Developing Open-source Catastrophe Risk Models

A white paper based on discussions held at the workshop "Open-source catastrophe risk modeling: how can we do it better?"

Richard J. Murnane
Risk Prediction Initiative
Bermuda Biological Station for Research

Ferry Reach
St. George's GEO1
BERMUDA

PO Box 405
11312 Rokeby Ave
Garrett Park, MD 20896

Executive Summary

Earthquakes, floods, and hurricanes are a part of our natural environment, but they also cause thousands of deaths and billions of dollars in losses every year. Planners, emergency managers, (re)insurers, and others interested in planning for and responding to natural disasters use catastrophe risk models to minimize losses of life and property. This white paper provides an overview of a nascent effort to develop open-source catastrophe risk models and is based on discussions from a workshop "Open-source catastrophe risk modeling: how can we do it better?" held in March 2005 at the Hewlett Packard campus in Cupertino, California.

A catastrophe risk model (or cat model) has three main components. The first simulates the relevant features of a hazard, the second simulates how structures respond to a hazard, and the third estimates the number of deaths and injuries, the cost of repair or replacement of a structure, and a number of other factors depending on a model. A number of companies develop proprietary risk models for licensing or in-house use. In addition, the Federal Emergency Management Agency has developed HAZUS-MH for modeling hurricane, earthquake, and flood hazard in the United States for use principally by emergency management support personnel.

For a number of reasons the source code (the computer program that people can read) for catastrophe risk models is rarely made available. Companies that develop risk models for in-house use or for licensing protect their intellectual property for competitive reasons. Government agencies attempt to maintain the standards and quality of the models they release by protecting source code from unauthorized and undesirable changes. However, the cost and time of producing models and their proven value in supporting disaster planning and business decisions underscores the need to have available source code from existing models to develop new models (for example, the State of Florida's hurricane wind loss projection model). The need for catastrophe risk models can be efficiently fulfilled with freely available source code.

An effort to develop open-source catastrophe risk models provides many other benefits. Consider just four examples. First, an open-source effort would speed model advances by permitting input from anyone throughout the world active in catastrophe risk modeling. Second, an open-source effort would minimize duplication of effort by allowing the use of the same or similar source code and data in more than one model and lower the startup effort for those interested in developing new modeling techniques. Third, the effort would involve educating students and help expand the emerging field of risk modeling. Fourth, existing risk models could incorporate the most recent and relevant scientific and engineering advances into their own risk models.

A number of initial steps have been made towards the development of open-source catastrophe risk models. The March workshop brought together scientists, engineers, regulators, insurers, modelers, and others interested in catastrophe risk modeling. Workshop participants decided to pursue a coordinated effort to develop open-source catastrophe risk models and identified a number of individuals to lead the effort. In response to workshop discussions a wiki (an open web site at open-risk.org) that will act as a virtual "home" for this effort has been created. In addition, an upcoming workshop will bring more people into the open-source effort and start the process of defining the goals and standards for the models.

Reducing death, destruction, and loss through open-source catastrophe risk models

Floods, earthquakes, and hurricanes[1] are an intrinsic feature of our natural environment. Ecosystems have evolved to withstand, and in some cases require, extreme events. The resilience and balance between extreme events and nature provide a stark contrast to the relationship between extreme events and society. A flood, earthquake, or hurricane becomes a disaster when it strikes a populated area and can cause massive losses of life and huge economic and insured losses.

Fortunately these losses are not inevitable. People can learn and adapt from experience. Some can move to less hazardous locations. Others can build structures that can withstand the forces inflicted by the hazard. For example, properly engineered dams and levees can reduce the risk of floods and buildings can be designed and built to withstand earthquakes and hurricanes.

Unfortunately, and for a large number of reasons, large losses of life and property continue to occur. At times the reasons are obvious. Some have no option but to live with inadequate shelter near rivers that flood, along faults subject to strong earthquakes, or on barrier islands that experience intense winds and storm surge from hurricanes. At other times the reasons can be more subtle. Structures designed to withstand the hazards in these locations may fail during an event because of flaws in design or construction. In many cases people choose to ignore a potential hazard and steps that can mitigate their risk until an event occurs. Whatever the reason, better tools to plan for and respond to extreme events could help minimize the loss of life and property.

