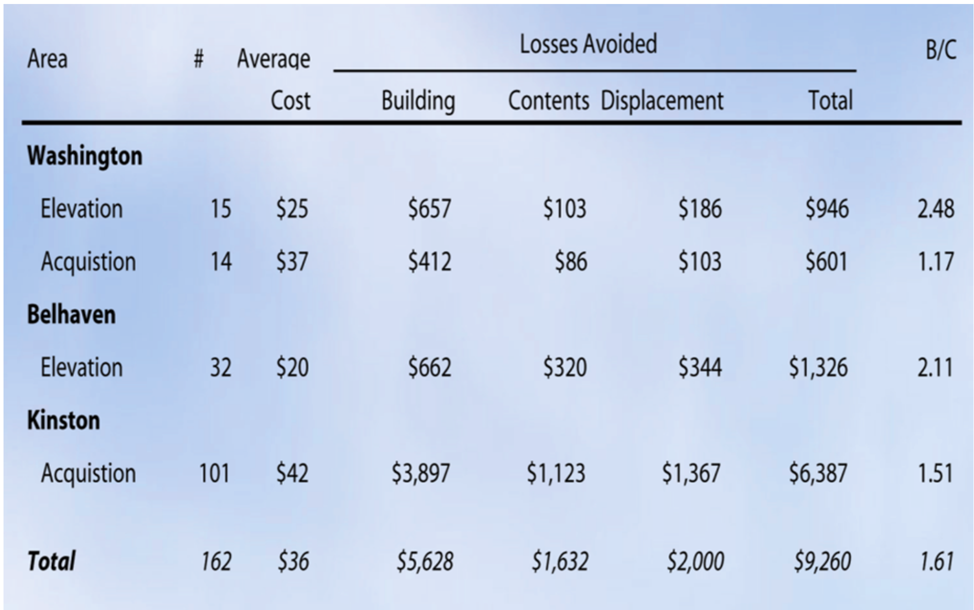
Disaster losses continue to rise in the United States and worldwide (Swiss Re 2012; Kunreuther and Michael-Kerjan 2009) in spite policies, programs, and investments associated with hazard mitigation-related activities (Mileti 1999; Burby 1998; Godschalk et al. 1999), including the existence of a sound knowledge base surrounding natural hazards risk management (White, Kates and Burton 2001; NAS 2006). Rising disaster costs are also due to pre- and post-disaster policies that incentivize risky development (Burby 2006; Platt 1999; Kunreuther et al. 2012) or fail to hold state and local governments accountable for their actions that increase risk (Smith 2009; 2011). While it is true that there is much we know about hazard mitigation, a robust method to comprehensively measure risk reduction activities that accounts for more than project-based approaches does not exist. Thus, how can we expect to tackle the challenges associated with natural hazards risk reduction if we cannot comprehensively estimate the current and future level of risk facing communities in a manner that accounts for the many factors that comprise it?

In this report we explore this problem and posit a new way to assess risk reduction in a way that aggregates a set of dimensions needed to provide a more accurate and holistic accounting of risk and its change over time. The approach proposed here focuses on flood hazards for two reasons: 1) Flood losses accounts for a disproportionate amount of damages to property in the United States and around the world, and 2) The analytical tools and data available to assess flood hazard risk are among the best developed when compared to other natural hazards. Factors included in what is referred to throughout this document as the *aggregate flood hazard risk reduction framework* includes the effects of: 1) Land use, 2) Changes in hydrology, and 3) The adoption of new policies and the implementation of risk reduction projects. Micro and macroeconomic analyses are described as a way to monetize aggregate risk based on policies and their effects at individual property to regional scales.

Hazard mitigation can be defined as actions, steps, policies, and programs that can be initiated to reduce the loss of life and property damage in the event of a natural disaster (Godschalk et al. 1999). FEMA relies on a similar definition, which is "…reducing or eliminating long-term risks to people and property from hazards and their effects…" (FEMA 2011, p.4). The ability to measure the degree to which pre- and post-disaster hazard mitigation has been undertaken and resulted in quantifiable results has tended to focus on a technique commonly referred to as "losses avoided" studies (Congressional Budget Office 2007; Smith 2009; Rose et al. 2007). These studies assess the benefits of hazard mitigation activities by reviewing individual projects (e.g., the relocation or elevation of flood prone properties out of the floodplain, hardening infrastructure to withstand storm surge or earthquake-induced ground motion) and determining the degree to which the implementation of these mitigation measures have resulted in future losses avoided should an event of a given magnitude strike the area in which the projects are located.[1]

Figure 1 depicts the estimated losses avoided from four projects undertaken in three North Carolina jurisdictions, including Washington, Belhaven, and Kinston. In the case of Washington, 15 homes were elevated and 14 acquired, demolished, and the land converted to open space, whereas Belhaven focused on the elevation of 32 homes while Kinston acquired 101. The resulting losses avoided (noted in thousands of dollars), compares the average cost to undertake the elevation or acquisition project with the costs associated with future losses to the building and its contents as well as costs tied to the displacement from one's home. The last column represents the benefit-cost ratio (e.g., the benefits associated with future losses avoided relative to the costs of undertaking the project). A benefit-cost ratio of 1 or greater shows that the project is economically efficient using FEMA's methodology.

Figure 1. Documentation of Losses Avoided in Washington, Belhaven, and Kinston, North Carolina following Hurricane Floyd



Area	#	Average	Losses Avoided				B/C
		Cost	Building	Contents	Displacement	Total	
Washington							
Elevation	15	$25	$657	$103	$186	$946	2.48
Acquistion	14	$37	$412	$86	$103	$601	1.17
Belhaven							
Elevation	32	$20	$662	$320	$344	$1,326	2.11
Kinston							
Acquistion	101	$42	$3,897	$1,123	$1,367	$6,387	1.51
Total	*162*	*$36*	*$5,628*	*$1,632*	*$2,000*	*$9,260*	*1.61*

Observations of this project's Principal Investigator following Hurricane's Fran and Floyd, which struck the State of North Carolina in 1996 and 1999 respectively, provided the initial impetus for this report. Following these storms, a number of municipalities and counties participated in

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[1] As noted in the FEMA Flood Loss Avoidance Methodology working paper located in Appendix A of this report,

one of the largest single-state housing acquisition efforts in the nation.[2] However, most jurisdictions did not link these project-based initiatives with the adoption of policies limiting future development in similarly flood-prone areas. Thus it was unclear to what extent the large-scale expenditure of funds made a difference in aggregate flood hazard risk if on the one hand large numbers of structures were being acquired and converted to open space while new post-disaster development continued to occur in and adjacent to the floodplain.

Creating a means to assess aggregate flood hazard risk is fundamental to the broader understanding of hazard mitigation and disaster resilience as the proactive application of land use techniques to guide the type, location, and density of development relative to known hazard areas is among the most effective techniques to advance risk reduction and the complementary aims of sustainability and resilience (Burby 1998, 2006; Godschalk 2003; Mileti 1999).

The ability to document the effectiveness of hazard mitigation measures has become increasingly relevant as members of Congress and the United States Office of the Inspector General have raised questions as to the value of federal hazard mitigation expenditures. These concerns arose in large part due to large unexpended balances of Hazard Mitigation Grant Program funds in a number of states across the U.S. (Smith 2009). Questions were also raised regarding the expenditure of federal funds on a President Clinton-era initiative named Project Impact. As a result, Congress commissioned the Multi-Hazard Mitigation Council to assess the cost effectiveness of hazard mitigation projects under the Hazard Mitigation Grant Program and the Flood Mitigation Assistance Program and broader mitigation initiatives that emphasized a process-based approach, namely Project Impact.[3]

The Congressionally-appointed Multi-Hazard Mitigation Council found a return on investment of 4 to 1 when assessing individual hazard mitigation projects and process-related activities funded by FEMA (FEMA 2005; Rose et al. 2007). This study employed a technique that combined benefit-cost analyses results across communities throughout the United States and supplemented this approach with a series of community-level case studies which uncovered a number of qualitative benefits not addressed in traditional losses avoided studies, including

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[2] When properties are acquired using hazard mitigation funds, the land is converted to open space in perpetuity.

[3] FEMA's Project Impact included the distribution of funds to all states and designated communities to develop public-private partnerships, conduct education and outreach initiatives, develop plans, and adopt new codes and standards. In an effort to assess the cost-effectiveness of process-based mitigation measures, qualitative case study research was conducted by the MMC in eight communities, including five Project Impact-designated jurisdictions (Ganderton, et al. 2006, pp. 1-2).

measures of “overall community resilience” (Godschalk, Rose, Mittler, Porter and West 2009, p. 741).[4]

Measuring Aggregate Flood Hazard Risk Reduction at the Community and Regional Level

The MMC study provides an important advancement in our understanding of the cost-effectiveness of hazard mitigation as practiced in the United States, including the merits of hazard mitigation on a project-by-project basis as well as qualitative findings associated with case study research. However, a number of critical factors were not addressed: 1) The MMC study did not consider existing and projected development in the surrounding area and how that affects hazard exposure and differing levels of vulnerability by population type (including social vulnerability); 2) The MMC approach did not account for changes in the hazard itself (e.g., changes in hydrology, shifting shorelines, etc.), which can lead to a significant increase in hazard vulnerability; and 3) The MMC study did not combine the benefits and costs of projects, policy choices, and land use into a model to assess the change in aggregate risk experienced in communities over time (Figure 2).

Government officials (e.g., federal, state, local), members of the private sector (e.g., corporations, private utility companies, small businesses, builders, developers, finance and insurance industries), non-profits (e.g., foundations, community groups, faith-based organizations), international aid organizations (e.g., United States Agency for International Development, United Nations, World Bank), nations, and individuals have spent billions of dollars in pre- and post-disaster hazard mitigation funding outlays, investments, and capacity-building initiatives. These diverse expenditures include pre- and post-disaster hazard mitigation grants, the provision of capacity-building initiatives, the payment of insurance claims and insurance premiums, investments of financial capital, construction of new developments and public and private infrastructure, and the investment in one’s personal place of residence. Yet the financial expenditures and provision of assistance needed to help build the collective capacity of communities, regions, and nations to mitigate natural hazards risk are currently operating on an incomplete metric of success.

The inability to assess aggregate flood hazard risk, including how this level of risk changes over time, is critically important for several reasons: 1) The approach would provide a more accurate baseline from which to measure risk reduction initiatives undertaken by the stakeholders noted above; 2) The approach would enable policymakers to assess how differing choices made by stakeholders affect hazard risk; and 3) The approach would provide better information upon which to develop collectively-derived decision making procedures, including risk reduction

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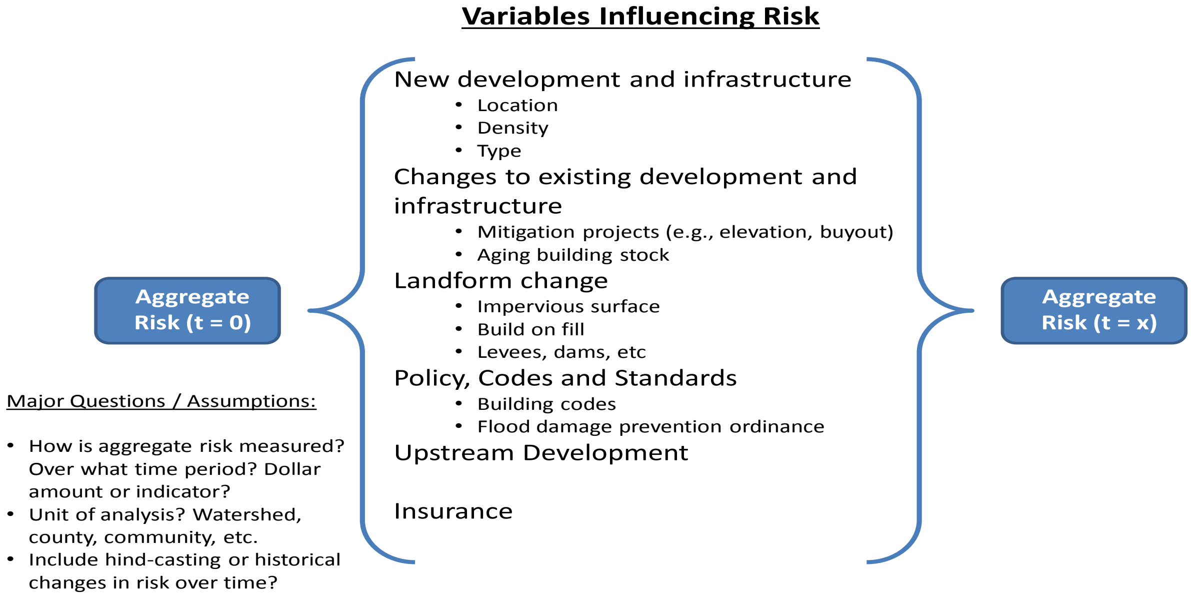
[4] The MMC study analyzed the cost effectiveness of 3.5 billion dollars in randomly selected project grants implemented during 1993 and 2003 (MMC 2005). The grants funded hazard mitigation projects addressing flood, wind, and earthquake-related hazards.

policies, and a more comprehensive fact base on which to develop, implement, and monitor hazard mitigation plans.

Figure 2. Initial Conceptualization of Aggregate Flood Hazard Risk Reduction Framework



Given the complexity of this effort, we have chosen to break this project into phases. The first phase is described in this report and focuses on a preliminary scoping of the problem. The scoping effort was designed to: 1) Develop a preliminary aggregate flood hazard risk reduction framework, 2) Identify data and conceptual models needed to conduct such an analysis, and 3) Raise any lingering questions that need further study. A second phase would refine the framework, operationalize identified components, and test the framework in a select number of communities located in a to-be-determined watershed.

Relevance to the Department of Homeland Security

Hazard mitigation is a key part of disaster resilience and provides an important set of recognized and tested actions that can help stakeholders actualize more disaster resilient communities (Beatley 2009; Godschalk 2003; Berke and Smith 2009), the latter of which is a mission of the Department of Homeland Security's Science and Technology Directorate. Walker and Salt (2004) note that in order to understand resilience we must realize that resilience is comprised of interrelated physical, social, economic, and environmental dimensions. Yet current measurements of hazard mitigation benefits remain focused on a project by project basis, emphasizing the physical dimension without accounting for other important elements. The ability to assess aggregate flood hazard risk reduction (and hence improve our ability to measure resilience) in a manner that accounts for other actions underway at the community and watershed level does not exist. This requires the integration of factors that affect vulnerability such as pre- and post-disaster implementation of federal hazard mitigation funding initiatives (e.g., the acquisition or relocation of flood-prone properties); changes in human settlements in hazardous areas due to new or amended building codes, flood ordinances, and land use choices; and changes in the nature of the hazard itself due to fluctuations in hydrology, erosion, and other factors.

Approach and Methods: Phase 1 Scoping Process

This multi-disciplinary scoping project identifies the variables and conditions necessary to assess aggregate flood hazard risk, recognizing that communities possess differing levels of technical capability and access to data. The scoping project represents the first step in what we intend to be a two-step process. Phase II will involve: 1) The development of an analytical model that is used to assess aggregate flood hazard risk reduction before and after disasters, 2) The testing of the model in differing communities and refining the approach based on the results, and 3) The development of how-to-guides that will inform FEMA, states, and local governments as to how this analytical process can be performed by practitioners.

The information needed to complete Phase I was accomplished through the hosting of technical experts at face-to-face meetings and the review of existing studies. This information was compiled and used by the project team to describe the data and process used to conduct future analysis, assess the level of capability needed to conduct differing analyses, and define specific outputs the proposed process would produce. The scoping document was developed to reflect the varied access to data and capabilities of three types of communities (defined as high, moderate, and low).

Review of Existing Hazard Mitigation Studies, Models, and Data Needs

The review of existing studies served to assess the work done to date on this topic. An initial scan of the literature was done in advance of the first meeting and included the review of the academic literature, post-disaster losses avoided studies, the Multi-Hazard Mitigation Council study, existing hydrological models, land use scenario models, and econometric models. This information was used to identify the elements of those models that could be used to create an integrated aggregate flood hazard risk assessment model. In addition, the project team identified the types of data that are needed to develop and run a model that can assess changes in aggregate flood hazard risk over time.

