UNISDR
The United Nations Office for Disaster Risk Reduction

GAR
Global Assessment Report on Disaster Risk Reduction
2015

BACKGROUND PAPER

Prepared for the 2015 Global Assessment Report on Disaster Risk Reduction

UNDERSTANDING RISK: THE EVOLUTION OF DISASTER RISK ASSESSMENT SINCE 2005

Global Facility for Disaster Reduction and Recovery (GFDRR)

March 31, 2014

Table of Contents

Abbreviations

AAL	average annual loss
AIFDR	Australia-Indonesia Facility for Disaster Reduction
ASEZA	Aqaba Special Economic Zone Authority
ASI	Italian Space Agency
AusAID	Australian Agency for International Development
BCR	benefit-cost ratio
BMKG	Metrological, Climatology and Geophysics Agency (Indonesia)
BNPB	National Disaster Management Agency (Indonesia)
BRACE	Building the Resilience and Awareness of Metro Manila Communities to Natural Disaster and Climate Change Impacts
BTOP	block-wise TOP
BUET	Bangladesh University of Engineering and Technology
CAPRA	Central American Probabilistic Risk Assessment
CARICOM	Caribbean Community and Common Market
CIMA	Centro Internazionale in Monitoraggio Ambientale
CIMNE	International Centre for Numerical Methods in Engineering
CEOS	Committee on Earth Observation Satellites
CEPREDENAC	Central American Coordination Center for Natural Disaster Prevention
CMIP	Coupled Model Intercomparison Project
CNES	National Center for Space Studies (France)
CSA	Canadian Space Agency
CSCAND	Collective Strengthening of Community Awareness on Natural Disasters
CTIS	Centre for Topographic Information in Sherbrooke
CV	coefficient of variation
DEM	digital elevation model
DFAT	Australian Department of Foreign Affairs and Trade
DLR	German Aerospace Center
DRFI	disaster risk financing and insurance
DRM	disaster risk management
DS	Divisional Secretariat
DSM	digital surface elevation model
DTM	digital terrain model
ENSO	El Niño-Southern Oscillation EO earth observation
EU	European Union
Europe Re	Europa Reinsurance Facility
FEMA	Federal Emergency Management Agency
FEWS-NET	Famine Early Warning Systems Network
FONDEN	Fondo Nacional de Desastres Naturales
GA	Geoscience Australia

GAR	Global Assessment Report on Disaster Risk Reduction
GCM	general circulation model
GDP	gross domestic product
GED	Global Exposure Database
GED4GEM	Global Exposure Database for GEM
GEM	Global Earthquake Model
GFDRR	Global Facility for Disaster Reduction and Recovery
GHSL	Global Human Settlement Layer
GIS	geographic information system
GLOF	glacial lake outburst flood
GLOFRIS	GLObal Flood Risk with IMAGE Scenarios
GMMA RAP	Greater Metro Manila Area Risk Assessment Project
GMPE	ground motion prediction equation
GPS	Global Positioning Satellite
GPWv3	Gridded Population of the World
GSNL	Geohazard Supersites and Natural Laboratories
GRUPMv1	Global Rural-Urban Mapping Project
GUF	Global Urban Footprint
GUI	graphical user interface
HEC	Hydrologic Engineering Center
HFA	Hyogo Framework for Action
HIU	Humanitarian Information Unit
HOT	Humanitarian OpenStreetMap Team
IDCT	Inventory Data Capture Tool
IHEP	Indonesian Earthquake Hazard Project
IMD	India Meteorological Department
InaSAFE	Indonesian Scenario Assessment for Emergencies
InSAR	Interferometric SAR
IPCC	Intergovernmental Panel on Climate Change
IRM	integrated risk management
ISC	international statistical classification
ISMEP	Istanbul Seismic Risk Mitigation and Emergency Preparedness Project
JAXA	Japan Aerospace Exploration Agency
JICA	Japan
LGU	Local Government Unit
MASDAP	Malawi Spatial Data Portal
MATRIX	New Multi-HAzard and MulTi-RIsK Assessment MethodS for Europe
MNA	Middle East and North Africa
MnhPRA	Morocco natural hazards probabilistic risk assessment
NASA	National Aeronautics and Space Administration