Catastrophe risk models are some of the most useful tools for planning and responding to natural disasters. The public sector successfully uses catastrophe risk models to plan for and manage emergency responses to natural disasters. The private sector uses catastrophe risk models for financial decisions involving billions of dollars. In almost all cases the computer source code for the models is not publicly available. This is not necessarily an optimal situation for society and it can be changed through the development of open-source catastrophe risk models. This paper provides an overview of current efforts related to open-source catastrophe risk modeling, summarizes the benefits that would accrue from an open-source effort, and presents the rationale for supporting a community effort to develop open-source software versions of catastrophe risk models.

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[1] Hurricane is the term used to describe a tropical cyclone in the Atlantic or eastern and central North Pacific Oceans when 1-minute sustained winds at 10 m elevation over open water are greater than or equal to 33 m s^{-1}. Other regions of the world use different names and criteria to classify tropical cyclones. For more information see Neumann Neumann, C. J. (1993), Global Overview, in *Global Guide to Tropical Cyclone Forecasting*, edited by G. Holland, World Meteor. Org. Tech. Doc. WMO/TD-No. 560, Report No. TCP-31, Geneva.. Here I use hurricane in a generic sense to describe a tropical cyclone in any ocean basin with hurricane force winds.

Catastrophe risk models

A catastrophe risk model (or cat model) can be divided into three main components (Figure 1). The first is a hazard component that simulates the relevant features of a hazard. For probabilistic calculations this component would include an event library, or a mechanism for generating a series of events, with realistic characteristics and frequencies. An event library would typically contain thousands of different events. Statistics describing the frequency, size, location, and other characteristics of hazard events generated by the hazard component should agree with an analysis of events taken from the historical record. The second is a vulnerability component that simulates how structures respond to a hazard. This component requires detailed information on the number, type, and distribution of structures that experience a hazard. In addition, this module often considers "follow-on" damage from phenomena such as fires after earthquakes and interior water damage after winds break windows. The third is a loss component that estimates the cost of repair or replacement of a structure and a number of other factors depending on a model. For insurance purposes the loss component can calculate coverage features such as business interruption losses, deductibles, etc. For emergency management purposes this component can estimate direct and indirect losses as well and the amount of emergency supplies, such as shelter and food, that would be needed for emergency management purposes.

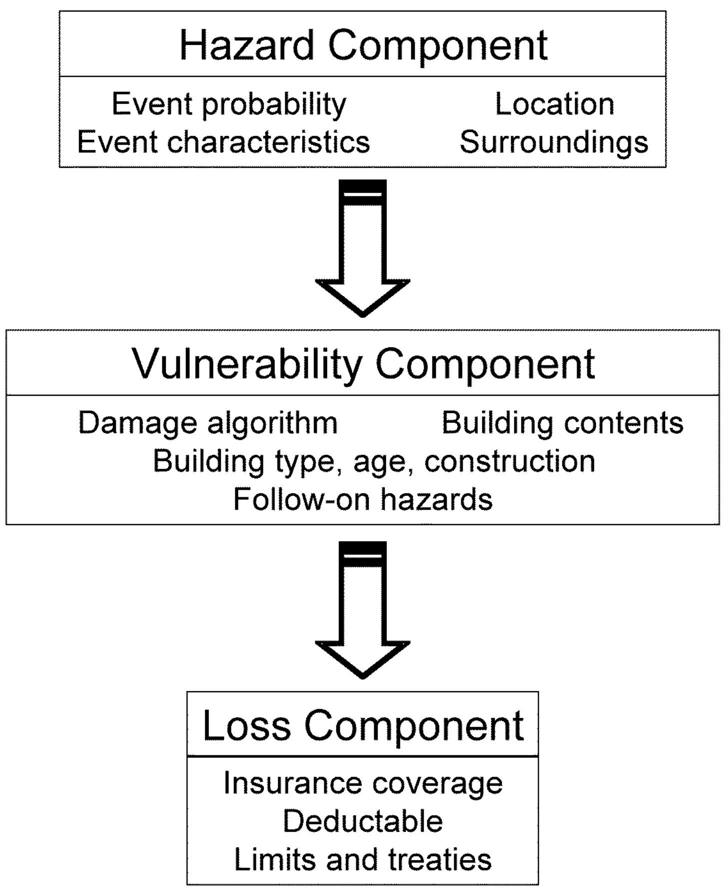

Figure 1. Schematic diagram of a typical risk model used by the insurance industry. The diagram highlights the three major components (hazard, damage, and loss) of a risk model.