Expert Input

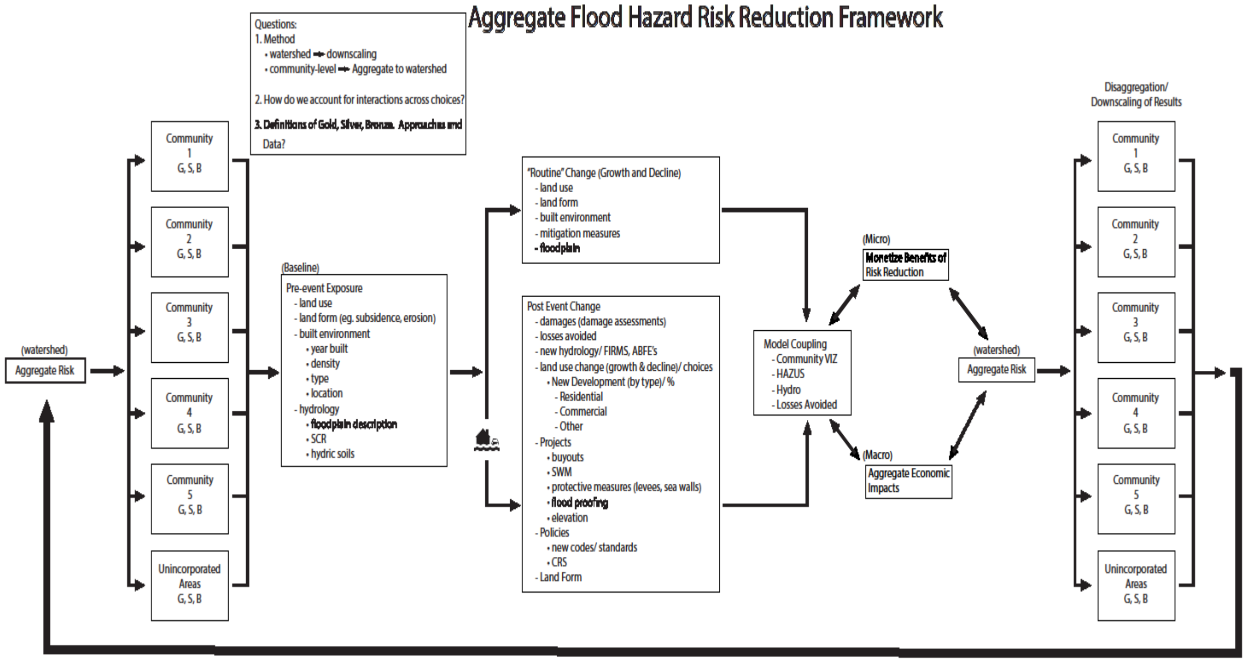
Four meetings were held with invited participants. These meetings helped to: 1) Define the content of the scoping document; 2) Clarify the roles and responsibilities of project participants; 3) Identify relevant studies, data, and tools; and 4) Assist in the development of the final scoping document based on the work of the group. In addition to the body of this report, individual working papers written by members of the research team are found in Appendix A.

Development of an Aggregate Flood Hazard Risk Reduction Framework

The research team, comprised of experts in hazard mitigation policy, economics, hydrology, and land use modeling identified the necessary elements of the aggregate flood hazard risk reduction framework (Figure 3; Appendix A) and the data needed to perform the analysis for communities of differing capabilities (Figure 4; Appendix B). The framework recognizes that the ability to conduct an aggregate flood hazard risk assessment is varied at the local level and three means of accomplishing this aim were identified and described.

Specific types of data used in the guides' creation include those tied to economic consequences (e.g., business interruption, disruption of transportation/distribution networks); changes in population density, distribution, and makeup; land form changes (e.g., physical alteration of the floodplain); land use changes (increases or decreases in the density of structures, amount of impervious surface, and transition from rural to urban in and adjacent to identified floodplains); the adoption of varied building codes and standards (e.g., freeboard requirements, the type of development allowed in the floodplain); and the implementation of specific hazard mitigation projects. Additional considerations, including needed data and proposed aggregate flood hazard risk reduction methods, were uncovered during an initial workshop. Later workshops helped to inform and refine the approach.

Figure 3. Aggregate Flood Hazard Risk Reduction Framework



Map Legend:
G = Gold standard level analysis
S = Silver standard analysis
B = Bronze level analysis

Aggregate Flood Hazard Risk Reduction Framework: Working Draft

Figure 3 depicts the proposed means by which researchers can assess, on the watershed and community-scale, the level of aggregate flood hazard risk present at a given point in time as well as the manner in which aggregate risk can change over time. We suggest that this can be achieved by establishing an aggregate risk level that is then disaggregated into a series of jurisdictions, defined as communities and unincorporated areas, each of which possess varied levels of technical sophistication and access to data (see Appendix B).

The pre-event exposure, or baseline, includes a number of variables including land use, land forms, the built environment, and hydrology. Each of these variables is interdependent as a change in one can affect the other. Changes over time can be understood as both "routine" change to include land use change (growth or decline), changes in land form (e.g., subsidence or erosion), changes in hydrology, and change as defined by the adoption of hazard mitigation measures (including policies or projects). Events, including those classified as extreme (disasters) or smaller (emergencies), may trigger measurable changes. Examples include changes in development and re-development patterns, altered hydrology, the adoption of new policies (e.g., codes and standards), and the implementation of post-disaster hazard mitigation projects (e.g., acquisition, elevation, etc.). Combined, these routine and event-driven changes alter the risk of individual communities and the level of risk found in a watershed.[5]

This data is fed into four models identified as part of the scoping process: 1) Community Viz, 2) HAZUS-MH, 3) Hydro, and 4) Losses Avoided. Challenges remain as to how the models can be effectively coupled, such as the use of differing data and possession of differing capabilities, defined as gold, silver and bronze, which hinder the re-aggregation of the cumulative results. Examples exist where models are being coupled as Community Viz and HAZUS-MH are beginning to be used in a coordinated fashion. In order to monetize aggregate flood hazard risk and benefits we posit that it is necessary to conduct two levels of analyses, including a micro (monetize benefits of risk reduction measures) and macro (assess aggregate economic impacts) approach. Once completed, the combined effect should result in a monetized level of aggregate flood hazard risk at the watershed level.

In order to prove useful to communities residing in a watershed (e.g., assessing their own level of flood hazard risk), the results must be disaggregated to fit jurisdictional boundaries, including unincorporated areas. This information is then used as part of a feedback loop and forms the basis of the latest aggregate flood hazard risk measurement, which is subject to change over time.

Distillation of Working Papers

The following section provides a summary of key findings drawn directly from individual research team member working papers (found in their entirety in Appendix A). Each working paper is organized across the following topical areas: 1) An overview of the model and their relevance to the larger project; 2) An assessment of strengths and weaknesses, accuracy, technical sophistication, and training needed to conduct the proposed analyses, the appropriateness of the model relative to the intent of the larger framework, and the geographic scale at which the model is best suited; 3) The level of acceptance by the research community

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[5] Disasters and emergencies often trigger the creation of new data as evidenced by post-disaster damage assessments, high water marks, Advisory Base Flood Elevation Maps, and Flood Insurance Rate Maps. This information can serve as a vital source of up-to-date data that should be incorporated into the framework whenever practicable.

and practitioners; 4) The manner in which models can be coupled and sequenced with others; and 5) A series of issues tied to data requirements. Specific issues include how models can be used by communities of differing levels of technical sophistication and those that possess differing resources (e.g., data, funding, trained staff, etc.), required to import data and run models.

These elements are further consolidated for the purpose of this section of the report to include: 1) General overview and relevance of model; 2) Strengths and weaknesses of each topical area, including accuracy, ease of use/technical skills and data required to use the model, and acceptance of results for use in practice; and 3) The degree to which the model can and/or has been coupled with other models.

General Overview and Relevance of Models

HAZUS-MH – John Pine. HAZUS-MH is a FEMA-sponsored program that is supported by a series of geo-spatial tools intended to assist communities assess the potential impacts of natural hazards on their community, of which the flood hazard module (HAZUS-MH riverine) is most germane to this project. Specific outputs include economic and social losses as well as physical damages. This tool is widely used by communities to assist them conduct a risk assessment as part of their hazard mitigation planning process. While the pre-packaged set of data can be useful as a general, or level 1 analysis (suggested bronze standard in aggregate flood hazard risk assessment model), the data is not as accurate or up to date as that derived from local sources. Conducting higher order analyses (level 2 [suggested silver standard in aggregate flood hazard risk assessment model] and level 3 [suggested gold standard in aggregate flood hazard risk assessment model]) requires greater proficiency and access to local building inventory data, thereby hindering the ability of less technically sophisticated communities to conduct a more robust analysis of flood hazard risk.

The quality of the riverine model (see the hydrology section of this report) and the accuracy of local building and infrastructure also plays an important role in the quality of the results. A good knowledge of building sciences and local land use regulations is also very important. Since HAZUS-MH is based on ESRI's ARC-GIS system, it is compatible with Community VIS, which relies on a similar platform. FEMA and the developer of Community VIS have begun exploring the integration of these programs, thereby addressing an important aspect of model coupling that will be required to undertake a robust aggregate flood hazard risk assessment. Furthermore, level 2 and 3 analyses, which involves the use of HEC2 flood analyses and FEMA's FIT tool, allows end-users to edit and input data for use in the flood module while a level 3 analyses allows the user to edit flood depth-damages curves based on expert opinion from engineers and building scientists. FEMA provides extensive documentation and technical support, thereby helping to address the varied capacities of local governments, regional planning organizations, and others who may be tasked with a hypothetical aggregate analysis of flood hazard risk.[6]

Hydrologic Modeling – Randy Kolar, et al. As noted in the hydrological modeling working paper, Dr. Kolar et al. explains that the fundamental question from a hydrological point of view is:

> … for a certain real or hypothetical rainfall event, what is the anticipated water level that will be seen at points of interest in the watershed? Given the wide range of conditions, diverse geographic characteristics, and sophistication of the end-user, one model may not be able to satisfy all needs. Thus, a more viable strategy is to develop/adapt a "user-friendly" analysis tool, which, given an expected flood elevation, translates that information to an interactive inundation map that is accessible to a wide-variety of users.

This observation may inform the proposed aggregate flood hazard risk assessment framework and may be used to encourage the further assessment of existing tools like FEMA's FIT tool. NOAA and the National Weather Service's GIS Advanced Hydrologic Prediction System provide an example of another prototype that merits review. The development and refinement of such a GIS-based high resolution spatial analysis tool would allow users to correlate the extent of flood damage with varied scenarios as part of an analysis of aggregate flood hazard risk, allowing for the input of multiple hazards-based variables (e.g., flood levels and extent) and the incorporation of land use changes, differing building characteristics (e.g., elevation, type of construction, use, etc.) and varied hazard mitigation options (e.g., policies and projects). A number of hydrological models are used in both research and practice, each with their own set of features as well as strengths and weaknesses (see Table 1, Kolar et al., p. 61-62).

The physics-based distributed model (Vflo) that utilizes a GIS-platform best meets the gold standard while the popular and widely available HEC-HMS/HEC-RAS models appears to be the best choice for both the silver and bronze approaches. A clear advantage of the Vflo model is the ability to capitalize on high resolution precipitation estimates from model forecasts, radar, satellite, rain gauges, or a combination of multi-sensor products. The fact that the Vflo model is commercially available is a big plus, while the ability to effectively run and interpret the model

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[6] The provision of technical assistance by FEMA raises an important issue worthy of further exploration, which is who will provide ongoing technical assistance to communities of varying capacities that are interested in conducting an aggregate flood hazard risk assessment and regularly updating this assessment over time?

results requires a Master's level education in hydrology. The HEC-HMS and HEC-RAS models are widely available and are used as part of the FEMA floodplain mapping program.

The silver and bronze approaches differ in their application of the modeling software. The silver approach would use the modeling system in forecast mode where an event (real or hypothetical) would drive the model system to produce outputs that simulates the dynamic response of the watershed. Land use changes could be imposed to generate various scenarios. The output would be coupled to the aggregate flood hazard risk assessment framework through an inundation interface shown in Figure 1 of the Kolar et al. working paper (p. 58). The bronze standard uses the HEC software but it does not perform any prognostic modeling which includes a full analysis of land use changes. Rather it relies on static digital flood insurance rate maps that estimate the extent of flooding based on differing flood recurrence intervals. One of the most pressing challenges involves the ability to couple the HAZUS-MH, losses avoided, economic, and land use models in an interactive IT framework. This will require a common data format, including in some cases inter-modal "filters" capable of translating data from one format to the other.

***Land Use* – Nikhil Kaza.** Land use planning models have been used to project varied scenarios over time and have been applied to a number of issues including the protection of natural resources, water allocation, and regional transportation investments. Fundamental to all land use models is the tracking of the conversion of land uses based on the suitability of a given land segment and their interaction with the larger conversion process. Thus the selection of any land use model must account for the unique issues that are relevant to assessing aggregate flood hazard risk and its change over time in a land use context, including how the conversion of land affects other models nested within the larger aggregate flood hazard risk reduction framework. An important factor that drives the selection of varied models includes who maintains the models over time and how these outputs are translated to action.

Land use models can be categorized by the type of user and the decision making process employed by that user. There are many land use projection models, including those that are based on estimated relationships of past trends and neighborhood patterns, both of which are derived from a set of change-based rules. Choosing land use models that are most relevant to the problem requires significant expertise and knowledge of how sensitive the models are to the scenario inputs and if they can adequately capture the processes that are assumed by the scenarios. More importantly, land use models have a reputation as being opaque because of the inter-related processes that affect urban development. As such, the simplicity, adaptability, and the acceptance of the models are as important as the accuracy of these models.

Since aggregate flood hazard risk models require future scenarios that are different from the trends observed in the past suggest that rules-based models such as What IF and Community Viz are most appropriate for this type of effort. These models operate on an underlying suitability score that is computed based on parcel characteristics (e.g., soil type, existing use) and a parcels geographic relationship or proximity to identified buildings, infrastructure, and geographic zones (e.g., schools, water/floodplains, transportation networks, etc.). While the characteristics and underlying geographical relationships are relatively stable, the user has the ability to weight these factors so that suitability can be updated over time. The ability to update model inputs is relatively transparent and therefore the models are gaining acceptance among practicing planners and public officials.

The benefit of using these models is that they are easy to use and the associated outputs are easy to understand. A primary weakness is that we don't know why the decisions surrounding suitability are made, nor do we know the way they are made. In addition to these limitations (and opportunities for strategic model strengthening through the coupling of econometric and land use models), the accuracy of model outputs must be clearly conveyed to decision makers as the scenarios are tied to hypothetical results. Furthermore, the use of these models requires high quality spatial data and an investment in and commitment to learning how to operate the software.

Coupling land use models with others identified in the aggregate flood hazard risk assessment framework offers a potential range of possibilities as noted in the econometric models and HAZUS-MH. There may remain some uncertainty as to whether the land use models can be effectively coupled with the hydrologic models as these models often apply a watershed-level analyses, although Kolar suggests that Vflo relies on a range of data, including that which can be applied at a community level or smaller scale. This issue merits further research and field testing. The fact that Community Viz is becoming increasingly popular among practitioners, including land use planners and regional planning organizations, suggests that this may provide an opportunity to address community- and regional- (e.g., watershed) level issues associated with the need to aggregate and disaggregate outputs as has been suggested by Kolar et al. In addition, there remains a need to more clearly define data requirements across communities of varied types in order to address data sets held by these communities that differ according to accuracy and resolution. Finally, the ability to coordinate regional infrastructure investments and regulatory policies will require a strong, formalized planning process that is accepted by parties in a watershed.

Losses Avoided Studies – Jae Park. Losses avoided studies represents the current state of practice used to assess the benefits of completed hazard mitigation projects. The approach relies on the assessment of the return on investment (ROI) for the following categories of avoided losses for flood hazard mitigation: 1) Direct physical damage (e.g., building and contents); 2) Loss of function and displacement costs; 3) Loss of life; and 4) Emergency response costs (e.g., police or fire crew dispatch, sheltering). The quantification of these categories is achieved through the use of Benefit-Cost Analysis. The process involves three steps, including: 1) Initial project selection and screening; 2) Flood event analysis, hydraulic analysis, and flood inundation analysis; and 3) Loss estimation analysis.

Initial project selection and screening involves the identification of completed hazard mitigation projects (e.g., an elevated or relocated group of homes[7], a flood control measure) and the data required to conduct the analysis. The flood event analysis involves identifying potentially damaging events that have occurred since the mitigation measure was implemented and determining whether high water marks or stream gage data is available for that event. If high water marks are not available to determine water surface elevations at the project site, a hydraulic analysis is conducted. A flood inundation analysis is used to determine the probable depths of flooding that would have occurred in each building or structure in the absence of the mitigation measure.

In the loss estimation analysis phase of the process, the user conducts an analysis of the effectiveness of each property improvement to determine the degree to which losses were attributable to the implementation of the mitigation measure. The analysis compares the flood depths before and after the project was implemented and relies on depth damage curves and return on investment techniques to accomplish this objective. The FEMA loss avoidance methodology focuses on two forms of flood hazard mitigation-building modification and flood control projects. Building modification projects mitigate structural, content, and other types of damage by altering the building to reduce its risk of flooding. Examples include elevation, acquisition, relocation, and flood-proofing. Flood control projects mitigate damage by reducing the presence of the hazard in defined areas. Examples include stormwater drainage system improvements; channel modifications; and flood walls, barriers, or levees.

The strengths of this project-based process and its relevance to this study include three primary benefits: 1) Depth-damage curves for different types of buildings (e.g., residential, commercial, industrial) have been developed and incorporated into HAZUS-MH, FEMA's BCA, and the US

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[7] Ideally housing acquisition or relocation projects are defined as a clustered group of contiguous properties. Given the voluntary nature of the program, it is not uncommon for some homeowners to refuse to participate, leading to a "checkerboard effect" whereby existing homes remain dispersed throughout the project area. This not only reduces overall benefits (e.g., future losses avoided) and increases the costs (e.g., future rescue costs, flood losses, and the provision of public services), the remaining homes should be accounted for in an aggregate flood hazard risk assessment.

Army Corps of Engineers design and evaluation of structural flood control measures and as such offer promise as a part of a more expansive aggregate flood hazard risk assessment framework. 2) The losses avoided methodology for flood control projects may be useful for land use modeling since the methodology analyzes flood level changes in large areas affected by stormwater drainage system improvements, channel modifications, and other techniques. 3) FEMA, which also manages the HAZUS-MH software and floodplain mapping program (and relies on hydraulic and flood inundation techniques noted by Kolar et al.), has developed and refined the flood loss avoidance methodology, thereby improving the likelihood of identifying common data and methods that span key components of the larger aggregate flood hazard risk assessment framework.

There are three primary limitations of this approach relative to the aggregate flood hazard risk assessment framework: 1) The losses avoided methodology does not measure some qualitative benefits generated by mitigation projects, such as environmental protection and the creation of recreational space. These elements, which can be accounted for in a land use model necessitates continued research and the further exploration of possible model coupling between losses avoided and land use models. 2) The losses avoided method is best suited to smaller-scale projects and is less relevant to larger watershed-level analyses and is not able to assess the effects a change in flood mitigation policy. 3) The losses avoided approach is very data intensive and requires individual property-level information (see Table 1 in Park, p. 55).