NGO	nongovernmental organization
OSM	OpenStreetMap
OpenDRI	Open Data for Resilience Initiative
PACCSAP	Pacific-Australia Climate Change Science and Adaptation Planning
PacRIS	Pacific Risk Information System
PAGER	Prompt Assessment of Global Earthquakes for Response
PCRAFI	Pacific Catastrophe Risk Assessment and Financing Initiative
PDNA	post-disaster needs assessment
PIC	Pacific Island country
PML	probable maximum loss
PTHA	probabilistic tsunami hazard assessment
RCM	Radarsat Constellation Mission
RFM	Regional Flood Model
RHoK	Random Hacks of Kindness
R&V	Risk and Vulnerability
SAR	synthetic aperture radar
SEEC CRIF	Southeast Europe and Caucasus Catastrophe Risk Insurance Facility
SOPAC	Secretariat of the Pacific Community Applied Geoscience Technology Division
SRTM	Shuttle Radar Topography Mission
TAP	Technical Assistance Project
TCLVs	tropical-cyclone-like vortices
UR	Understanding Risk
UNDP	United Nations Development Programme
UNEP-GRID	United Nations Environment Program–Global Resource Information Database
UNISDR	United Nations Office for Disaster Risk Reduction
UNSC	United Nations Statistical Commission
USAID	U.S. Agency for International Development
VGI	volunteered geographic information
WSPA	World Society for the Protection of Animals

Overview

The 10-year-long Hyogo Framework for Action (HFA) set out to substantially reduce impacts from natural disasters by 2015. Despite efforts toward this goal, economic losses from natural disasters are rising—from $50 billion each year in the 1980s, to just under $200 billion each year in the last decade (World Bank, 2013). The economic losses sustained by lower- and middle-income countries alone over the last 30 years represents a full third of all total development assistance in the same time period, offsetting tremendous efforts by governments, multilateral organizations, and other actors.

As the HFA period ends against a backdrop of challenging disaster risk trends, and consultations toward a post-2015 framework move forward, it is important to reflect on the role of disaster risk assessments in achieving disaster and climate resilience, and on the contributions risk assessments have made over the last 10 years. *Understanding Risk: The Evolution of Disaster Risk Assessment Since 2005*, which was developed to inform post-HFA discussions and the 2015 Global Assessment Report on Disaster Risk Reduction (GAR),[1] reports on the current state of the practice of risk assessment and on advances made over the last decade. Case studies spanning 43 countries showcase emerging best practices, demonstrate how risk assessments are being used to inform disaster risk management (DRM) and broader development, and highlight lessons learned through these efforts. Taken as a group, these case studies evidence the need for continued investment in accurate and useful risk information and provide recommendations for the future.

Experience has shown that a purely technical assessment of risk, however sophisticated and cutting-edge, is by itself unlikely to trigger actions that reduce risk. Successful risk assessments produce information that is *targeted*, *authoritative*, *understandable*, and *usable*. Thus the first steps in a risk assessment include understanding why the assessment is *needed* and *wanted*, defining the *information gaps* that currently prevent DRM actions, and identifying the *end-users* of the information. These steps can be completed only if there is communication and trust among all involved parties: scientists, engineers, decision makers, governmental authorities, and community representatives. A risk assessment designed along these lines will enable the development of information useful for risk mitigation.