A number of firms in the private sector have developed proprietary cat models. Insurance and reinsurance companies are the main users of the proprietary models and therefore the catastrophe risk models are focused on hazards and regions with significant insurance business. The major insurance markets are North America (mainly the U.S.), Japan, and Europe (Figure 2 of Insurance world?). Catastrophe (or cat) risk models for these areas focus on the hazards that cause the largest insured losses: earthquakes and hurricanes in the U.S. and Japan, wind storms and floods in Europe. The commercial modeling companies continue to develop models for other areas and hazards that are of interest to (re)insurers. In addition, some (re)insurance companies develop in-house cat models for business purposes.

Many federal, state, and local agencies in the U.S. involved in disaster management use the Federal Emergency Management Agency's (FEMA) catastrophe risk model, HAZUS-MH. This model can simulate flood, earthquake and hurricane events for the U.S. We are not aware of comparable models for other parts of the world.

Open-source software

Before defining open-source software it is worth describing how text that people can read is converted into something that a computer can use. The term software is used to describe the set of instructions, or program, that either allow a computer to function or comprise the applications that run on a computer. The term "system software" describes the programs that make a computer work, for example, the operating system, device drivers, etc. The term "application software" describes the programs used on a functioning computer, for example, a spreadsheet, word processor, etc. Software that people write is termed source or source code. A program in source code format needs to be converted to object code (zeros and ones, or binaries) that can be understood by a computer. A computer program called a compiler converts the source code to object code. Finally, another computer program called a linker takes one or more pieces of object code and combines them into a program that can be run, or executed, on a computer.

It can take a significant amount of time (and/or money) to develop complex software. Many private companies view software that they've produced as proprietary technology and distribute the object code to users under strict licensing conditions. Open-source software describes programs whose source code is freely distributed under license. The details of the license associated with an open-source program vary[2] and have implications for how a user may use the code.

Many well-known and widely used open-source software efforts involve system software. Examples include: the operating system GNU/Linux; the mail transfer program Sendmail; and the web server Apache. Efforts to develop open-source application software are generally less well known and often not as widely used. Examples include: the statistical computing and

[2] Differences in open-source software licenses arise, in part, from philosophical positions that can be crudely divided into two positions: person should either be free to create proprietary software or be free from the creation of proprietary software. The terminology can be clever (for example, copyleft as opposed to copyright) but also confusing. A starting point with links to a variety of licenses can be found at the free software foundation web site: http://www.fsf.org/licensing/licenses/license-list.html#NonFreeSoftwareLicense

graphics program R, the programming language Python, and the office suite software OpenOffice.org. While these examples are all considered open-source software, they are not necessarily distributed under the same license conditions.

Open-source catastrophe risk modeling

A number of related but separate events suggest that it is now time to initiate a coordinated effort to develop an open-source catastrophe risk modeling effort. First, several research efforts are developing different components of an open-source catastrophe risk model. For example, an open-source seismic hazard effort, OpenSHA, could form the basis of a hazard component of a cat model, and an open-source seismic engineering effort, OpenSEES, could be used to develop vulnerability curves for the damage component of a cat model. These efforts (described below) are growing within their own community, but their combined value would be enhanced through a coordinated effort that would enable the output of OpenSHA to be used as input to a model based on OpenSEES software.

Second, the State of Florida is developing a "Public Hurricane Loss Projection Model". It appears that, like HAZUS, this will be a public model and the source code will not be freely available. The Florida Department of Insurance's interest in developing its own risk model demonstrates that value of cat models for regulators. The development of an open-source hurricane cat model could be of value to other states subject to hurricane landfall and help reduce the duplication of effort. In addition, it seems likely that regulators in states with significant earthquake hazards, such as California, would be interested in analogous efforts to develop cat models for earthquakes.

Third, the National Institute of Building Sciences and the Mid-America Earthquake Center are working to develop new risk assessment models for a variety of hazards throughout the globe. The effort will use the Network for Earthquake Engineering Simulation (NEES) grid to share data, use advanced GIS capabilities, and create new tools.

Finally, the experience of the Risk Prediction Initiative (RPI) with making science useful for business shows that the most efficient way for hurricane and earthquake science to be used in business decisions is to have it incorporated into cat models. Most (re)insurance companies use cat models for their business decisions, many are interested in science and have their own technical staff, and some develop their own in-house cat models. Almost all of the companies use cat models developed by commercial risk model vendors. The insurers would be interested in additional information provided by an open-source modeling effort. This effort could also benefit commercial model vendors by providing them with additional scientific, engineering, and financial expertise.