In order to improve the ability of the losses avoided methodology to play a role in the aggregate flood hazard risk assessment framework, several steps need to be taken: 1) Identify the types of risk reduction measures that will be included in the model (e.g., structural modifications such as elevation, acquisition, building code adoption, floodproofing) as well as geospatial and floodplain changes (e.g., land use, roads, channelization, and other stream modifications). 2) Determine the types of risk reduction that will be measured (e.g., quantitative and qualitative impacts). 3) Define the unit of analysis (losses avoided analysis is best suited to a single community or smaller scale unit of analysis) and whether the losses avoided findings can be aggregated and disaggregated. 4) Identify missing data (e.g., structural information). 4) Enhance HAZUS-MH to include a land use component and H&H simulation modeling capabilities. This improvement should include the following functions: 1) Allow communities to input their local building inventory; 2) Allow for the creation of different scenarios, such as adding freeboard, land use changes, and population growth; 3) Display quantitative impacts, including number of people affected by the mitigation measure being studied and associated property damages; and 4) Provide a graphic display of flood boundary changes.

Economic Model – John Whitehead. The economic analysis model proposed includes microeconomic and macroeconomic elements. Microeconomic effects include those that are realized at the individual level such as the degree to which households respond to projects and policies that change (decrease or increase) risk. Benefit-cost analysis is typically used to conduct these types of analyses. Macroeconomic effects are realized at a broader scale, in this case at the regional or watershed level. Further, hazard mitigation benefits include market and nonmarket impacts. Market damages are defined as damages avoided by the mitigation project or policy. HAZUS-MH and losses avoided techniques have been used to perform these analyses on a regular basis. Nonmarket benefits are often referred to as consumer surplus or willingness to pay. These benefits can be measured using revealed and stated preference methods.

The hedonic price method is representative of a revealed preference method that exploits the relationship between the characteristics of property markets and housing prices. For instance, land parcels inside a floodplain may have differing values relative to those located elsewhere. In some circumstances it has been shown that the implicit price can be used to trace the demand for flood risk reduction and used to measure economic benefits. The contingent valuation method represents a stated preference approach that directly elicits willingness to pay statements from survey respondents. The method involves developing a scenario (perhaps through the use of the proposed aggregate flood hazard risk assessment framework) that respondents are informed about flood risks and aggregate risk reduction policy. Other contextual details about the policy are provided, such as the means by which it would be implemented and the payment vehicle (e.g., stormwater management fees, insurance, homeowner's association dues, grants, loans, etc.) used. Costs may include lost economic benefits due to new development while benefits may include improved water quality and an increase in property devoted to parks and greenways. Respondents could be presented with multiple scenarios comprised of numerous possible permutations and associated options or choices. The contingent behavior method is similar, but involves hypothetical behavior instead of hypothetical willingness to pay.

Combing revealed and stated preference approaches seeks to exploit the strengths of both while minimizing their weaknesses. The strength of a revealed preference approach is that it is based on actual choices whereas the strength of the stated preferences approach is tied to its flexibility. Based on a review of the literature, the aggregate flood hazard risk policy context would be difficult to implement solely with revealed preference methods but straightforward to implement with stated preference models. Similarly, it would be relatively straightforward to adapt the existing revealed and stated preference housing market methods to the proposed aggregate flood hazard risk reduction framework.

Combining and conducting a joint estimation of revealed and stated preference data is highly technical, requiring extensive training in environmental economics and econometrics. However, results from the model could be used to develop a benefit function transfer model where users would be able to input a set of local, pre-defined parameters to estimate benefits. Additional issues to consider include the fact that revealed and stated preference models, while widely used for federal policy analyses, are most appropriate at a local scale (e.g., county-level).

Macroeconomic models include economic models such as IMPLAN and HAZUS, time-series models of income and employment, and computable general equilibrium models. Economic impact models are based on input-output models where inputs are translated linearly into outputs using technical coefficient estimates. These models have been used to estimate the regional economic effects of natural disasters based on adjustments to these technical coefficients. Results must be analyzed closely, however, as post-disaster reconstruction can lead one to conclude that disasters improve an economy, when in reality rebuilding is typically unproductive as it usually involves replacing what was lost (unless post-disaster assistance includes additional funds above and beyond the cost to rebuild to pre-event conditions to include risk reduction measures).[8]

Time-series models analyze the effects of lagged measures of the current value of a macroeconomic variable and other intervening variables on the current value. This approach may be used to help assess how a policy may mitigate the negative effects of natural hazards in labor markets. Computable general equilibrium models (CGE) are more complex than economic impact and time-series models and are based on the circular flow model of an economy where households and business firms interact in labor, capital, and intermediate and final product markets. Where the economic impact models hold prices fixed, CGE models allow prices to change in response to changing demand and supply conditions. These price changes bring about simulated behavioral changes amongst households and business firms and may lead to more accurate modeling of the natural hazards recovery process.

Time-series macroeconomic models are most appropriate when measuring the ex-post effects of natural hazards on outcomes. In other words, with a policy already in place the effects of the policy can be determined. Since an aggregate flood hazard risk reduction policy is ex-ante, i.e., it has not been implemented, alternative approaches must be considered to estimate the

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[8] What is often referred to as the "broken window fallacy" in economic development merits further exploration as we assume that rebuilding may include additional investments not present in the pre-event timeframe to include hazard mitigation policies and projects. Not only does this potentially add to the financial value of a given structure, it reduces the likelihood of future damages and hence operational downtime for businesses or public infrastructure, which provides a number of services that can be monetized. The efficiency of these investments should be assessed with benefit-cost analysis relative to economic impact analysis.

potential impacts. Economic impact, time-series, and CGE models can be used to simulate the policy with linkages from other models. Results from the land use modeling and HAZUS-MH runs could be used to adjust parameters in each model to determine the regional economic effects of differing policies.

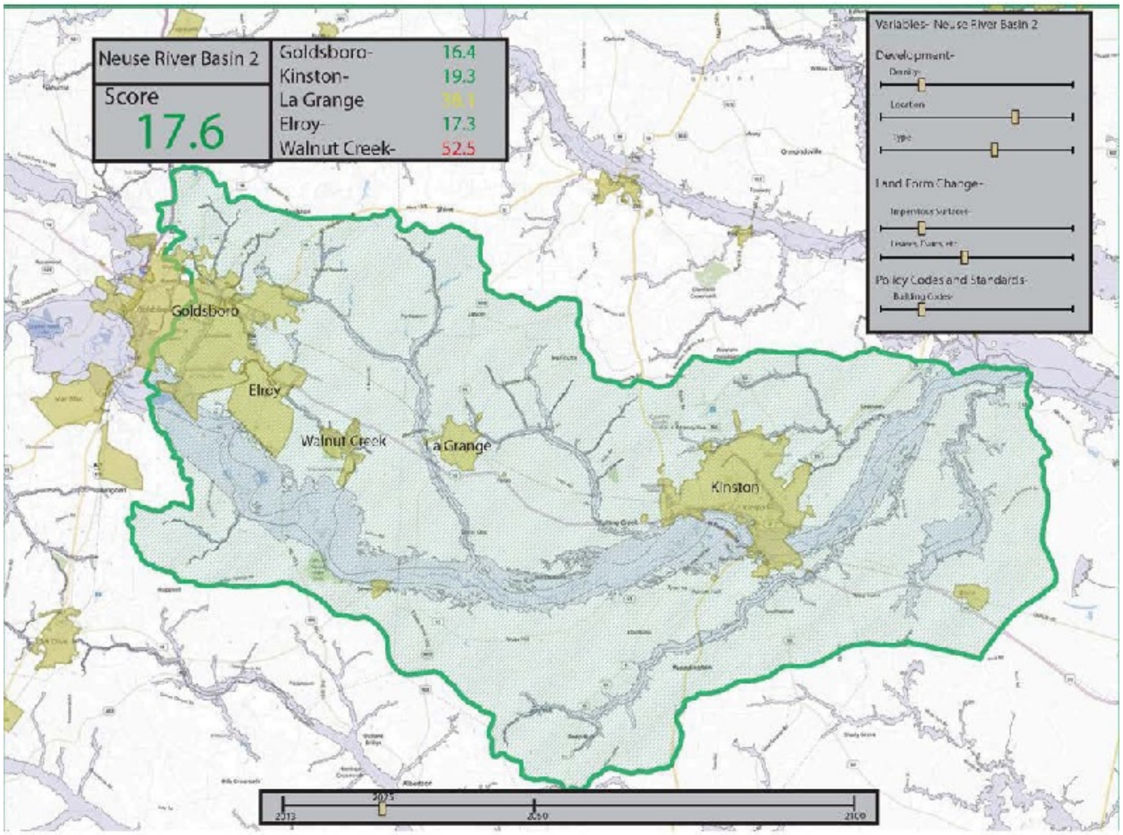
The strength of the economic impact model is its simplicity. Its weakness is its lack of flexibility with respect to the recognition that behavior changes in response to prices. The strength of the time series modeling is its simplicity. Its weakness is its inability to estimate the effects of policy without historical precedent. The strength of CGE models is its greater incorporation of reality in terms of the complexity of economic decision making. The weakness is its complexity. The data needed to conduct these analyses is widely available, software for economic impact and time-series models is readily available, analyses can be conducted on a regional scale, and these models are generally accepted by local officials. The accuracy of macroeconomic models applied to the aggregate flood hazard risk policy context is unknown and merits further research. Training of users is required and canned routines using spreadsheet software can be developed, albeit to perform bronze-level (e.g., simplified economic impact) analyses. These methods are reluctantly accepted by the research community given the variability of economic forecast models and the lack of viable alternatives.

Initial Thoughts on the Application of the Framework in Practice

Applying the framework in practice means: 1) Operationalizing the individual model components, 2) Devising methods to couple these models, and 3) Testing the aggregate flood hazard risk assessment framework under controlled, or simulated conditions as well as in the field. As such, the aggregate flood hazard risk model and its proposed sub-models (e.g., Econometric, HAZUS-MH, hydrological, losses avoided study methods, and Community Viz) still need to be coupled in a manner that allows them to work together concurrently. Part of this challenge is tied to how to use differing datasets across three approaches (gold, silver, and bronze) that reflect differing levels of local government capability and access to data of differing types and quality.

The research team developed a preliminary schematic that shows how the differing aggregate flood hazard risk variables could be tied to a tool used by local officials to assess their aggregate flood hazard risk over time. Dr. Kaza suggested the development of a “use case” approach that would enable the framework to be applied in an identified setting. This led to a simple schematic shown in figure 4.

Figure 4. Screenshot of Hypothetical Aggregate Flood Hazard Risk Assessment Tool



Remaining Questions and Conclusions

A number of important issues require further study. These include: 1) Identifying a comprehensive list of accessible baseline data required for any community and associated watershed to undertake an aggregate flood hazard risk assessment; 2) Developing a means to archive this data in a manner that can be updated and shared with others over time; 3) Refining the monetization of the benefits and costs of various hazard mitigation policies, changes in human settlements and land use, and changes in hydrology and landforms; 4) Facilitating the use of an aggregate flood hazard risk assessment approach given the varied capabilities of jurisdictions, the degree to which they are willing to act collaboratively, and the perceived salience of the hazard threat; and 5) Enhancing the accuracy of the aggregate flood hazard risk assessment framework and eventual model, including its validity and reliability.

This project represents the first phase of a larger proposed study and testing of a model that enables users to assess jurisdictional- and region-wide (e.g., watershed) flood hazard risk on an aggregated and disaggregated scale. Phase I research has enabled the team to: 1) Create a preliminary aggregate flood hazard risk assessment framework, 2) Identify data needs across three community types, 3) Create a series of working papers addressing issues across the primary focus areas, including economics, land use, losses avoided studies, HAZUS-MH, and hydrology; and 4) identify remaining issues that need further study.

The Government Accountability Office noted in 2007 that a “comprehensive strategic framework” for mitigation needs to be developed (GAO 2007). Since that time FEMA has developed a National Mitigation Framework (2013) and Presidential Policy Directive 8, which provide broad-based guidance, emphasizing the need to create more resilient communities through the active involvement of larger governance networks, referred to as the “whole of community” concept. Yet neither policy explicitly addresses the need to more accurately assess risk as suggested here. Nor do references to hazard mitigation plans discuss how improved decision making tools and processes could be used to help achieve this aim.

In their study of state-level hazard mitigation plans (409 Plans) developed in accordance with the Robert T. Stafford Disaster Relief and Emergency Assistance Act, Godschalk, et al. (1999) found that plans were generally weak and did not provide a clear, comprehensive implementation framework. In a more recent study of state and local Disaster Mitigation Act of 2000-compliant hazard mitigation plans, Berke, Smith and Lyles have found that the quality of plans, while improved, remains highly varied and still do not provide a comprehensive framework for systematically addressing natural hazards risk (Berke and Smith 2009; Berke, Smith and Lyles 2102; Smith, Lyles and Berke 2013; Lyles, Berke and Smith 2013). For instance, the monitoring component of hazard mitigation plans focus on the degree to which identified projects have been implemented, not the degree to which aggregate risk in a geospatially defined area has been reduced over time.

Furthermore, none of the federal policy initiatives described above effectively addresses the importance of establishing a clear baseline from which to assess the progress the nation has made in reducing hazard risk, including the varied effects of hazard mitigation policies, plans, and projects. Nor do current policies account for changes in development, hydrology, and land forms. The continued reliance on project-based assessments does not provide an accurate assessment nor do they account for changing conditions over time. The need to more fully address this issue is becoming increasingly prescient with the advent of climate change and an alteration in the characteristics of extreme events. These changes require the incorporation of scenario-based planning to account for varied futures, levels of uncertainty, and the emerging knowledge base tied to the tangible effects of a changing climate in geospatially defined areas. An evolving aggregate flood hazard risk assessment model should ultimately account for new return period definitions, mitigation designs, land-use standards, and the use of new datasets that do not currently exist that account for the impacts of a changing climate.

Next Steps: Clarification and Operationalization of Measures, Selection of Case Study Sites, and Testing of the Aggregate Flood Hazard Risk Assessment Framework

Much remains to be done and this scoping project provides a way to begin this effort. Among the most pressing next steps involve addressing the issues that were identified in this scoping project, and once clarified, operationalize the measures of aggregate flood hazard risk and test the framework in selected sites. Phase II study areas should possess the following characteristics: 1) A high level of flood hazard risk; 2) A large number of housing relocations and elevations; and 3) Access to good data tied to watershed hydrology, relocated and/or elevated structures, existing structures (including first floor elevations, building type, year built), and land use features. The data described here represent a gold standard community, and as such, other case study sites should reflect silver and bronze level characteristics as described in this document.

The Tar-Pamilco River watershed in North Carolina is an optimal choice given the high hazard risk, access to hydrological data conducted as part of work within the Department of Homeland Security - Coastal Hazards Center of Excellence, large buyouts following Hurricanes Fran and Floyd, and access to the North Carolina Division of Emergency Management's floodplain mapping data.[9] We anticipate using the Tar-Pamlico watershed, and communities located therein to: 1) Clarify the data needed to perform aggregate flood hazard risk analyses across gold, silver, and bronze communities; 2) Finalize the variables that should be included in the analytical model; 3) Test the aggregate flood hazard risk assessment framework; and 4) Amend the framework based on the results.

Later phases of this project will build on the work done to date to include the construction of an analytical model and testing it in the field in collaboration with the State of North Carolina and select communities. Once tested and refined by applying the model in multiple flood-prone communities, and gaining feedback from local officials and other stakeholders, training materials could be developed and used to show local officials how to use the model. After the testing of the aggregate flood hazard risk assessment tool is completed, the lessons drawn from

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[9] North Carolina has developed the most sophisticated floodplain mapping program of any state in the nation. As part of this effort, the state has taken ownership of what is typically a federal responsibility-the mapping of their floodplains. Following Hurricane Floyd, the state drew on "rainy-day funds" to remap the entire state, which involved collecting 2 foot contour LIDAR data, conducting new flood studies in defined areas, and producing digital FIRM's superimposed on aerial imagery.

the experience could be used to inform the development of coupled models capable of addressing other natural hazards (e.g., earthquake, wildfire, landslide, etc.), including those influenced by a changing climate.

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Appendix A: Working Papers

Each of the four working papers provide information which was used to help create the aggregate flood hazard risk reduction framework and raise questions that are pertinent to Phase II of this study. The papers describe: 1) An overview of the respective models; 2) An assessment of strengths and weaknesses, accuracy, technical sophistication, and training needed to conduct the analysis, the appropriateness of the model relative to the larger framework, and the geographic scale at which the model is best suited; 3) A discussion of the level of acceptance by the research community and practitioners; 4) The manner in which models can be coupled and sequenced with others; 5) A description of how models can be used by communities that possess differing resources (e.g., data, funding, trained staff, etc.); 6) Remaining questions; and 7) Proposed next steps.

Aggregate Flood Hazard Risk Reduction Economic Model

John Whitehead, Appalachian State University

Overview

A policy that promotes aggregate flood hazard risk reduction may include microeconomic and macroeconomic effects. Microeconomic effects include those that are realized at the individual level. For example, how would households respond to projects and policies that change risk? These changes in behaviors would be monetized as benefits. Benefit-cost analysis is the appropriate policy analysis tool for microeconomic effects. Macroeconomic affects are realized at a broader (e.g., regional) scale. Once individual behavioral changes are aggregated there are policy impacts at the regional level to income, employment, population, and land use.