This publication is not a "how-to" guide for risk assessment. It is aimed at government officials, donors, and nongovernmental organizations considering investment in the development of risk information. It does not provide a technical articulation of the risk assessment process; rather, it provides insight into the potential richness and range of risk assessment approaches and their

---

[1] The Global Assessment Report, whose preparation is overseen by the United Nations Office for Disaster Risk Reduction, is released every two years. Like previous reports, the 2015 edition addresses progress and challenges to achieving each of the Hyogo Framework for Action objectives. The Global Facility for Disaster Reduction and Recovery led the development of the analysis on "Priority Action 2: Identify, assess and monitor disaster risks."

capacity to meet a variety of purposes and contexts within the same overarching framework. For scientists, engineers, and others producing risk information, the publication highlights some of the challenges in understanding risk—beyond the strictly technical aspects that are described in many other publications.

Risk Information as the Basis for Decision Making

Risk information provides a critical foundation for managing disaster risk across a wide range of sectors. In the insurance sector, the quantification of disaster risk is essential, given that the solvency capital of most non-life insurance companies is strongly influenced by their exposure to natural catastrophe risk. In the construction sector, quantifying the potential hazard expected in the lifetime of a building, bridge, or critical facility drives the creation and modification of building codes. In the land use and urban planning sectors, robust analysis of flood risk likewise drives investment in flood protection and possibly effects changes in insurance as well. At the community level, an understanding of hazard events—whether from living memory or oral and written histories—can inform and influence decisions on preparedness, the location of important facilities, and life-saving evacuation procedures.

This publication focuses on four key areas where risk information is driving decision making. Each of the case studies included in this publication deals with the planning, development, and application of risk information for at least one of these areas:

1. *Raising awareness of disaster risk.* Managing disaster risk is just one of myriad challenges faced by governments, communities, and individuals, and it is one that may be easy to neglect. Because the true cost of historical disasters is often not widely known, and because the potential cost and impacts of future disasters—such as a rare but high-impact event—may not be known at all, DRM is given a low priority. Appropriate communication of robust risk information at the right time can raise awareness and trigger action. Among the case studies that demonstrate this point are the following:

- "Risk Assessments as an Advocacy Tool for DRM in the Middle East and North Africa"
- "A Cost-Benefit Analysis of Livestock Protection in Disaster Risk Management"
- "Informing Disaster Risk Management Plans in Aqaba, Jordan, through Urban Seismic Risk Mapping"
- "Global River Flood Risk Assessments"
- "Global Probabilistic Risk Assessment: A Key Input into Analysis for the 2013 and 2015 Global Assessment Reports"
- "Global Water-related Disaster Risk Indicators Assessing Real Phenomena of Flood Disasters"
- "Disasters and Climate Change Adaptation Management: A Guide for Local Governments"
- "A Hazard Identification and Risk Assessment Tool for the Province of Ontario and Communities"

- "Build Back Better: Where Knowledge Is Not Enough"

2. *Developing financial applications to manage and/or transfer risk.* Disaster risk analysis was born out of the financial and insurance sector's need to quantify the risk of comparatively rare high-impact natural hazard events. As governments increasingly seek to manage their sovereign financial risk or support programs that manage individual financial risks (e.g., micro-insurance or household earthquake insurance), developing new risk information is critical. It is important to recognize that investment in risk information for insurance or financial purposes is typically resource-intensive and needs to adhere to specific standards of analysis. The following case studies suggest how risk information may be used for financial purposes:

- "Morocco Comprehensive Risk Assessment Study"
- "Risk Assessment for Financial Resilience"
- "Pacific Catastrophic Risk Assessment Financing Initiative"
- "Southeast Europe and Caucasus Catastrophic Risk Insurance Facility"

3. *Informing policies, investments, and measures intended to reduce risk.* Hazard and risk information may be used to inform a broad range of activities to reduce risk, from improving building codes and designing risk reduction measures (such as flood and storm surge protection), to carrying out macro-level assessments of the risks to different types of buildings (for prioritizing investment in reconstruction and retrofitting, for example). The following case studies show risk information being used in the effort to reduce risk:

- "Comprehensive Approach to Probabilistic Risk Assessment (CAPRA) (including case studies on Costa Rica, Peru, and Colombia)"
- "Incorporating Disaster Resilience into Cultural Heritage Buildings in Bhutan"
- "Detailed Island Risk Assessment in Maldives to Inform Disaster Risk Reduction and Climate Change Adaptation"
- "Malawi: How Risk Information Guides an Integrated Flood Management Action Plan"
- "Reducing Seismic Risk to Public Buildings in Turkey"

4. *Informing risk planning and preparedness at various levels.* An understanding of the geographic area affected, along with the intensity and frequency of different hazard events, is critical for planning evacuation routes, creating shelters, and running preparedness drills. Providing a measure of the impact of different hazard events—potential number of damaged buildings, fatalities and injuries, secondary hazards—makes it possible to establish detailed and realistic plans for better response to disasters, which can ultimately reduce the severity of any event. The following case studies focus on using risk information for planning and preparedness:

- “Government-to-government Risk Assessment Capacity Building in Indonesia and the Philippines”
- “InaSAFE: Preparing Communities to Be a Step Ahead”
- “Tsunami Risk Reduction: Are We Better Prepared Today Than in 2004?”

A Framework for Quantifying and Understanding Risk

In its most simple form, disaster risk is a function of three components—hazard, exposure, and vulnerability (Figure 1).

- *Hazard* refers to the likelihood and intensity of a potentially destructive natural phenomenon, such as ground shaking induced by an earthquake or wind speed associated with a tropical cyclone.
- *Exposure* refers to the location, attributes, and value of assets that are important to the various communities, such as people, buildings, factories, farmland, and infrastructure that are exposed to the hazard.
- *Vulnerability* is the reaction of the assets when exposed to the spatially variable forces produced by a hazard event. For example, a building’s vulnerability to earthquake increases with the intensity of ground shaking and decreases with improved conformity to seismic design standards. Similarly, socioeconomic conditions can make responding to a hazard event easier or more difficult.

Figure 1. The components for assessing risk and the difference between "impact" and "risk."

Of course, within this simple framework a multitude of possible approaches to risk assessment and risk modelling is possible.

It is important to emphasize that exposure and vulnerability, not just hazard level, drive the scale and impacts of any disaster (Figure 2). Rapid and/or unplanned urbanization—characterized by dense populations living in poorly constructed housing—sets the stage for significant losses in lives and property when it occurs in areas at risk of flooding, earthquake, or other hazards. Indeed, evidence now points to urbanization—the unplanned and unchecked swelling of cities and megacities—as among the most important drivers of disaster risk (GFDRR, 2012). Fortunately, a catastrophic disaster is not the inevitable consequence of a hazard event, and much can be done to reduce the exposure and vulnerability of populations living in areas where natural hazards occur (frequently or infrequently).