It seems clear that an open-source cat modeling effort would enhance the value of ongoing open-source efforts and be of great interest to the public and private sectors. This concept was explored at the workshop "Open-source catastrophe risk modeling: how can we do it better?". The workshop was held March 15-16, 2005 at the Cupertino campus of Hewlett Packard. Workshop participants included scientists, engineers, (re)insurers, risk modelers, regulators and emergency managers interested in earthquakes, hurricanes, and floods. The workshop was jointly sponsored by the RPI, the Southern California Earthquake Center (SCEC), the National Oceanic and Atmospheric Administration (NOAA), and the Western Disaster Center.

Most of the workshop presentations[3] described ongoing efforts to develop different components of an open-source catastrophe risk model. Additional presentations examined the history of catastrophe risk modeling, private and public sector risk models, and an overview of open-source software. Workshop discussions focused on potential benefits and synergies of a more coordinated effort and an exploration of possible challenges. There was a strong consensus to move forward with a coordinated effort to develop open-source catastrophe risk models. This document summarizes many of the presentations and much of the discussion at the workshop and is the next step in an evolving community open-source effort. The following sections provide more detail on the benefits and potential challenges of a coordinated effort to develop an open-source cat model, existing modeling efforts, and a discussion of future directions.

Summary of Benefits

The overarching interest for the development of catastrophe risk models is to minimize death, destruction and loss caused by natural hazards. While this is a commendable interest, it is important to explore the specific benefits associated with an open-source catastrophe risk models. The benefits were identified through breakout sessions at the workshop and can be divided into two main classes. The first class would benefit a wide range of users and at times developers. The second class would mainly benefit those actively developing cat models.

The first class of benefits could broadly be described as advancing the state of the art of catastrophe risk modeling. An open-source catastrophe risk modeling effort would allow the inclusion of relatively small players and encourage new entries into the field. The effort could be hosted at a website which would provide a description of the different models and distribute the various versions of source and object code.

The effort might also begin to enhance the community of people interested in educating students in an emerging field of risk modeling. Catastrophe risk modeling companies in most cases need to train people in the field of risk modeling. In addition, the modeling companies could benefit from freely available source code that incorporated the most recent and relevant scientific and engineering advances.

The second class of benefits could broadly be described as improved information sharing. An open-source effort would provide a source code warehouse for people working on different aspects of cat models and also provide a forum where people could agree on standards that would describe how different components of the model would exchange information. The source code warehouse would lower the barriers to entry for people interested in working on cat models. It is always easier to start a programming project by having examples of existing code. The standards would make it easier to integrate new functions into existing models and help to leverage existing model functions into other efforts.

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[3] Workshop presentations can be seen at:
http://www.bbsr.edu/rpi/public/meetings/2005/mar05.html

The open-source effort could also provide opportunities for unanticipated synergies. For example, data bases or source code could be used by more than one type of hazard or modeling group.

Publicly available data bases are another important component of improved information sharing. These data bases would not only benefit model developers but also be of potential interest to the public, regulatory agencies, and (re)insurers. The open-source effort could contribute to efforts that attempt to create standards for data bases that can be used for cat modeling. Examples of information that is crucial for realistic cat modeling are location dependent data on a structure (e.g., construction, height and age of building, occupancy) and its environment (e.g., soil and bedrock characteristics, elevation, surrounding topography). An open-source cat modeling effort would also need improved availability of data on losses from natural hazards. This information would be of value for other interests [*Changnon*, 2003] as well as existing modeling efforts.

Existing model efforts

Attempts at modeling the benefits and costs of natural hazards can arguably be traced to 1932 and the publication of Freeman's book "Earthquake Damage and Earthquake Insurance" [*Freeman*, 1932]. There were also flood mitigation efforts at that time but no attempts at assessing the costs and benefits. Perhaps the next important publication was Cornell's 1968 paper on Engineering Seismic Risk Analysis [*Cornell*, 1968]. Since then, risk assessment has grown through efforts in the fields of flood control [*Hydrology Committee*, 1976], nuclear reactor safety [*Rasmussen and al.*, 1975], and seismic design [*McGuire*, 1978]. The major commercial risk modeling firms (AIR, EQECAT, and RMS) emerged in the 1980's and became increasingly important as a series of large losses, culminating in Hurricane Andrew (1992), forced the (re)insurance industry to adopt a much more quantitative approach to risk analysis. The 1989 National Academy of Sciences report, "Estimating Losses from Future Earthquakes", [1989] was commissioned by FEMA and summarized the resources needed to estimate earthquake losses. State and federal governments started to develop user-friendly benefit-cost analysis tools after the 1994 Northridge earthquake. This started with California's support of Regional Assessment of Mitigation Priorities (RAMP) and moved onto FEMA's support of HAZUS for earthquake loss modeling methodology. In 2003 FEMA released an extended multi-hazard loss model, HAZUS-MH, that included loss modeling for floods and hurricanes.