Microeconomics Model

The benefits of flood hazard mitigation policies involve market and nonmarket impacts. Market impacts are the damages avoided by the mitigation policy. For example, suppose a flooded area requires the removal of flood-prone housing and infrastructure or the reconstruction of a neighborhood. Future losses and associated reconstruction costs could be avoided by hazard mitigation efforts (e.g., projects and policies). The reductions in future costs associated with the repair and reconstruction of the neighborhood are measured as the benefits of the mitigation efforts. HAZUS-MH, for example, can be used to measure these market benefits. The nonmarket benefits are the values of avoiding damages over and above market-based impacts.

These are commonly referred to as consumer surplus or willingness to pay. Willingness to pay for flood hazard mitigation can be measured using revealed and stated preference methods.

The hedonic price method is a revealed preference approach that exploits the relationship between characteristics of property markets and housing prices. Flood risk is a disamenity for some landowners. Land parcels in close proximity to water bodies with high flood risk command lower prices in land markets relative to others. The housing price differential is a measure of the implicit price of locational disamenity. Yet, only in certain situations can the implicit price be used to tease out the demand for flood risk reduction and used to measure economic benefits (Phaneuf, Taylor and Braden 2013).

The contingent valuation method is a stated preference approach that directly elicits willingness to pay statements from survey respondents. The method involves the development of a hypothetical scenario (e.g., referendum voting) that is posed to respondents through in-person, telephone, mail, or other types of surveys. In the hypothetical scenario respondents are informed about flood risks and the aggregate flood hazard risk reduction policy. Other contextual details about the policy are provided such as the implementation rule (e.g., majority rule) and the payment vehicle (e.g., increased taxes). Finally, a hypothetical question is presented to respondents about reductions in flood risk and associated increased costs versus maintaining the status quo. Respondents can be presented with multiple scenarios and allowed to make multiple choices.

The contingent behavior approach is similar to the contingent valuation method in that it involves hypothetical questions. In contrast, the questions involve hypothetical behavior instead of hypothetical willingness to pay. For example, with discrete choice experiments respondents can be asked about hypothetical housing choices with differing flood risks. Respondents can be presented with multiple scenarios and allowed to make multiple choices.

The combination and joint estimation of revealed and stated preference data seeks to exploit the contrasting strengths of the approaches while minimizing their weaknesses (Whitehead, Haab and Huang 2011). Combining data has been shown to produce improved measures of values. In some case studies the revealed and stated preference methods are not statistically different which lends validity to both methods. In other case studies the values diverge and researchers argue that the stated preference values can be identified using the revealed preference methods.

Strengths/weaknesses of model. The strength of a revealed preference approach is that it is based on actual choices. With revealed preference data individuals consider the internal costs and benefits of their actions and experience the consequences of their actions. Choices based on the perceived costs and benefits better reflect the values of the population and allow more valid estimates of willingness to pay. The major weakness of revealed preference approaches is their reliance on historical data. New government policies, such as a policy addressing aggregate flood hazard risk reduction, are often beyond the range of historical experience. For example, few residents of a high flood hazard risk area have experience with flood mitigation techniques beyond the level of a single housing unit.[10] Observed behavior in response to policies designed to reduce aggregate flood hazard risk is nonexistent. Analysis of the nonmarket benefits of broader policies is difficult to undertake with revealed preference data.

A strength of the stated preference approaches is flexibility. Stated preference approaches can be used to construct realistic scenarios for most new policies. Oftentimes, hypothetical choices are the only way to gain policy relevant information. The major weakness of the stated preference approaches is their hypothetical nature. Respondents are sometimes placed in unfamiliar situations in which complete information is not available. At best, respondents give truthful answers that are limited by their unfamiliarity. At worst, respondents give trivial answers due to the hypothetical nature of the scenario.

The strengths of the revealed preference approaches are the weaknesses of the stated preference approaches. The combination and joint estimation of revealed and stated preference data seeks to exploit the contrasting strengths of the various approaches while minimizing their weaknesses. Revealed preference data can be enhanced by stated preference data. Stated preference surveys can be designed to collect data on hypothetical behavior to allow for the estimation of behavior beyond the range of historical experience.

The size of the market is another important issue to address when selecting appropriate economic models. Hedonic property value models use data on housing market transactions. As a result, the market size is limited to current consumers. General population surveys can be used to survey future housing market consumers. This allows for the analysis of the decision to enter the market but these data are limited when trying to understand changes in participation in response to a new aggregate flood hazard risk reduction policy. Combining revealed preference data with stated preference data from surveys of the general population can be used to understand changes in the economic value of the policy with existing consumers and those who might enter the market through the adoption of defined hazard mitigation actions.

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[10] Homeowners and renters may also be unaware of the varied mitigation techniques they could employ to reduce the vulnerability of their home to flood-related losses.

Even when there is experience with the product or policy under consideration, there is often a high correlation between variables of interest and other variables in hedonic property value models. For example, the disamenity of flood risk is correlated with the amenity of waterside property. Multicollinearity among characteristics can lead to statistically insignificant coefficient estimates in property value models which make it difficult to estimate the value of changes in the variables of interest. When revealed and stated preference date are collected under an appropriate experimental design, they can be used to break the multicollinearity.

Stated preference data can be enhanced by revealed preference data. Hypothetical bias can be a major problem with stated preference data. In many cases, hypothetical choices may not reflect budgetary and other constraints on behavior. Combining stated preference data with revealed preference data grounds hypothetical choices with real choice behavior and can be used to detect and reduce hypothetical bias and validate stated preference methods.

Accuracy. Since stated preference methods are based on responses to hypothetical questions there are concerns about the accuracy of value estimates. The accuracy of a theoretical construct's measure (e.g., willingness to pay) is defined by its validity and reliability. Validity is the extent to which a valuation method generates a measure that is unbiased. Reliability is the extent to which a valuation method consistently generates the same measure. Reliability can be demonstrated through repetition and replication. Validity is more difficult to demonstrate when valuing nonmarket goods and services since the "true" value of nonmarket goods and services are unknown.

Most stated preference studies are able to test for theoretical validity. Theoretical validity tests begin with economic theory. Comparative static results are derived from the willingness to pay function as derived from the assumed underlying preference structure. Hypothetical choices tend to be sensitive to price and the quality and quantity of the choice. Jointly estimated revealed and stated preference data studies represent one way to test convergent validity. Convergent validity exists if two methods for measuring willingness to pay yields measures that are not statistically different. Joint estimation can be used to restrict parameter estimates in theoretically appropriate ways to test for convergent validity. Combination and joint estimation of revealed and stated preference data can be used to validate both types of data.

Relevance to Project / Research Question

A large number of studies have assessed the effects of natural hazards on property value models. For instance, Bin and Polasky (2004) used Pitt County, North Carolina data before and after Hurricane Floyd. Bin and Landry (forthcoming) show how property values change over a longer period of time in Pitt County. They found the price discount from locating within a floodplain was larger after Hurricane Floyd. Morgan (2007) found that subsidized insurance reduced perceived risks of living in floodplains. Bin, Kruse and Landry (2008) found that houses located within a flood zone have lower property values. They argue that risk information is contained in flood zone designation and insurance premiums.

A few papers have used stated preference models to help understand behavior after disasters. Baker et al. (2009) considered contingent behavior relocation decisions after Hurricanes Katrina and Rita. They found differences between subjective and objective hurricane risks and these risk preferences significantly affected relocation decisions. Landry et al. (2011) used a discrete choice experiment to estimate the willingness to pay to rebuild New Orleans after Hurricane Katrina. They found that individuals were willing to pay for increased storm protection for New Orleans, but values differed among residents of the New Orleans metro area and other US citizens.

Combined revealed and stated preference models have been applied infrequently in hedonic property models. Earnhart (2001, 2002) applies the discrete choice revealed and stated preference model to housing choice. The revealed preference component is a discrete choice model of recent home sales drawn from a sample of home buyers. The stated preference choice set includes randomly drawn houses that were available at the same time as the purchase. The stated preference choice experiment attempts to simulate the same decision-making conditions among the households and a recent home sales sample. The experiment is designed to focus on the valuation of water-based (e.g., wetlands) and land-based amenities (e.g., forests). There are large differences in the amenity values found in independently estimated revealed and stated preference models. The jointly estimated models improve the estimation of amenity values.

Phaneuf, Taylor and Braden (2013) combine housing market transactions and discrete choice experiment data. The survey of the homeowners serves as the transactions data. The estimation is derived from a comparison of a traditional hedonic price model and a discrete choice experiment survey model. The discrete choice experiment compares hypothetical housing alternatives with what is deemed the status quo among actual purchases. It was found that combining data leads to improvements in the accuracy of value estimates. The focus of the experiment was to assess the valuation of distance from a hazardous waste site. They argue that revealed preference methods tend to produce better baseline estimates while stated preference methods tend to produce better estimates of value in response to changes in the baseline.

The aggregate flood hazard risk reduction policy context would be difficult to implement solely with revealed preference methods but straightforward to implement with stated preference methods. Similarly, it would be relatively straightforward to adapt the existing revealed and stated preference housing market methods to the case of aggregate flood hazard risk reduction. We envision an approach similar to Earnhart (2001, 2002) and Phaneuf, Taylor and Braden (2013). Given a sample of housing transactions in the study area, a discrete choice housing model could be developed. The housing choice decision would be estimated alongside a randomly selected number of available properties that were not chosen. This would be compared to the traditional hedonic housing price model. A discrete choice experiment would then be developed with housing characteristics found to be important from the revealed preference analysis and characteristics of an aggregate flood hazard risk reduction policy. Inputs from the physical and landscape models would be used at this stage of the analysis. The revealed and stated preference discrete choice data sets would then be jointly estimated. Estimates of the value of aggregate flood hazard risk reduction policy would be developed from these models and combined with the market value estimates for use in benefit-cost analysis.

Technical Sophistication/Training Needed to Conduct Analysis. Combination and joint estimation of revealed and stated preference data is highly technical. Extensive training in environmental economics and econometrics is required to estimate the model. However, results from the model can be used to develop a benefit function transfer model where users would be able to input local parameters to determine benefit estimates. See Whitehead and Rose (2009) for discussion about benefit transfer.

Appropriateness of Model. The revealed and stated preference housing model is most appropriate at a local scale.

Acceptance by Research Community. While the contingent valuation method for measuring passive use values is still controversial (see the Fall 2012 issue of the Journal of Economic Perspectives), use of revealed and stated preference methods for estimating use values has gained wide acceptance by the research community. Combination and joint estimation of use values has also gained wide acceptance.

Acceptance by practitioners/local officials. Revealed and stated preference value estimates have been used in a wide variety of federal and other policy analyses.

Data Requirements Across Community Types. The economic data required to conduct the revealed preference analysis includes property transactions data and flood risk measures (e.g., Flood Insurance Rate Maps). The stated preference analysis would require a mail, in-person, or internet survey of the population.

Macroeconomics Model Overview

Regional and macroeconomic models include economic impact models (e.g., IMPLAN and HAZUS-MH), time-series models of income and employment, and computable general equilibrium models. The economic theory of production of well-being is based on the aggregate production function: $Y = f(L, K, T, \delta)$; where Y is potential output (e.g., regional economic output, income), L is labor, K is physical capital (e.g., buildings, machinery), T is technology, and δ is "other" factors. An aggregate flood hazard risk reduction policy could be included as a factor that affects δ. Simple economic theory suggests that a change in the inputs (L, K, T and δ) will lead to a change in output. For example, an increase in labor or capital will lead to an increase in output. Natural hazards will reduce the levels of inputs, such as capital, and lead to a decrease in output. An aggregate flood hazard risk reduction policy could mitigate the effects of natural hazards on labor and capital inputs. Labor market impacts can be analyzed directly through the unemployment rate. The natural rate of unemployment, u^*, is inversely related to potential output, $Y^* > Y$. The actual unemployment rate, u, depends on the natural rate and the output gap: $u = u^* + \phi (Y - Y^*)/Y^*$, where $\phi < 0$. Natural hazards will cause Y to fall below Y^* and increase the unemployment rate.

Economic impact models are based on input-output models developed in the 1950s. Inputs are translated linearly into outputs using technical coefficient estimates. Economic impact models have been used to estimate the regional economic effects of natural disasters with adjustments to these technical coefficients. Economic impact models can be used to estimate the short run negative impact of disasters and the medium and long run positive impacts. For example, Guimares, Hefner and Woodward (1993) forecast South Carolina income before Hurricane Hugo and compare these forecasts with counterfactual simulations from an economic model. West and Lenze (1994) present estimates of economic impacts from Hurricane Andrew. Results from economic impact models must be interpreted with caution lest it be concluded that natural hazards improve an economy. Rebuilding activity will increase regional economic activity. However, rebuilding is inherently unproductive since it is only replacing what has been lost, often referred to as the broken window fallacy.

Time-series models analyze the effects of lagged measures of the current value of a macroeconomic variable and other intervening variables on the current value. For example, Ewing, Kruse and Thompson (2005) found that the Corpus Christi unemployment rate fell after Hurricane Bret. Similarly to regional economic output, results such as these must be interpreted with caution. In the case of the labor market, rebuilding activity will reduce the unemployment rate but this should not be used to conclude that natural hazards are necessarily good for an economy. More directly related to the aggregate flood hazard risk reduction policy context, Ewing and Kruse (2002) consider the effect of Project Impact on the labor market in Wilmington, North Carolina using time-series data and models. They find that Project Impact mitigates the effects of hurricanes on the unemployment rate. In the same way, an aggregate flood hazard risk reduction policy may mitigate the negative effects of natural hazards in labor markets.[11]

Computable general equilibrium (CGE) models are more complex than economic impact and time-series models. CGE models are based on the circular flow model of an economy where households and business firms interact in labor, capital, and intermediate product and final product markets. A major advance of CGE models over economic impact models is the role of prices in these markets. Where economic impact models hold prices fixed, CGE models allow prices to change in response to changing demand and supply conditions. These price changes bring about simulated behavioral changes amongst households and business firms and may lead to more accurate modeling of the natural hazards recovery process. Rose and Liao (2005) illustrate these advances with a computable general equilibrium model that assesses the effects of water systems following an earthquake. Narayan (2003) provides a less detailed example of CGE modeling of natural hazards.

Relevance to Project / Research Question

Time-series macroeconomic models are most appropriate when measuring the ex-post effects of natural hazards on outcomes. In other words, with a policy already in place the effects of the policy can be determined. Since an aggregate flood hazard risk reduction policy is ex-ante, i.e., it has not been implemented, alternative approaches must be considered to estimate the potential impacts. Economic impact, time-series, and CGE models can be used to simulate the policy with linkages from physical and other models. Results from the land use modeling and HAZUS-MH runs could be used to adjust parameters in each model to determine the regional economic effects of the policy.

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[11] Project Impact was created by FEMA in the 1990’s in order to assist communities build public-private partnerships and reduce hazards-related losses. Project Impact-designated communities were given wide latitude to tailor risk reduction and educational initiatives to address local needs and conditions through the use of pre-disaster financial resources and technical assistance. The program was discontinued under President George Bush’s administration and replaced with the Pre-Disaster Mitigation (PDM) grant program, a nationally competitive funding stream tied to the creation of the Disaster Mitigation Act of 2000 (DMA). PDM funds have been used to pay for the creation of hazard mitigation plans (plans are required under the DMA in order to remain eligible for pre- and post-disaster hazard mitigation funds) and the implementation of cost-effective hazard mitigation projects.

Strengths/Weaknesses of Model

The strength of the economic impact model is its simplicity. Its weakness is its lack of flexibility with respect to the recognition that behavior changes in response to prices. The strength of the time series modeling is its simplicity. Its weakness is its inability to estimate the effects of policy without historical precedent. The strength of CGE models is its ability to incorporate reality in terms of the complexity of economic decision making. Its principal weakness is its complexity.

Accuracy. The accuracy of macroeconomic models in this policy context is unknown.

Technical Sophistication/Training Needed to Conduct Analysis. Each of the models requires some level of training.

Appropriateness of Model. The models are appropriate to measure the macroeconomic effects of an aggregate flood hazard risk reduction policy. However, there is little theory to suggest that an aggregate flood hazard risk reduction policy will have any macroeconomic impacts.

Geographic Scale. The macroeconomic models can be estimated at the county, region, state, and national levels.

Acceptance by Research Community. Economic impact, time-series, and CGE models that estimate the effects of past events on macroeconomic models are widely accepted. Since the accuracy of macroeconomic forecasts varies, predictions from these models are reluctantly accepted.

Acceptance by Practitioners/Local Officials. Local officials are fully accepting of economic impact models.

Data Requirements. Relevant regional and macroeconomic data is available for each of the models described in this paper.

Ability to Import Data into Model. Each of the models would allow for the importing of data and results from other modeling approaches.

Access to Necessary Analytical Tools (including what tools may be needed). Software for economic impact and time-series models is readily available. Typically, CGE models must be developed from the ground up by the user.

Ability of differing communities to use varied analytical tools needed to run model. Canned routines using spreadsheet software can be developed so that any community can estimate the model at the Bronze (e.g., simplified economic impact) level.

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Hazards United States – Multi Hazards (HAZUS-MH)

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FEMA released its initial version of Hazards United States (HAZUS) in 1997 in an effort to support community hazards identification and risk assessment, emergency preparedness, and the implementation of hazard mitigation initiatives. The initial release of HAZUS supported an effort to improve the earthquake modeling capability within the United States, to include community-level risk assessments. Additional releases of HAZUS have addressed riverine flooding, wind hazards, and coastal storms, collectively referred to as HAZUS-MH. FEMA adapted the HAZUS-MH in 2004 to allow users to import additional risks such as chemical releases of hazardous substances.

Overview

HAZUS-MH 2.0 is a Microsoft Windows XP SP3 or Windows 7 (Enterprise or Professional – 32-bit editions) based program that runs on ArcGIS 10 SP1, which is available from ESRI. Software in HAZUS-MH is written in Visual C++ and can use Visual Basic/VBA as needed (Schneider and Schauer 2006). For risks associated with riverine flooding, hurricane storm surge, and wind hazards, HAZUS-MH can import the outputs from models such as HECRAS, ADCIRC, or data provided by the National Weather Service Severe Weather Warnings. The hazard model results, including a risk layer, help to clarify the impacts of flood, storm surge, or wind hazards on a community and can be used by planners to evaluate development decisions in the context of potential risks from floods, earthquakes, and hurricane winds (Srinivasan 2003). As stated by FEMA, [HAZUS-MH] "… is meant to provide an analytic, decision support tool to help communities make informed decisions regarding land use within flood prone areas" (2003, p. 2-1). The HAZUS-MH program has been used by communities throughout the United States to assist them prepare hazard mitigation plans and to document hazards-related impacts.

Relevance of HAZUS-MH to research question and Flood Hazard Risk Assessment Framework

HAZUS-MH was developed as a set of geo-spatial tools to assist communities better understand the potential impacts of hazards on local assets. HAZUS-MH also helps to identify hazard mitigation strategies a community may choose to implement based on the findings of a risk assessment (Schneider and Schauer 2006). Understood in the context of flood hazards, the primary focus of HAZUS-MH is to clarify the direct and indirect economic impacts of riverine flooding events in a geographic region, including the depreciated values of structures (Scawthorn 2006). Figure 1 provides a graphic description of the types of data included in

HAZUS-MH and the types of direct physical damage that is included as outputs (FEMA, HAZUS-MH Flood Technical Manual p. 2-2). The outputs include direct economic and social losses as well as induced physical damage, direct physical damage, and indirect economic losses.

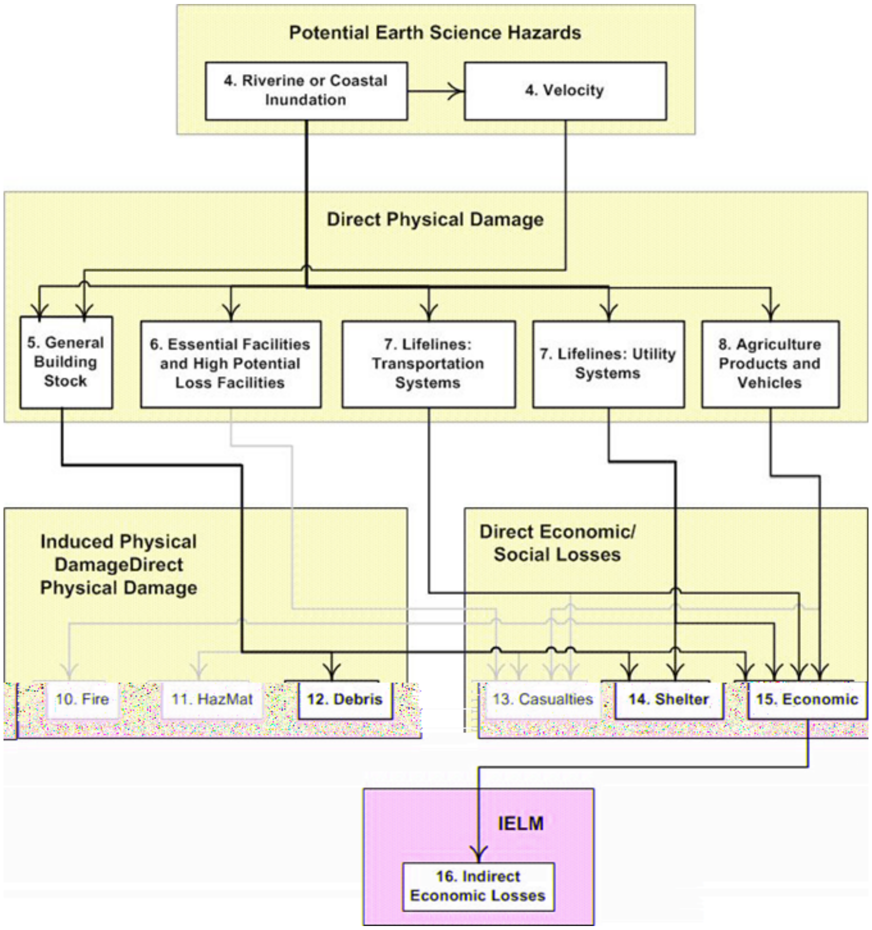

Figure 1: Flood Model Schematic (FEMA, HAZUS-MH Flood Technical Manual p. 2-2)

The geo-spatial analysis tools within HAZUS-MH also allow the user to identify potential social/cultural impacts such as the number and characteristics of the population within a hazard risk zone and any structures or landscapes that have a cultural/historical value.

Data from the Census Bureau is used to estimate direct social loss due to displaced households and casualties due to floods. The Bureau's population census data describes the characteristics of the population including age, income, housing, and ethnic origin (FEMA, 2003, HAZUS-MH Technical Manual).

HAZUS-MH can identify structures or critical infrastructure in a risk zone that could be damaged by a flood hazard of a given magnitude (Assaf 2011; Remo 2012). As a result, HAZUS-MH is a useful planning tool that allows a local community to determine the potential damage throughout a defined area and the differential impacts that may result from varied flood hazards.

Strengths/weaknesses of HAZUS-MH

The HAZUS-MH riverine flood risk zone is based on a set of models that are used by FEMA and the Flood Insurance Administration (FIA) to determine local flood zones and flood insurance rates. As riverine models are updated or new models are approved by FEMA and FIA, the results of these new models can be imported and used in a HAZUS-MH risk assessment.

Access to local data is critically important to conduct an accurate geospatial analysis using the HAZUS-MH software. FEMA provides a base set of data for all communities in the United States, which can be used to conduct a general impact assessment of riverine flooding (referred to as a Level I analysis in HAZUS-MH). "Extensive national databases are embedded within HAZUS-MH, containing information such as demographic aspects of the population in a study region, square footage for different occupancies of buildings, and numbers and locations of bridges. Embedded parameters have been included as needed. Based on this information, users can carry out general loss estimates for a region" (FEMA, 2003) (Loss estimation analysis is performed on a Census Block level). This data does not reflect the current location and characteristics of local structures (latitude/longitude coordinates, base flood elevation, etc.), model results from community flood insurance studies, nor high resolution elevation contours. Local communities may add additional information about the characteristics of structures, including the type, location, and other pertinent data.

FEMA provides a tool to facilitate the import of data into HAZUS-MH. They offer training workshops for users and provide technical support for those who encounter difficulties in using the import tool. This process is technically difficult to undertake and communities may not have the technical staff required to incorporate and utilize local data sets.

A broad-based team is essential and should include private consulting firms, local or regional colleges and universities, volunteers from other local governments, and state agencies. State or regional user groups exist throughout the U.S. and are often able to provide needed technical support. Training and consultation is also available from FEMA at no cost to local communities.

Users of HAZUS-MH benefit from an understanding of the factors impacting riverine flooding such as the nature of water features; slope and elevation characteristics of the area; the location of roads, bridges, and culverts; impermeable surfaces; lakes; and water retention structures. In addition, the HAZUS-MH team needs to understand building sciences and how the characteristics of structures, influenced by state or local building codes, Flood Damage Prevention Ordinances, age of construction, building types, etc., could impact potential damage from riverine hazards. Further, damage to structures could be influenced by the density of local development and the use of structural and non-structural hazard mitigation strategies. A multi-disciplinary team of individuals that represent civil and environmental engineering, building sciences, community planning, and emergency management is needed to ensure that quality data forms the basis of the risk assessment and that the findings and conclusions are an accurate reflection of the conditions faced in the community.

Many local governments throughout the U.S. have invested in geographic information systems and are using ESRI products. This capacity can be bolstered by building accurate local maps for 911 communication districts or investments made by public utility districts in local geo-spatial systems. Acknowledging that many local government units possess geo-spatial data and identifying which local entities have this data (and its quality) is a critical step in understanding a local government's capacity to use HAZUS-MH. In addition, many state agencies have collaborated on the development of statewide data sets including high resolution images, LIDAR, landuse, landcover, and critical infrastructure sites while encouraging local jurisdictions to use common data formats. As local governments enhance their GIS capabilities, these communities will be in a position to use HAZUS-MH as a tool to improve hazard mitigation planning, including the identification of cost-effective risk reduction measures, and the documentation of their implementation and monitoring over time.

Given that many states have initiated broad-based geospatial data initiatives, it is possible that a regional risk assessment may be possible for many communities who are just beginning to develop local data. Further, many businesses and non-profit organizations need to understand hazards and risks at the local and regional level and thus could be included in an aggregate flood hazard risk reduction initiative. It should be noted that HAZUS-MH does not account for uncertainty (Hardmeyer and Spencer, 2007; Scawthorn et al 2006), and rather provides estimates of flood depth and depth-damage curves to estimate flood damage for residential and business structures, lifelines, and agriculture losses.

Moffatt and Laefer (2010) note that the HAZUS-MH software code precludes the use of two major advancements in the computing industry, namely open source software and Internet-based applications. They explain that the HAZUS-MH design is restricted by an underlying commercial off-the-shelf (COTS), closed source geographic information system (GIS). The program is limited to Microsoft Windows platforms and precludes its integration into an Internet web infrastructure. This structure limits the number of users over an enterprise distributed network system. Moffatt and Laefer recommend that the program should be a part of a web-based user interface and that the system should be decoupled in order to enhance user flexibility and that an open source be created.

Accuracy. The accuracy of HAZUS-MH (Riverine) is based on two factors, the quality of the riverine model that describes the nature of the hazard event and the accuracy of the local building and infrastructure data sets. Riverine modeling is a complex process that is intended to replicate a dynamic system that is impacted by physical conditions as well as the duration and intensity of a rain event. An accurate assessment of the risk is also based on the quality of local building data that must be incorporated into the model by a local official, consultant, university-based team member, or other capable individual, and updated over time to reflect changing conditions.

As noted in the HAZUS-MH Technical Manual-Flood, “Uncertainties are inherent in any loss estimation methodology. They arise in part from incomplete scientific knowledge concerning the hazard and its effect upon buildings and facilities. Uncertainties also result from approximations and simplifications that are necessary for comprehensive analyses. Incomplete or inaccurate inventories of the built environment, demographics, and economic parameters add to the uncertainty. These factors can result in a range of uncertainty in loss estimates produced by HAZUS-MH, possibly at best a factor of two or more” (FEMA, 2003).

There have been a limited number of studies that assessed the accuracy of the HAZUS-MH model using not only local hydrological models but also local data (Ding 2008; Myer 2002). Both studies examined the validity of the data included with HAZUS-MH and determined that while some difference were observed, inaccuracies were most prevalent in high growth metropolitan areas. The Level 1 analysis within HAZUS-MH did reveal discrepancies in estimated losses with the Level 2 analysis proving much more reliable.

Technical Skills Required to Operate HAZUS-MH. As noted earlier, a broad-based team should be formed to work with HAZUS-MH. Members should have the knowledge and skills required to conduct a community riverine hazards analysis. It is critical that members of the team have a comprehensive understanding of both riverine hydrology (the science that deals with the properties, distribution, and circulation of water on land) and hydraulics (the science associated with determining the depth of flooding for a specific event in a geographic area).

The HAZUS-MH team also needs individuals who have a strong knowledge of building sciences as flood waters can impact the integrity of a structure. Further, an understanding of both structural and non-structural hazard mitigation strategies are critical in identifying alternatives for dealing with risks presented by flood hazards. Knowledge of state or local land use regulations and building codes is also essential. Another key player in the HAZUS-MH team is a skilled user of ARC-GIS and one who understands spatial analysis. This person should recognize the limitations of various data used in HAZUS-MH and can assist the team interpret and apply the results, including its use in conjunction with other local and external datasets.

Appropriateness of HAZUS-MH and Geographic Limitations. HAZUS-MH is intended to support the development of comprehensive hazard mitigation plans by local communities. It is also a useful tool to assist in the identification of local hazard mitigation initiatives.   Technical documentation notes that HAZUS-MH has spatial limitations that impact its analysis. The 2003 documentation states that it is restricted to approximately four counties (approximately 90,000 census blocks).

Acceptance of HAZUS-MH Results. The development of the HAZUS-MH (Riverine) involved the input and collaboration of civil engineers from colleges and universities, private firms who conduct hydrologic and hydraulic analyses associated with the federal floodplain mapping program, and local public works and community planning officials.   Acceptance of the findings and conclusions resulting from the use of HAZUS-MH (Riverine) is greatly impacted by the team that uses the program as well as the skills and knowledge of local officials, the business community, and the general public. Resistance to the use of HAZUS-MH (Riverine) has been greatest where the make-up of the local team did not include members who had the required knowledge or skills, the riverine model was based on inaccurate or outdated data, or post-disaster damage assessments conducted using the loss estimation tool did not include accurate or updated information concerning structures in hazard risk zones.

Coupling HAZUS-MH Outputs with other Models. HAZUS-MH makes use of alternative hydraulic models and is based on ESRI's ARC-GIS. As a result, the possibility of linking these elements to other social, economic, or environmental models is possible, utilizing the input data from hydraulic models or data sets within HAZUS-MH. For instance, compatibility with other ARC-GIS based geo-spatial programs such as Community VIS is possible and merits a further discussion with FEMA staff and representatives from Community VIS in order to explore options regarding how the coupling of these models can improve the quality of hazard mitigation plans (to include land use as a risk reduction technique) and the future operationalization of a critical component of the proposed aggregate flood hazard risk assessment framework.[12]

Data Requirements. FEMA designed HAZUS-MH so that it can be used by communities of varying capabilities regardless of the expertise of staff and outside resources. A Level 1 analysis as shown in Figure 2, requires no modification of model parameters and data provided by FEMA. Despite the limitations that come with a Level 1 analysis, the program outputs provide local communities with a general assessment of flood risks. For communities with internal or external expertise, the Level 2 analysis provides information that is well suited for many hazard mitigation strategies. For communities with a broad experience in flood modeling and use of GIS-spatial analysis tools, a Level 3 assessment is possible. A summary of data requirements needed to conduct gold, silver, and bronze-level analyses associated with the aggregate flood hazard risk assessment framework are shown in Table 1.

Table 1. HAZUS-MH Data Requirements for Gold, Silver and Bronze-Level Analyses

HAZUS-MH	
Level 1 *	DEM (digital elevation model) imported into the flood model- topographic data
	DEM combined with stream discharge data to determine flood surface elevation
	"Inventory data" (population, buildings, infrastructure, agricultural resources, within flood boundary included in Flood Model
	Uses national data on general building stock to estimate direct physical damage to buildings and contents
	Direct economic losses, Indirect economic losses and exposure of essential facilities and people are calculated
	Appropriate Depth Damage Curves are applied to determine levels of damage
	Resulting damage and loss estimates apply to all building occupancy classifications and general building types
	Economic losses are estimated based on physical damage to buildings, debris generated is computed as well as shelter requirements for displaced people
Level 2**	Flood surface data- Coastal Base Flood Elevations (BFE's), Digitized stream Cross Sections or Digitized BFE's from FIRM
	Digitized floodplain boundaries- DFIRM, Q3 data, or any other floodplain map in polygon form
	Ground Elevation Data- built from contours, Triangulated Irregular Network (TIN) or other
Direct Damage Module Inputs	Building Occupancy Type and first floor elevation data
	Depth of Flooding (FIT model) or level 1 analysis or area weighted throughout the census block where the building is located
Depth Damage Functions	Federal Insurance Administration's (FIA) "credibility weighted" depth-damage curves and curves for various districts of USACE for estimating damage to general building stock
	Essential facilities- default depth damage curve, editable by user.
	Lifeline systems- separate set of damage functions

A Level 1 risk analysis as shown in Figure 2 is the simplest type of analysis requiring minimum effort by the user as it is based principally on input provided by pre-existing HAZUS-MH datasets (e.g., census information, broad regional patterns of floodplain code adoption, etc.). The user is not expected to have extensive technical knowledge. Documentation of each data layer is complete and available on a national basis. While the methods require some user supplied input to run, the type of input required could be gathered by contacting government agencies or by referring to published information. At this level, estimates are generalized and not suitable for use in determining property-specific mitigation strategies (e.g., property

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[12] In a six-year study of the quality of state and local hazard mitigation plans, Berke, Smith and Lyles found that a primary weakness in plans was the limited use of land use planning as a risk reduction technique (Lyles, Berke and Smith 2013; Smith, Lyles and Berke 2013).

buyouts or elevations; retrofit of public facilities, etc.), nor changes to FIRM boundaries. HAZUS-MH is suitable as a tool to determine where more intensive flood studies might be initiated or hazard mitigation projects considered, pending the assemblage of more detailed information. Given that loss estimates are generalized and not based on specific flood studies, outputs are appropriate only as initial loss estimates to determine where more detailed analyses are warranted.