Perhaps the most evolved open-source risk modeling effort is Open Seismic Hazard Analysis (OpenSHA), a joint venture between SCEC and the U.S. Geological Survey. The goal of OpenSHA is to develop a flexible framework that can easily be used with any arbitrarily complex earthquake rupture forecast, ground-motion, or engineering-response model. An example of a possible engineering response model is the Open System for Earthquake Engineering Simulation (OpenSees). OpenSees is hosted at the Pacific Earthquake Engineering Research Center and has the goal of developing a software framework for simulating the seismic response of structural and geotechnical systems.

I am not aware of similar open-source efforts in the hurricane or flood modeling community. However, the Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers has for years provided an extensive set of freely available software for flood frequency and loss estimation modeling. Source code for the HEC models is available on a case-by-case basis. This software is highly respected and used worldwide, but would not be considered open-source because of the restrictions on the source code. There are a number of reasons for the HEC source code restrictions (see below).

The State of Florida is developing a Hurricane Loss Projection Model for regulatory purposes. It seems likely that the source code for this model will not be freely available. The development of this model provides an example of the importance, and difficulty, of obtaining loss data for natural hazards.

There are a number of commercial risk modeling companies that develop and market proprietary catastrophe risk models. The companies work closely with the insurance industry in an effort to tailor their model to the market's needs and to develop new models. Some (re)insurers develop in-house catastrophe risk models for their business decisions. Finally, there are smaller modeling efforts that cater to other needs such as those associated with state insurance departments.

Challenges

Not surprisingly there are a number of challenges associated with efforts to develop open source catastrophe risk models. They can be broadly classified into three categories: legal, technical, and user/developer. None of the challenges are insurmountable, but it is worth summarizing some of the major ones for future reference.

The legal issues are common to essentially all open-source efforts and involve liability and licensing. Legal liability may seem to be a major worry given the large sums of money involved with catastrophes, however, all copies of the code will be issued with the proper disclaimers. And to date, no one has been sued over open-source liability issues.

Decisions regarding the form of open-source license will be more difficult. There are a variety of different open-source license formats. A good summary can be found on the Free Software Foundations web site (http://www.fsf.org/licensing/licenses/license-list.html). The most "militant" position on open-source software is taken by the Free Software Foundation which in general recommends the use of the GNU General Public License. This license includes a copyright statement with distribution terms that require that any redistribution of changed source code be subject to the same freedom for copying or distribution. They term the combination of copyright and the additional distribution term "copyleft". Other licensing options allow for linking the free software to proprietary libraries (for example, the GNU Lesser General Public License) or impose additional restrictions. The choice of licensing for the open-source risk models will likely determine whether commercial risk modeling companies or (re)insurers contribute software, and perhaps data, to the development effort.

Technical issues will most likely be similar to those experienced by other efforts to develop open-source software. These include decisions on how to handle multiple model versions in various stages of development, the possibility of a small development community, and concerns on how to devise quality control efforts. All of these challenges have been surmounted by other open-source efforts and the catastrophe modeling community need only pick and chose which approach would be best to adapt for this purpose.

The biggest user/developer issues will likely be identifying resources (money) for the open-source effort. Most of the contributed software will likely be written by people receiving support from their employer, especially if there is a decision to let the model evolve "naturally". However, financial support will probably be needed for some aspects of the effort. For example, support will be required for workshops at which scientists, engineers, and others interested in catastrophe risk modeling can meet to make the initial decisions needed to define the open-source modeling efforts such as how the interface between different model components will be defined.

Another possible issue concerns how to recognize the contributions made by different programmers involved in the development of the different open-source models. Many of the people that could potentially contribute to this project are academics that will be concerned with tenure and almost everyone is concerned with career advancement. Devising a method of acknowledging their software as a peer-reviewed "publication" could be of great value and an aid in attracting talent.