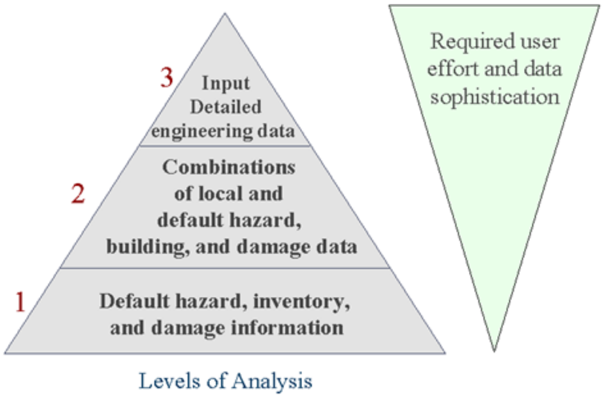

Figure 2: Levels of Analysis and User Sophistication (HAZUS-MH Flood Technical Manual, 2003)

A Level 2 analysis is intended to improve the results from Level 1 by utilizing additional data. Data such as HEC2 flood analysis may be available in a community and imported into HAZUS-MH Flood. HEC2 studies meet the methodological requirements of HAZUS-MH analysis and are part of the overall Flood Insurance Administration flood assessment efforts. In Level 2, the user may need to determine data inputs from published reports or maps.

The Level 2 analysis may also include more extensive property and infrastructure inventory data that may reflect a more accurate count of building types, numbers of structures, contents, and age of construction. For instance, many local communities have accurate records of the first floor elevation of the structure. HAZUS-MH Flood includes the FIT ‘tool’ that is used to edit and input building inventory data and to pre-process the data for use in the Flood Model. The HAZUS team may need to employ technical staff to assist in data input and the use of the FIT tool. FEMA provides training for those interested in learning how to use the FIT tool and how to import this data along with HEC2 studies into HAZUS-MH.

The Level 2 analysis allows for the use of outputs from HEC2 type flood studies and local building infrastructure data. HAZUS-MH provides the user with pre-packaged estimates of flood damage/loss using the standardized HAZUS methods, settings, damage curves, and calculations that are included in the methodology.

The HAZUS-MH development team has designed a methodology that allows users to take advantage of ongoing flood studies in their community. In many communities throughout the U.S., flood studies have included extensive field surveys. In addition, many communities have acquired high resolution surface contour data (LIDAR). Enhancements to hydrologic modeling and the use of LIDAR data may be imported into HAZUS-MH. Developments in hydrologic modeling and the use of high resolution LIDAR data are well documented and enhance the hazard analysis process.

A Level 3 analysis allows the user to edit depth-damage curves associated with water levels and associated damages to general building stock. Engineers and building scientists can provide suggestions on editing the damage curves used in the HAZUS-MH analysis processes. These changes incorporate results from engineering and economic studies carried out using methods and software associated with the HAZUS-MH methodology. At this level, one or more technical consultants may be needed to perform analyses, assess damage/loss, and interpret the results of damage assessments. It is anticipated that at this level there will be extensive participation by local utilities, special facilities, and businesses.

Conclusions

HAZUS-MH (Riverine) was designed to support community efforts to enhance hazard mitigation initiatives. As HAZUS-MH has evolved since its introduction in 1997, it has proven to be a valuable tool in enhancing a community's hazard mitigation capabilities. HAZUS-MH is science based and provides communities with a framework for visualizing numerous hazards and their potential consequences. By using HAZUS-MH, the results of a community hazards analysis are data driven and therefore better serve the needs of communities. For those communities that have the requisite staff and financial resources, HAZUS-MH provides for model and high resolution geographic data input, editing of local data, and the modification of damage estimates (damage curves). A strength of the HAZUS-MH is its extensive documentation and technical support. HAZUS-MH thus provides the emergency management and hazard mitigation planning needs of communities regardless of their size and resources.

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FEMA Flood Loss Avoidance Methodology

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Overview

The Federal Emergency Management Agency (FEMA) has developed a methodology to calculate losses avoided for buildings that have implemented mitigation measures to reduce the likelihood of future flood-related damages (FEMA 2009). Since the enactment of the Robert T. Stafford Act in 1988, FEMA has provided States and communities with billions of dollars of hazard mitigation funding for projects intended to reduce or eliminate risks from natural hazards. The loss avoidance methodology is intended to quantitatively assess the benefits of a completed project after an actual flood event. The methodology compares the estimated dollar amount of avoided losses with the cost of the project to illustrate the value of investing in mitigation measures.[13] The calculated losses avoided for a given project show the return on investment (ROI) for the following categories of avoided losses for flood hazard mitigation: 1) Direct physical damage to buildings and contents; 2) Loss of function and displacement costs; 3) Loss of life; and 4) Emergency response costs, such as police or fire crew dispatch and sheltering.

Process of Losses Avoided Analysis

The FEMA loss avoidance methodology has three phases for capturing the losses avoided by implementing hazard mitigation projects: 1) Initial project selection and screening, 2) Flood event analysis, and 3) Loss estimation analysis (FEMA 2010).

Phase 1. Initial Project Selection and Screening. Phase 1 involves identifying an initial list of completed mitigation projects and the data required to conduct the analysis. The projects are then prioritized based on the availability of the data. If missing data cannot be augmented by other sources or standard values, the project is removed from the candidate list.

Phase 2. Physical Parameter Analysis. Phase 2 includes a flood event analysis, hydraulic analysis, and flood inundation analysis. To estimate losses avoided, there must be a flood event

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[13] The implementation of hazard mitigation projects can produce quantifiable and non-quantifiable benefits, depending on its type. FEMA typically uses Benefit-Cost Analysis (BCA) modules to quantitatively assess losses avoided, whereas the federal agency has yet to develop comparable methods to assess qualitative benefits or account for them when calculating a project's cost effectiveness.

severe enough to have caused damage in a before-mitigation scenario. The most important information needed to conduct the analysis is the depth of flooding inside the building. The depth of flooding inside a building is best determined using high water marks (HWMs) obtained in the study area. If HWMs are not available, flood depth can be estimated using stream gage discharge data, stream gage stage data, or precipitation gage data.

Flood event analysis – Identifies potentially damaging events that have occurred since the mitigation measure was implemented and assesses the availability of HWMs or nearby gage data for those events.

Hydraulic analysis – Conducted if HWMs are unavailable to determine water surface elevations at the project site from known storm events.

Flood inundation and boundary analysis – Using HWMs or flood depth data, the flood inundation and boundary analysis determines flood boundaries and probable depths of flooding that would have occurred in each building in the absence of the mitigation action.

Phase 3. Loss Estimation Analysis. In this phase, the user conducts an effectiveness analysis of each property improvement to determine if any losses were avoided as a result of implementing the mitigation action. The analysis compares the flood depths before and after the implemented flood mitigation project. Losses avoided for all properties are calculated using depth-damage curves and ROI.

Relevance to Project / Research Question

The FEMA loss avoidance methodology for riverine flood hazard focuses on two forms of flood hazard mitigation: building modification and flood control projects. Building modification projects mitigate or eliminate structural, content, and other types of damage by modifying the building. Project types include elevation, acquisition, relocation, and floodproofing. Flood control projects mitigate damage by reducing the likelihood of the hazard impacting the built environment (up to a defined design standard). Flood control projects include stormwater drainage system improvements, channel modifications, flood walls/barriers, and other projects.

Depth-damage curves for different building types used in the FEMA loss avoidance methodology could be applied to a new aggregate flood hazard risk assessment model that captures the level of risk or potential loss for buildings in a project area. The FEMA loss avoidance methodology for flood control projects may be useful for land use impact modeling since the methodology analyzes flood level changes in large areas affected by stormwater drainage system improvements, channel modifications, or flood walls/barriers.

Issues Requiring Additional Research

Project Area. Defining a project area can be difficult and their selection will affect outcomes. Political, administrative, and watershed-based boundaries should be considered when choosing the proposed study area.

Risk Reduction Measures. Selecting which risk reduction measures to include in the study requires additional research. There are many structural and non-structure risk reduction measures that could be considered. The effects of some non-structural measures cannot be measured quantitatively. For example, public outreach and training may have a significant effect in a community, but its impact on risk reduction is hard to measure.

Strengths/Weaknesses of Model Use in Proposed Projects

The FEMA loss avoidance methodology has been tested in a range of communities nationwide, and it accurately projects the effectiveness of risk reduction measures for smaller-scale projects (e.g., multiple structural buyouts, single or multiple elevation projects, or a localized flood control project). It includes depth-damage curves that have been used in other hazard analysis methods (e.g., HAZUS-MH, U.S. Army Corps of Engineers, and FEMA BCA). If HWMs are available, hydrologic and hydraulic (H&H) modeling is not required. The FEMA methodology does not, however, measure qualitative benefits generated from the mitigation projects being studied, such as environmental protection or the creation of recreational space. It is most useful for smaller-scale projects and not as useful for large regional studies. The process is very data intensive and requires individual property-level building information.

Accuracy. The FEMA loss avoidance methodology has been tested and accurately projects the effectiveness of risk reduction measures for a smaller-scale projects. The methodology relies on established depth-damage curves to determine losses that would have been caused by floods if the mitigation project had not been implemented. These depth-damage curves, which have been developed by FEMA, the U.S. Army Corps of Engineers, and other agencies using observed data from historical events, identify the loss that is likely to occur at certain intervals (e.g., different flood depths). The flood depth-damage curves are either nationally published estimates or derived from local damage information and an interpolative calculation. The following curves are used in the FEMA loss avoidance methodology: 1) Building-damage; 2) Contents-damage (e.g., damage sustained to a building's contents); 3) Displacement-time (e.g., displacement time for occupants and/or the loss of rental income); and 4) Loss-of-function (e.g., stoppage or delay of business income and the loss of public services). There are 28 depth-damage curves for general building stock categories (6 residential, 10 commercial, 6 industrial, and 6 other) for flood depths ranging from -2 to 16 feet.

Appropriateness of FEMA Loss Avoidance Methodology. The methodology analyzes the effectiveness of hazard mitigation projects implemented after flood events. It is not designed to estimate risk reduction on a macro level using a what-if scenario. Specifically, it cannot model the impacts of differing land use regimes, nor their change over time. Progress is being made in the ability of the methodology to estimate the effects (e.g., losses avoided) of flood mitigation policy choices as FEMA is currently conducting a study of varied building codes and their measureable effects on future losses. More research is needed to explore ways to expand the ability of the methodology to monetize the effect of other policies, including the adoption of varied land use techniques.

Geographic Scale. The FEMA loss avoidance methodology has only been tested on a community level but can be expanded to a county level as long as building data and flood depth data are available.

Acceptance by Practitioners/Local Officials/Research Community. The FEMA methodology has been used in several states and communities to demonstrate the effectiveness of hazard mitigation measures. The study results have been well received by practitioners, government, and members of Congress.

Coupling Model with Others. The FEMA methodology can be coupled with HAZUS-MH if certain building attributes, such as first floor elevations (FFEs), size and type, and H&H modeling capability (e.g., digital data, staffing, and resources) are available at the community level.

General Data Requirements for Estimating Losses Avoided Using FEMA Methodology

After the initial list of projects is selected, data collection begins. Projects can be removed from the analysis during Phase 1 if required data are not available or cannot be easily estimated. Projects may also be eliminated if the quality of the data is insufficient. Data can be collected from numerous sources, including site visits, project files, local governments, consulting engineers, and third-party vendors.

Study area: The study area may include a reach of a river or channel, a single community, a watershed, a region, or a jurisdictional boundary (e.g., city, county, state, special district).

Hazard type: Coastal or riverine flooding. The selected flood hazard will determine which depth-damage curves are used.

Study baseline: The date the mitigation project was completed and a storm event of sufficient severity in the study area are critical to determine if the completed mitigation project will generate losses avoided.

Building modification projects, such as acquisition, elevation, or dry floodproofing require the following data: 1) Project cost; 2) Project completion date for each building; 3) First Finished Floor Elevation (FFE) before and after the mitigation measure is implemented, preferably in the form of FEMA elevation certificates; 4) Building location information in the form of latitude/longitude data, address, and/or assessor parcel number (APN); and 5) Building-specific information, such as HWM, Number of floors, Square footage, and Building Replacement Value (BRV).

Flood control projects require the following data: 1) project cost, 2) Project completion date, 3) Functional downtime of affected utilities and roads due to flooding (if applicable), 4) Traffic counts and detours for affected roads due to flooding (if applicable), 5) Hydraulic modeling before and after construction scenarios, and 6) Detailed topographic data.

Level of Accuracy. Table 1 provides a list of data required for performing Losses Avoided Analysis at three different levels, including Bronze, Silver, and Gold. Bronze level data may be suitable for a large project area with multiple jurisdictions. The Silver and Gold level data will increase the accuracy of analysis significantly, but not all communities can provide Gold level information.

Table 1. Data Requirements and Level of Accuracy

Data Category	Bronze	Silver	Gold
Basic Data	Area of interest (single community, watershed, region, etc.), hazard type, project type and project completion date		
Project cost	Lump sum project cost	Categorical project cost	Detailed project cost with line items
FFE	Ground elevation from LiDAR/Topo map and foundation height	2' LiDAR and Est. Foundation Height	FFE (FEMA elevation certificates)
Building Location	Property addresses	Tax parcel on GIS	GIS & aerial photo
Building Data	HAZUS building inventory	Building size; construction type; number of stories; size; foundation	Building information plus garage and basement
Topographic Data	Contour map or USGS DEM	LiDAR	2' LiDAR
Storm Event Data	Stage data or precipitation gage data	Aerial photographs or stream gage discharge	High water marks
Flood Inundation and Boundary Analysis	Normal depth calculations	Existing H&H model	New hydrologic model including-watershed delineation, land use, soil type, ground cover info, cross section elevation data, roughness coefficients, boundary conditions, and inflow from storm event analysis
Data Category	**Bronze**	**Silver**	**Gold**
Physical Damages/Loss of function	Using census data for average loss estimation by census block level analysis	Use standard values from HAZUS or other readily available analytical tools	Utilize individual structural or facility information to estimate losses

Research Questions and Discussion

Community type needs to be defined beyond high, medium, and low capability. For instance, High capacity communities (gold standard) could be defined as possessing staff that are highly trained in GIS, stormwater management engineering, emergency management, floodplain management, and building code enforcement. Communities should maintain tax parcel data in a GIS format with FFEs and Digital Flood Insurance Rate Maps (DFIRMs). Medium level capacity communities (silver standard) could be defined as possessing moderately capable staff in GIS, floodplain management, and stormwater engineering. They should maintain FIRM and tax parcel data in a digital format with or without latitude/longitude attributes. Low level capacity communities (bronze standard) could be defined as possessing little or no capabilities in GIS and stormwater engineering, and their property data and FIRM's are likely to be in a paper format.

Use of the Model by Communities of Differing Levels of Technical Sophistication and Resources. Some communities with a medium or high level of capacity are already using the tool to evaluate losses avoided from some mitigation projects, such as property acquisition or elevation. For flood control projects, it requires more modeling work to compare before- and after-mitigation flood depths. For this type of project evaluation, communities may need to hire a qualified contractor to conduct the analysis, which can be costly.

Data Access, Availability (pre- and post-event), and Reliability (metadata). Communities should have project files with property address and building characteristics in order to conduct detailed analyses. Communities and regional users of the data could use standard values for some missing information; however this will decrease the accuracy of results.

Ability to Import Data into Model. Most loss avoidance analyses are conducted using MS Excel spreadsheets, which have built-in depth-damage curves. Most building attributes and water depths are either manually entered or copied into the spreadsheet.

Next Steps/Gaps/Recommendations/Needs/Remaining Questions

Five features need to be integrated into the proposed aggregate flood hazard risk assessment model.

1) The proposed model needs to clearly identify the types of risk reduction measures to be included in the analysis; of which two types should be considered: 1) non-structural

measures such as acquisition, elevation, building code, floodproofing etc.; and 2) structural measures such as channeling, detention area construction, dams/levees, etc.

2) After deciding the types of risk reduction measures to use in the model, determining how they will be measured must be determined. For instance, quantifiable risk reduction, including structure and content losses avoided, avoided loss of function and business, improved property values, or reduction in government assistance, should be captured. In addition, qualitative impacts will need to be assessed, including environmental benefits and quality of life measures.
3) The current unit of analysis is the community or project-scale due to the ease of building data collection and availability of other data, such as land use, floodplain management, and capital improvements. The ability to expand the unit of analysis to multiple communities and a region (e.g., the watershed) will require significant advancements in current losses avoided methodology.
4) Missing data remains a significant, but not insurmountable challenge. For instance, missing structural information can be augmented with 2010 Census data as long as the community provides the number of buildings by type. FFEs are key data points for assessing the effectiveness of flood hazard risk reduction measures. If the FFE is missing, a proxy FFE can be established using a typical foundation type and estimated ground elevation.
5) It is suggested that FEMA's HAZUS-MH should be enhanced to include land use and H&H simulation modeling capabilities. The updated model should include the following functions: 1) Allow communities to input local building inventory; 2) Allow different scenarios, such as adding freeboard, land use changes, and population growth; and 3) Display quantitative impacts, including number of people affected by the mitigation measure being studied, as well as a graphic display of flood boundary changes.

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Hydrologic Modeling

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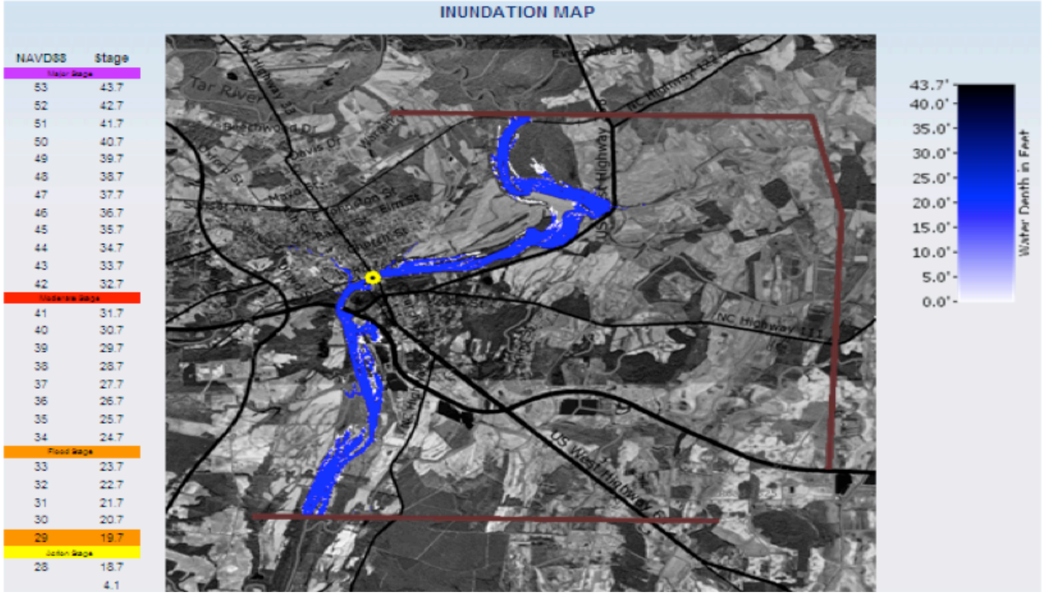
Overview

The hydrologic response question, from an aggregate flood hazard risk assessment point-of-view, boils down to this: for a real or hypothetical rainfall event, what is the anticipated water level that will be seen at points of interest in the watershed? Given the wide range of conditions, diverse geographic characteristics, and sophistication of the end-user, one model may not be able to satisfy all needs. Thus, a more viable strategy is to develop or adapt a "user-friendly" analysis tool, which, given an expected flood elevation, translates that information to an interactive inundation map that is accessible to a wide-variety of users. A prototype for such a system has been developed by the NOAA/National Weather Service for flood inundation mapping as part of its Advanced Hydrologic Prediction System. A GIS-interface example is shown in Figure 1 in which the system has been ported to Google Earth.



NAVD88	Stage
Major Stage	
53	43.7
52	42.7
51	41.7
50	40.7
49	39.7
48	38.7
47	37.7
46	36.7
45	35.7
44	34.7
43	33.7
42	32.7
Moderate Stage	
41	31.7
40	30.7
39	29.7
38	28.7
37	27.7
36	26.7
35	25.7
34	24.7
Flood Stage	
33	23.7
32	22.7
31	21.7
30	20.7
29	19.7
Action Stage	
28	18.7
	4.1

Figure 1. Example of a possible interface to display inundation levels that are produced by a hydrologic model. High-resolution spatial analysis tools would allow researchers to correlate the extent of flood damage with analysis scenarios associated with aggregate risk modeling.

In this type of display, the model used to estimate the flood level remains transparent to the user. More specifically, a chosen model generates a predicted flood level, based on conditions provided by the user. Regardless of the source of that data, it is then transmitted to the end-user system for display. Interactive controls allow the user to customize the visualization product in order to meet their needs, be it a flood forecast warning or an aggregate flood hazard risk reduction study. The next section discusses possible modeling approaches that may be used “behind the scenes” of the interface to generate estimated flood levels.

General Approaches to Hydrologic Modeling and their Relative Strengths/Weaknesses

Statistical models (e.g., flood-frequency analyses) rely on historical stream gage data, which is used to fit an assumed probability density function. Once determined, the probability density function can be used to estimate the flood flows associated with various return intervals. The methodology is often used in practice, but it suffers from several drawbacks: 1) Its skill depends on the accuracy of gage data, 2) It is only valid at the site where the data is collected,[14] and 3) It cannot be used to predict the impact of land use changes. The latter drawback precludes this approach from being a viable tool for aggregate flood hazard risk assessment.

Empirical models rely on observations from a watershed to develop response functions to the precipitation input. Unit hydrographs (UH), which are the most widely used approach, falls into this category. While the UH method has been used in practice for a number of years and forms the basis of some popular hydrologic models, the UH method tends to lump basin information together at large scales, which makes it difficult to separate the relative contribution of a watershed’s physical attributes (e.g., land use) that determine the amount of runoff. Furthermore, the accuracy of the UH depends on large amounts of historical data upstream of the site of interest, which may not be available. Thus, while problems with both the scale and approach preclude the use of this model as the “gold standard,” their long history and familiarity among a wide-variety of end users make them desirable for “silver” and “bronze” standards.

Physics-based models solve balance laws from physics (e.g., conservation of mass, momentum, energy) in order to predict the movement of water through the system. Nearly all of these rely on some empirical relations, such as Horton’s infiltration equation, to close the system. Distributed hydrologic models offer the ability to provide high-resolution, physics-based,

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[14] There are a limited number of gage sites relative to existing rivers and streams in the United States.

spatially-descriptive simulations from catchment to river basin scale. If properly designed, they can be run as an event-based model or as a continuous model. In contrast to lumped-parameter hydrologic models that have dominated practice for years, such as the UH approach mentioned above, distributed models are better at representing the spatial variability of factors that control runoff, as they allow one to capitalize on access to high-resolution digital data. Distributed models also provide flood information at any point in the watershed, not just at the outlet of the basin or a limited number of internal control points.

Distributed models are typically classed into one of three types, including kinematic wave, diffusive wave, and full dynamic, depending on their dominant physical processes. Kinematic wave models apply to shallow flow on steep slopes or long-duration flood waves with no backwater effects. Diffusive wave models (also called non-inertial models) apply to situations where inertial terms are negligible compared to gravity, pressure, and friction. Full dynamic models apply to nearly all hydrologic conditions experienced in geophysical fluid flows, and they can be one-, two-, or three-dimensional. The flexibility of distributed models makes this class the best choice for the “gold” standard.

Potential Hydrologic Models within Each Class

Table 1 summarizes key aspects of common hydrologic models, both lumped and distributed, that are found in research and practice. A physics-based, distributed model that operates within a GIS framework is reflective of the gold standard, because it balances the sophistication of governing equations with ease of use and time required to run the models. One model in which the research team is familiar and that may be used in the proposed framework is Vflo. The hydrologic model has been thoroughly vetted in a variety of settings and is discussed in further detail in the subsequent section. For the silver and bronze standards, the best choice would be the popular and publically-available HEC-HMS/HEC-RAS model, which is also discussed in a subsequent section.

Table 1. Summary of Prominent Hydrologic Models

Model	Developer	Features
HL-RDHM	NOAA/OHD	distributed, structured grid, SAC soil moisture accounting (SMA), 1D kinematic wave
TREX	Colorado State University	distributed, structured grid, DEM, Green-Ampt infiltration, no SMA, 2D diffusive wave overland routing, 1D diffusive wave channel routing, evolved from CASC2D, sediment and contaminant transport
Vflo	OU/Vieux and Associates	distributed, structured grid, integrated with GIS, DEM, Green-Ampt infiltration, empirical SMA, 1D network kinematic wave overland routing, 1D kinematic wave channel routing
PIHM	Penn State University	distributed, triangular unstructured grid, Richard's equation, lateral groundwater flow, 2D diffusive wave or kinematic overland routing, 1D diffusive or kinematic channel routing
HRC-DHM	Hydrologic Research Center	distributed by catchment, SAC soil moisture accounting, 1D kinematic wave channel routing
MIKE SHE	Danish Hydraulic Institute	distributed, orthogonal structured grid, Richard's equation, 3D saturated groundwater flow, 2D diffusive wave overland routing, 1D kinematic, diffusive, or dynamic channel routing, or simple empirical routing methods
WASH123D	University of Central Florida	distributed, triangular unstructured grid, 3D groundwater flow model, 2D kinematic, diffusive, or dynamic overland flow, 1D kinematic, diffusive, or dynamic channel routing, levees
TOPNET	Utah State University	lumped by subcatchments, TOPMODEL SMA, Green-Ampt infiltration, constant hillslope velocity model, 1D kinematic wave channel routing
HYDROTEL	University of Quebec	distributed at subwatershed scale, kinematic or diffusive wave overland routing, 1D kinematic or diffusive wave channel routing
HEC-HMS/ HEC-RAS	Hydrologic Engineering Center, Army Corps	lumped, gridded SMA, various infiltration models, unit hydrograph or ModClark or kinematic wave for overland flow, reservoirs, kinematic wave or Lag, Modified Puls, Muskingum channel routing
tRIBS	MIT	distributed, triangular irregular network, surface energy budget, continuous SMA, kinematic wave channel routing

DHSVM	University of Washington	distributed, structured grid, vertical moisture budget, unit hydrograph or linear reservoir routing, Muskingum-Cunge or cascade of linear reservoirs for channel routing
VIC-3L	University of California-Berkeley	macroscale model for large basin, Horton or Philip or Green-Ampt infiltration, subgrid scale soil heterogeneity
SWAT	USDA/Texas A&M	lumped subbasin model, variable storage or Muskingum, includes water quality, land use, modified SCS curve method
GSSHA	Coastal and Hydraulics Lab, Army Corps	distributed, reformulation of the CASC2D model, SMA, saturated and unsaturated groundwater flow (1D and 2D), 2D diffusive wave overland flow, 1D diffusive wave channel routing
CREST	University of Oklahoma/ NASA	distributed, variable infiltration curve, linear reservoir routing at subgrid scale, surface and subsurface flow via cell-to-cell routing, embedded optimization routine.

Specific Hydrologic Models for Various Standards

The aggregate flood hazard risk framework divides models into gold, silver, and bronze standards. The sophistication of the model, which also manifests itself by the level of education needed by those who run the model, as well as the amount of data needed to set-up and run the model, decreases as one moves from gold to silver to bronze. For each standard, the subsections below describe the basic characteristics of the model, the data needs, and the level of education needed to run the model.

The Gold Standard: Vflo, a Physics-based, Distributed Hydrologic Model Dynamically Integrated with GIS. Vflo is physics-based, distributed hydrologic model that is applicable from the catchment to regional scales. Model input for event-based simulations includes the following digital maps: 1) Topographic data in the form of a Digital Elevation Model (DEM), which could be acquired from any source, such as LIDAR, photogrammetry, or land surveying; 2) Soil type and depth; 3) Land use/cover, including impervious area; 4) Channel geometry; and 4) Hydraulic channel characteristics. Vflo has been designed to capitalize on high-resolution quantitative precipitation estimates from model forecasts, radar, satellite, rain gauges, or combinations of multi-sensor products. Digital data sets can be used at any resolution and the system is tightly integrated with GIS.

The model's parameters are derived from geospatial data and are used for initial model setup, which can be refined during the calibration processes. Vflo has been extended to support continuous modeling by accounting for soil moisture. Past applications include land use changes, reservoir recharge from infiltration, flood event reconstruction, operational flood alerts, education, and research and analysis of hydrologic phenomena.

An advantage that Vflo has over some of the other models is that it is a commercial product, so a significant amount of attention has been given to the customer experience. For instance, it employs an easy-to-use GUI interface, which simplifies model setup and application. However, as with any sophisticated model, the user should have a strong background in the underlying hydrologic science, preferable at the Master's level. On the other hand, the commercial aspect of the model is also a disadvantage because of licensing costs and because the source code is not open access. The latter means that custom modifications would have to be done by the developers, which takes time and money.

For routing flood waves down large river basins, Vflo could be loosely coupled to HEC-RAS (described in the section below). In either case, the model would be coupled to the aggregate flood hazard risk-reduction framework through an inundation interface shown in Figure 1.

The Silver and Bronze Standards: HEC-HMS/HEC-RAS. HEC-HMS (Hydraulic Engineering Center – Hydrologic Modeling System), or HMS, developed by the Army Corps of Engineers, represents the watershed with a basin model. Features of the software, as taken from HEC-HMS documentation, include the following elements:

1) Hydrologic elements (subbasin, reach, junction, reservoir, diversion, source, and sink) are connected in a dendritic network to simulate runoff processes. Computation proceeds from upstream elements to downstream elements.
2) Options to simulate infiltration losses for event-based modeling include initial constant, SCS curve number, gridded SCS curve number, exponential, and Green-Ampt methods. For continuous simulations, the one-layer deficit constant method can be used for simple cases, or the five-layer soil moisture accounting method can be used for complex infiltration and evapotranspiration environments. Gridded methods are available for both the deficit constant and soil moisture accounting methods.
3) Several methods are included for transforming excess precipitation into surface runoff. Unit hydrograph methods include the Clark, Snyder, SCS, user-specified, and the modified Clark method (for use with gridded meteorological data). Also, an implementation of the kinematic wave method with multiple planes and channels is included.

4) Baseflow methods include recession with an exponentially decreasing low from either a single or multiple sequential events, the constant monthly method, and the linear reservoir method.
5) Hydrologic routing methods, used to simulate flow in open channels, include the lag method, the traditional Muskingum method, and the modified Puls method. Channels with trapezoidal, rectangular, triangular, or circular cross sections can be modeled with the kinematic wave or Muskingum-Cunge methods. Channels with overbank areas can be modeled with the Muskingum-Cunge method and an eight-point cross section.
6) An extension, HEC-GeoHMS, interfaces with GIS systems.

Often, HMS and RAS (River Analysis System) are operated in a loosely coupled fashion, with HMS simulating the upland rainfall/runoff processes and RAS routing the flood wave downstream. RAS water surface elevations are then superimposed on the topography to estimate the lateral extent of the floodplain.

One of the biggest advantages of HMS is its immense popularity, which means that consultants and scientists are familiar with the software. It is less complex than the gold standard described above, thus it is more accessible to users with a B.S. degree. Moreover, professional organizations, such as the American Society for Civil Engineering, offer short courses on the use of the software. Its popularity also means that there is a plethora of applications published, covering a wide-variety of spatial and temporal scales, where it has shown considerable accuracy. Another advantage of the software is that it is in the public domain, so it is free via the web, along with an extensive set of documentation and example problems. However, as with Vflo, the source code is not available.

The primary disadvantage of HMS is that it is more empirical than the gold standard, thus a large amount of data is necessary for calibration and validation. Furthermore, empirical models are prone to errors when extrapolated to events outside of the range for which they are calibrated (e.g., events with very long return periods). However, it is precisely such events that must be simulated for long-range aggregate flood hazard risk analysis and planning. Finally, empirical models are also more prone to errors when examining interior flood levels that are not used as calibration points.

Similar to HMS, RAS is publically-available, is widely used, is well-documented, and is accepted in practice as the standard used to create FEMA’s FIRMs. HEC-RAS uses energy-based methods for steady-state routing in channel networks, it can accommodate irregular cross-sectional geometry, and it uses conservation of mass and momentum equations for unsteady simulations. Like HMS, RAS also has an extension that interfaces with GIS.

The silver and bronze standards differ in their use of the HMS/RAS modeling system. The silver standard would use the modeling system in a forecast mode where an impending event (real or fictitious) drives the model system to produce output that simulates the dynamic response of the watershed. Land-use changes could be imposed to generate various aggregate flood hazard risk scenarios. The output would be coupled to the aggregate flood hazard risk reduction framework through an inundation interface (see Figure 1). Data needed for this includes watershed topology, channel network, unit hydrographs for each hydrologic unit (which may be derived from watershed characteristics, such as land use/land cover, using synthetic formulas), and soil information.

The bronze standard also relies on the use of the HEC software. However, it does not perform prognostic modeling, which would preclude a full analysis of land use changes. Rather, it relies on static DFIRMs that estimate the extent of the floodplain for events with different recurrence intervals on a static domain. The digital maps can be fed to the common interface illustrated in Figure 1.

Research Issues

For the intended application, we believe the models described above are sophisticated enough to embed in the proposed aggregate flood hazard risk reduction framework across gold, silver, and bronze-level communities with very little modification. The research challenge will be to couple the models in an interactive IT framework, so that users can easily look at permutations and have the cyber system compute the change in aggregate flood hazard risk. For such a framework to be feasible, a common data format would need to be established. If one or more models require data to be formatted to reflect specific requests, then inter-model “filters” would have to be written that translate data from one format to another.

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Land Use Models

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Overview

A variety of land use models have been used to project future land use patterns across multiple scenarios. Scenario-based planning can be used to support transportation planning initiatives, natural resource use, water allocation, the protection of ecosystem services, economic development, and more recently, climate change adaptation. In this working paper, we explore how land use models can be used to help measure aggregate flood hazard risk.

All land use models project future land use patterns based on the suitability of a particular land segment and their interaction with land conversion processes. For instance, a desertification model assesses the change of fertile land to infertile land through natural and human induced processes, whereas an urbanization model assesses the conversion of non-urban land into urban land or the redevelopment of urban land into different types of uses and intensities. While no model can fully capture the range of processes that are at play, models should be selected based on their applicability to particular research questions and goals.

A Potential Use Case

Consider a watershed that consists of multiple jurisdictions. Imagine three cities of varying sizes and fiscal capacities, a mass transit district whose spatial extent overlaps two of the city boundaries and extends beyond them. A sanitary district provides sewer service to parts of these two cities who are upstream and another district that serves the other city. One of the upstream cities contains ecologically sensitive lands that are at risk of urban conversion. Imagine a single county that has jurisdiction over the unincorporated land in the watershed and controls development regulations. The state department of natural resources (DNR) has jurisdiction over a park and other state lands and the state department of agriculture (DOA) administers a farmland preservation program. In addition, a national environmental group is in the process of purchasing easements that protect environmentally sensitive lands. A large public university plans to build a large satellite campus that includes a research park.