Consideration should also be given to a decision on how to handle the distinction between "official" versions of a risk model and an open-source version. Consider the flood models that are produced by the Hydraulic Engineering Center (HEC) of the U.S. Army Corps of Engineers (USACE). These models are highly regarded and used worldwide and the object code is freely available. Under certain conditions the HEC releases the source code for the models. If the source code for these programs, or for other similar efforts, is contributed to an open-source flood risk model, then how does the HEC limit its responsibility for subsequent changes to the code? Answering these types of questions will be critical for engaging a number of organizations, such as the HEC.

After an open-source risk model is developed, most users will still likely require the assistance of experts. There will likely be technical issues regarding the correct combination of model components, how to interpret the output of the model simulations, and what data will be needed to initialize and use a model. These needs could provide new business opportunities that are analogous to others open-source business ventures. Perhaps the best known example would be Red Hat, a company that provides training, consulting, and services to companies that use the open-source operating system Red Hat Linux.

Incentives

The rate at which open-source catastrophe models develop will be closely tied to the availability of funds. The current open-source efforts related to hurricane, earthquake and flood modeling are essentially a result of uncoordinated research with no overall goal of developing a useable catastrophe risk model. Contributors to other open-source efforts are motivated by a variety of factors including peer-recognition and the desire to improve the software that they use. It seems likely that the same people working on the components of catastrophe risk models are interested in coordinating their efforts to produce a tool that could be used to reduce the number of deaths and amount of destruction caused by natural disasters. However, it seems unlikely that altruism and personal glory provide sufficient incentives for speeding the development of open-source catastrophe risk models.

Money is a proven incentive for many research and development projects and could certainly be used to accelerate model development. If a source of support for specific components of a catastrophe risk model were provided then there would be a ready supply of scientists, engineers, and others interested in working to contribute source code to open-source catastrophe risk models. It seem logical that federal and state agencies, reinsurers, and foundations interested in minimizing the impacts of natural disasters would be interested providing support for an open-source development effort. An interested community developing open-source catastrophe risk models would provide supporting agencies and others a continual source of improved resources for all catastrophe risk modelers, an new source for risk estimates that complements proprietary and public models, and, if climate change scenarios could be used to develop hazard libraries, perhaps a new method of providing benefit-cost estimates for climate change scenarios.

Next steps

The workshop in March 2005 was an important step in the effort to organize a community working toward the development of an open-source catastrophe model. Workshop participants identified a group of individuals that would lead efforts on various topics (Table 1). The affiliations listed in Table 1 make it evident that there is a wide range of institutions already interested in this effort, but it is somewhat U.S.-centric. It would be beneficial to broaden participation on an international scale. As a first step in making this possible we have purchased a web site domain name, open-risk.org, and have set up a wiki[4], http://www.open-risk.org, that will be used as a center for the modeling effort and to coordinate meetings, discussion, and development efforts. The wiki now has links to the presentations given at the March workshop.

Table 1. Leaders and topics for open-source catastrophe risk models.

	Leader	Affiliation
Earthquake Hazard	Edward Field	USGS
Earthquake Engineering	Greg Deierlien	Stanford University
Earthquake Modeling	Charles Scawthorn	Kyoto University
Tropical Cyclone Hazard	Mark Powell	NOAA
Tropical Cyclone Wind Engineering	Kurt Gurley	University of Florida
Tsunami and Surge Modeling	Bruce Harper	SEA
Flood	Darryl Davis	USACE
Loss modeling	Keith Porter	Cal Tech
HAZUS	Philip Schneider	NIBS
Project Leader	Richard Murnane	BBSR

Participants in the March workshop also agreed that a follow-up workshop is needed to bring in more interested parties and to start the process of defining standards for the open-source catastrophe risk model. We are currently working on finalizing plans for a workshop at

[4] A wiki is a server program that allows anyone to use their web browser to edit a remote web site. This enables project members to collaborate efficiently and quickly. Wiki is from the Hawaiian word "wikiwiki" meaning "fast".

Princeton University in Princeton, NJ. A possible path forward is to select a few small projects for development and then let the program develop as the community grows.

There will be many challenges involved with the development of an open-source risk model, but none of the challenges are insurmountable. More importantly, however, open-source catastrophe risk models will provide many benefits to a wide range of users and help to minimize the death and destruction caused by natural disasters. Certainly these benefits will make the efforts made to overcome the challenges all the more rewarding.

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