The task is to figure out the effects of various combinations of actions, plans, and programs in the watershed. Does building the research park affect the attractiveness of the region that, in turn, spurs growth? Or would the venture fail to take off and produce a localized effect? Given the uncertainty about future population projections, how do local governments plan their transportation and other infrastructure investments? What are the feedback effects of these investments on the location, type, and density of future urban growth? Does DNR's acquisition program and the sanitary district's infrastructure investments change the aggregate flood hazard risk in the watershed? How do the mass transit district's future investment plans along with the comprehensive development plans of the various cities affect the total risk borne by different groups in the watershed? How does decreased state government fiscal capacity to fund new acquisitions or administer the farmland preservation program affect aggregate flood hazard risk? What is the effect of a population displacement in the downstream city, because of an extreme weather event that triggers the acquisition of flood-prone housing? Inevitably these questions are linked to the distribution of risk as well. For instance, lax development regulation in upstream communities affect the risk of downstream communities and these effects may be differentially distributed based on race and class.

Each of these questions require capturing the processes of urbanization; factors that affect change; the interactions of these factors; and the impacts of different regulations, investments, and strategies. Once these models are developed, ceterius paribus simulations are not useful, because more often than not, the effects of these actions are superadditive or subadditive. Therefore the models need to capture different impacts of actions, regulations, and feedback effects and project land use change into the future. In order to accomplish this aim, it is necessary to obtain consistent data across the watershed and to apply a uniform set of processes that affect urbanization patterns. In other words, ceteris paribus, the effect of building a new train station in a city should have the same effect as building it in a different city. Furthermore, in order to capture dynamic change in risk, natural process models should be coupled with urbanization models as the perceptions of risk affect the rates and locations of urbanization.

In addition to the conceptual and technical challenges associated with the model building process, there is a significant institutional challenge as to who would `own' and maintain these models. For instance, in the use case, ownership might reside with one of the three cities, a research team at a university, or a metropolitan planning organization. If so, this would imply that there are multiple models in place. Thus how can outputs be translated between models and be consistent with the aggregate flood hazard risk reduction framework? Ultimately, these inter-organizational management challenges may drive the success of the process more than the technical aspects of the models.

Types of Land Use Models

Modeling urban change has fascinated researchers since Britton Harris pioneered the use of computers in urban planning environments. Land use models can be classified by the type of decision maker and the decision making process. For some models (e.g., Cellular Automata models such as SLEUTH and LEAM), the geographical segment drives the decision making process while in other models (e.g., microsimulation and agent based models such MEPLAN and UrbanSim) the decision maker is an individual, household, or an organization. The type of decision in the former case is whether to convert or not, and if so, into what type of land use. The type of decision in the latter case is primarily about where to locate and relocate. The decision process in the former case is based on local neighborhood change and suitability. The latter case is based on some type of utility optimization and alternative evaluation process. There are also other kinds of models such as reduced form models, which take a more macroview by allocating population and employment to zones and then calculating land use indicators based on these allocations (e.g., DRAM/EMPAL). Like Cellular Automata models, rule based models such as WhatIf? and Community Viz use geographic entities (e.g., parcels) and allocate growth based on a suitability score that is derived from parcel characteristics that possess geographic and non-geographic relationships.

These models are used to project future land use patterns based upon exogenous inputs which are comprised of population and demographic structures or specific actions such as moratoria on development in certain zones or prioritizing development in other zones. Because the mechanisms that are used to project development and redevelopment are different in different models, care should be taken to choose the appropriate model for the scenarios in question (Table 1).

Table 1. Sensitivity of Different Land Use Models to Different Processes and Actions

Process/Action	DRAM/EMPAL	MEPLAN	LEAM	SLEUTH	UrbanSim	Whatif? /Community Viz
Property Taxes	No	Yes	No	No	Yes	Yes
Subsidies (Business Redevelopment Zones)	No	Yes	Exogenous	No	Yes	Yes
Development Charges	Exogenous	Yes	Exogenous	No	Yes	Yes
Public Housing	No	Yes	No	No	Yes	No
Utilities (excluding Transportation)	Exogenous	Yes	Yes	No	Yes	Yes
Seeds for development	No	Yes	Yes	Yes	Yes	No
Zoning	Exogenous	Yes	No	No	Yes	Yes
Building and Neighborhood issues	No	No	No	No	Yes	No
Urban decline	No	No	No	No	No	No
Non development zones (Buyouts etc.)	No	Yes	Yes	Yes	Yes	Yes

Choice of the Land Use Model for Aggregate Flood Hazard Risk Assessment Framework

Aggregate flood hazard risk measurement is dependent on the limits of the community (e.g., the domain of aggregation) and how risk is measured (e.g., how to aggregate). Thus the model choice is dependent on the links between other models, the attractiveness of the model to practitioners, data requirements, and the ability of the model to convey the results. These issues may be more important than the 'reliability' and 'parameterisation' of the model because the primary purpose of the model is to project future scenarios that are different from the trends identified in the past. Rule based models such as What IF? and Community Viz are suitable for these purposes.

The rule-based model produces a suitability score that is dynamically computed based on parcel characteristics (e.g., area, soil type, existing use, etc.) and a set of geographic relationships (e.g., proximity to school, water, transportation networks; allowable development zones; etc.). While these characteristics and underlying geographical relationships are relatively stable, the user has an ability to weight each of these factors so that suitability can be dynamically updated.

Relevance to Project / Research Question. The relevance of land use models depends on desired outcomes. For instance, the user may want to allocate future population projections (2050 households) contingent on some potential set of actions (e.g., no build zones, new schools, modified transporation network). Or is it desired to assess what happens to current populations in the event of a flood? It is much easier to do the former. The latter is more difficult because the user needs to think carefully about the relocation decisions of the household and other actors in the watershed.

Strengths/Weaknesses of Model. The strength of the model is that it is easy to use and outputs are easy for people to understand. The weakness of the model is that behavior is not included in land use models (e.g., we don't know why the decisions about suitability are made the way they are made). Nor are there prices or alternative assessments available.

Accuracy. This is not a major concern. If we are trying to produce scenarios, because we can't rely on past behavior, we need to make assumptions anyway. The chief concern here is whether planners and decision makers will accept the logic of the model rather than whether the model predicts the outcome accurately in a hypothetical case.

Technical Sophistication/Training Needed to Conduct Analysis. Planners need to have access to high quality spatial data and should be willing to invest the time required to learn the software. It should be easy for the end user to manipulate models based on the presence of slider bars that allow for the incorporation of varied assumptions over time.

Appropriateness of Model. The appropriateness of a chosen model depends on the scenarios that are run and the degree to which other hydrologic, economic, and losses avoided models can be coupled and how the aggregate flood hazard risk is calculated.

Geographic Scale. The proposed land use models are appropriate for small to medium sized communities. Watershed level analysis requires moving beyond tax parcel level geography. The loss of spatial resolution may not be problematic if we can assume homogeneity of uses within a single parcel. This may be problematic for other models (e.g., hydrological model may require a single impervious surface measure for each parcel).

Acceptance by research community. Acceptance remains low, although researchers increasingly see land use models as a participatory engagement tool rather than a predictive one.

Acceptance by Practitioners/Local Officials. Land use models are becoming increasingly popular and are being used by Metropolitan Planning Organizations as well as other planning agencies.

Coupling with other Models. Community Viz has been linked to HAZUS-MH and is beginning to be used in the update of state and local hazard mitigation plans. The coupling of land use models with hydrologic, hydraulic, and economic models merits additional research and application in practice.

Data Requirements across Community Types. Communities have access to different types of geographic information, including different resolutions and differing levels of accuracy. While the modeling software is relatively easy to acquire, building reliable models that are consistent with the models that other agencies and organizations use in the watershed is difficult to achieve in practice and would require significant coordination.

Furthermore, the scenarios each organization employs as a part of their planning effort to direct their infrastructure investment and regulatory strategies differs from others in the watershed due to factors such as differing planning horizons and varied data inputs. It is, therefore, difficult to coordinate these scenarios without a formalized planning process and an organization that is responsible for managing this multi-stakeholder, multi-jurisdictional effort.

Ability to Import Data into Model. Geographic and associated data is relatively easy to import. The main challenge is to link the hydrological model input and output with the land use model.

Next Steps

Perhaps the most significant challenge in the development of an aggregate flood hazard risk assessment framework is to define the scope of the aggregate risk assessment tool and how it would be used, for what purposes, and by whom. Without clear answers to these questions, it is very difficult to identify which of the land use models are useful. As statistician George Box once said, “All models are wrong, but some are useful.”

Appendix B: Data Requirements Across Community Types

Integrated Hazard Risk Management Tool developed by NC Division of Emergency Management

Bronze Data	Represents the typical hazard and vulnerable system data available for the majority of the nation Building data- point identifying structure or parcel boundary Finished floor elevations from best available topographic data, such as five-foot contours
Silver Data	Building data- building footprint Finished floor elevations based on LiDAR bare earth returns adjacent/surrounding the building footprint Reasonable assumption for the type of foundation
Gold Data	Building data- did not discuss Finished Floor elevations refined based on available elevation certificates, building permits, field measured information Foundation type from local tax assessor records

Source: http://www.ncfloodmaps.com/pubdocs/nc_3ms_business_plan.pdf

The GTM-NCFMP will design and build analytical/communication application(s) that will demonstrate an approach for enhanced and integrated natural hazard identification, risk assessment, and communication strategies that support mitigation planning. The application(s) will be capable of:

- Identifying and displaying likelihood of natural hazards of a given magnitude and extent from a parcel up to a statewide perspective;
- Identifying and displaying vulnerable systems statewide (including critical infrastructure/key resources, the built environment by leveraging building footprints for structures greater than or equal to 1,000 square feet, population, etc.) that have a probability of being impacted by these natural hazards;
- Calculating estimated annual losses at a parcel and up to a statewide level;
- Effectively communicating the probability of damage from each hazard, estimated losses, and appropriate mitigation actions;
- Determining cost beneficial mitigation actions;
- Calculating and communicating estimated losses avoided at a parcel and up to a statewide level from mitigation actions;
- Prioritizing mitigation actions;
- Performing all the previous items using different tiers of data (such as typical data available nationally or the best available data set that will be developed for the four pilot counties);
- Preparing a local hazard mitigation plan template;
- Utilizing more detailed and/or current data provided by the user; and
- Transferring/exporting data and/or results to and from HAZUS-MH.

Community Viz

Type of Assessment	**Data Needed**
Build Out Wizard^	Land-use Polygons Density rules for each land use Constraints (steep slopes, wetlands, habitat, etc.) Existing building points or footprints Minimum Separation distances Roads 3-D models of buildings Mixed use building mix ratios Efficiency Factors Development Growth Rate
Hazus Risk Assessment^^	A Scenario 360 Analysis must be opened No Data Layers are required for the HAZUS Risk Assessment Data is pulled from HAZUS analysis into a Scenario 360 Analysis, copies the HAZUS data and generates Scenario 360 components

^The Build-Out Wizard performs all the work necessary for a build-out analysis, the most common basic type of growth projection.
The wizard supports numeric, spatial and 3-D visual build-out analysis.

^^Hazus is a tool from the US. Federal Emergency Management Agency (FEMA) that models the effects of natural hazards including earthquakes, floods, and wind.
They work with Hazus-MH 2.0 and 2.1 (which are made for ArcGIS 10), and they assume you as a user already have Hazus on your computer and know something about it.
The Hazus Risk Assessment Wizard and Exporter are two sister decision tools that connect Hazus outputs to CommunityViz and vice versa.

Losses Avoided

	Data Category	**Info Required for LAS**
Phase 1		
Initial Project Selection	Basic Data	Area of Interest (single community, watershed, region, etc.), Hazard Type, Project Type Project Cost Study Baseline
	Building Data	First Floor Elevations (FEMA elevation certificates) Building Location data (tax parcel data, GIS, aerial photos) Building Type, Building Construction Type (wood frame, manufactured), Number of Stories, Square Footage, Foundation Type, Basement Info, Garage Info (field visit, census housing survey data, existing photos etc.)
	Topographic Data	Topographic Data (LiDar, USGS DEM, contour data)
Phase 2		
Storm Event Analysis	Storm Event Data	High Water Marks or Aerial Photographs, or Stream Gage Discharge or Stage Data or Precipitation Gage Data
Hydrologic Analysis (reqd. only if Precipitation Gages are used)	Hydrologic Model	Existing Hydrologic Model, or New Hydrologic Model Including- watershed delineation, land use, soil type, ground cover info
Hydraulic Analysis	Hydraulic Model	Existing Hydraulic Model, New Hydraulic Model- includes cross section elevation data, roughness coefficients, boundary conditions, Inflow from Storm Event Analysis,
	Normal Depth Calculations (used only if no hydraulic model exists and new model is unavailable)	Peak Event flow rate, Channel Cross Section Geometry, Channel Slope, Roughness Coefficients
Flood Inundation Analysis		Water Surface Elevations
Flood Boundary Analysis		Water Surface Elevations and Flood Extents
Phase 3		
Loss Estimation Analysis	Physical Damages	Buildings Replacement Value, Building Contents Value, Road and Bridge Damages, Utilities Damages, Landscaping Damages, Vehicles and Equipment Damages
	Loss of Function	Displacement Expenses, Loss of Rental Income, Loss of Business Income, Lost Wages, Disruption Time for Residents, Loss of Public Service, Economic Impact of Utility Loss, Economic Impact of Road/Bridge Closure
	Non-Traditional Benefits	Shelter and Subsistence, Debris Removal, Emergency Response Services, Emergency Medical Services

Losses Avoided quantify losses avoided for completed mitigation projects using actual post-construction events.
Source: Loss Avoidance Study: Riverine Flood Methodology Report 2009

Vflo Model

Data Required
Topographic data DEM (LiDAR, photogrammetry, land survey)
Soil type and depth
Land use/land cover including impervious area
Channel geometry
Hydraulic channel characteristics
Rain gauge data

Physics based, distributed hydrologic model tightly integrated with GIS
PBD hydrologic models use conservation equations to route runoff through a network of channel and overland flow elements.
The model then uses rain gauge data to determine the extent to the flooding

HAZUS-MH

Level 1 *	DEM (digital elevation model) imported into the flood model- topographic data DEM combined with stream discharge data to determine flood surface elevation "Inventory data" (population, buildings, infrastructure, agricultural resources, within flood boundary included in Flood Model Uses national data on general building stock to estimate direct physical damage to buildings and contents Direct economic losses, Indirect economic losses and exposure of essential facilities and people are calculated Appropriate Depth Damage Curves are applied to determine levels of damage Resulting damage and loss estimates apply to all building occupancy classifications and general building types Economic losses are estimated based on physical damage to buildings, debris generated is computed as well as shelter requirements for displaced people
Level 2**	Flood surface data- Coastal Base Flood Elevations (BFE's), Digitized stream Cross Sections or Digitized BFE's from FIRM Digitized floodplain boundaries- DFIRM, Q3 data, or any other floodplain map in polygon form Ground Elevation Data- built from contours, Triangulated Irregular Network (TIN) or other
Direct Damage Module Inputs	Building Occupancy Type and first floor elevation data Depth of Flooding (FIT model) or level 1 analysis or area weighted throughout the census block where the building is located
Depth Damage Functions	Federal Insurance Administration's (FIA) "credibility weighted" depth-damage curves and curves for various districts of USACE for estimating damage to general building stock Essential facilities- default depth damage curve, editable by user. Lifeline systems- separate set of damage functions

The HAZUS Flood Model is an integrated system for identifying and quantifying flood risks and is intended to support communities in making informed decisions regarding land use and other issues in flood prone areas.
*Level 1 requires minimal user interface and data, while Level 2 requires user-supplied local data for performing more detailed analyses, with the assistance of the Flood Information Tool FIT .
** For Level 2 analyses, the Flood Information Tool "FIT" tool is used to preprocess site-specific flood hazard data and facilitate its import into the Flood Model for further analysis of damage and loss.
**In Level 2, more detailed site-specific data can be employed to replace the default national datasets for buildings and other parts of the inventory. Development and importation of site-specific data are facilitated by use of the Building Inventory Tool "BIT" and InCAST tools http://www.fema.gov-/hazus/hz_meth.shtm .
** The FIT tool has been designed to operate as an extension within ArcGIS and allows users to create depth grids for various return periods and other parameters.
**output results from FIT are integrated into HAZUS Flood Model

Source: HAZUS-MH Flood Loss Estimation Methodology. I: Overview and Flood Hazard Characterization

Appendix C: Meeting Agendas

1. Meetings

Preliminary Brainstorming Meeting (October 2012; in-person and call-in)

- Define/clarify project scope and approach; identify necessary and available data, analytical techniques, and studies; seek feedback from small sub-group of experts

Meeting 1: Project Kickoff Meeting (December2012)

- Discuss project purpose and end-users
- Identify existing studies that may support the project
- Identify roles (working group leads) and make work assignments
- Schedule follow up conference call with PI's to clarify assignments, answer questions, etc.
- Begin development of conceptual framework used to inform the scoping document
- Revisit project deadlines and Meeting #2 agenda

Meeting 2: Working Group Meeting (January 2013; workshop at CHC-timed to coincide with CHC Annual Meeting)

- Refine draft scoping document based on review comments
- Identify additional issues / questions
- Identify relevant data needed to develop aggregate flood hazard loss estimations (tied to varied community capabilities and access to data)
- Refine framework used to inform the scoping document
- Aassign working papers

Meeting 3 Conference Call***: Draft Scoping Document Feedback (April 2013; in-person and call-in)***

- Solicit feedback from researchers.
- Note suggested improvements and incorporate into final document

Conference Call: Final Scoping Document Feedback (June 2013; in-person and call-in)

Project Timeline

Preliminary Brainstorming Meeting (October 2102; In-person and call-in)

Meeting 1: Project Kickoff Meeting (December 2012; in-person and call-in-project PI's and advisors)

Meeting 2: Working Group Meeting (January 2013; workshop at CHC-timed to coincide with CHC Annual Meeting)

Meeting 3: Draft Scoping Feedback (April 2013; in-person and call-in)

Scoping Document Completed (December 2013)