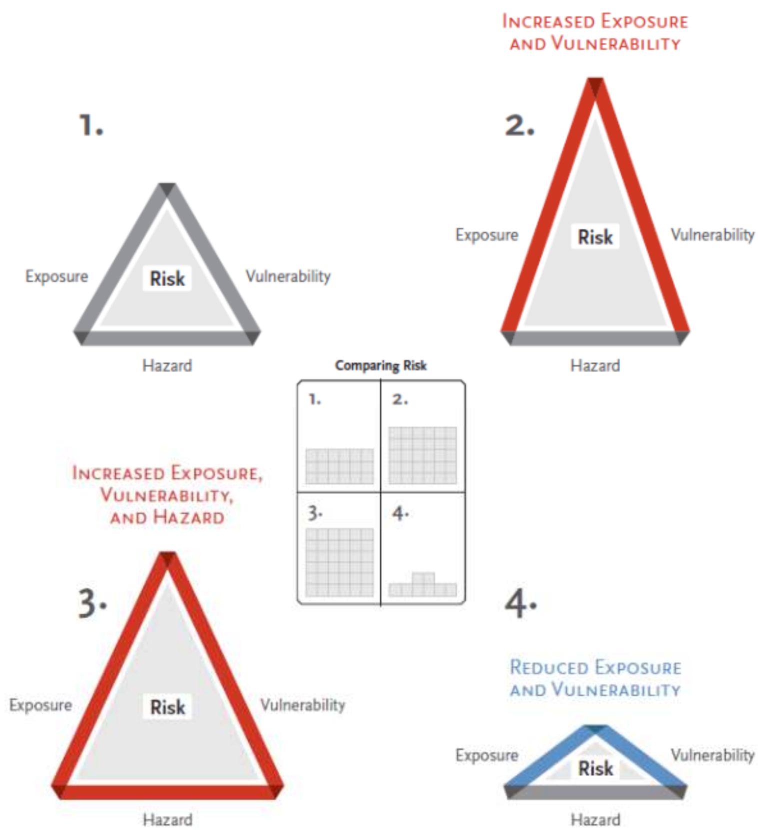


Figure 2. Risk as a function of hazard, exposure, and vulnerability.

Note: Triangle 1 shows equal contributions to the risk equation. Triangle 2 shows a rapid increase in exposure and vulnerability, leading to increased risk (as in rapidly urbanizing cities). Triangle 3 shows increased hazard, exposure, and vulnerability, leading to increased risk (as in a rapidly growing coastal city where the effects of climate change are increasingly felt). Triangle 4 shows controlled exposure and vulnerability (such as through proactive DRM), leading to lower overall risk.

The two strongest tropical cyclones ever to strike India constitute an instructive example of what can be achieved through understanding and managing risk. In 1999, the Odisha cyclone made landfall and resulted in 10,000 fatalities.[2] Fourteen years later, Cyclone Phailin struck nearby and resulted in 45 fatalities.[3] This dramatic reduction in loss of life highlights the extensive efforts made by the state of Odisha in disaster management and preparedness. A similar example is offered by New Zealand and Japan, where efforts by governments over decades massively reduced potential losses from the Christchurch and Great East Japan (Tohoku) earthquake events in 2011.

Advances and Key Remaining Challenges

Though important challenges remain in assessing risk, since 2005 significant progress has been made on each critical element of the risk assessment process. Many hazards are better understood; tools and models for identifying, analyzing, and managing risk have grown in number and utility; and risk data and tools are increasingly being made freely available to users as part of a larger global trend toward open data. More generally, and in contrast to 2005, today there is a deeper understanding—on the part of governments as well as development institutions such as the World Bank—that risk must be managed on an ongoing basis,[4] and that DRM requires many partners working cooperatively and sharing information.

This section summarizes technical advances and challenges associated with the fundamental elements of risk—hazard, exposure, vulnerability, and the modelling that integrates these components—as well as operational and institutional progress and challenges associated with new modes of addressing risk such as multi-stakeholder collaboration, communication, and open data and models.

Hazard. A wide range of data is required for understanding the potential extent and intensity of one or more natural hazards. In the last decade, there has been substantial progress toward

---

[2] The 1999 Odisha cyclone, Cyclone 05B, was the first storm to be categorized by the India Meteorological Department (IMD) as a super cyclonic storm. The 10-minute sustained wind was derived using a factor of ~0.85 to convert from 1-minute to 10-minute sustained winds.

[3] According to IMD (2013), Cyclone Phailin's winds at landfall were ~215km/hr. IMD uses 3-minute sustained winds as an average. A factor of ~0.9 was used to convert from 3-minute to 10-minute sustained winds.

[4] According to GFDRR (2012), a recent report by the World Bank's Independent Evaluation Group finds "a clear shift toward risk reduction in Bank-supported investment projects since 2006," though it also notes that "there is more to be done to systematically integrate an assessment of risks into the design and implementation of World Bank-financed projects (9)."

creating and providing open access to many global and national data sets critical to understanding hazard. Moreover, significant advances have been made in generation of so-called synthetic catalogs of hazard events, which are used to ensure that the full range of hazard events is captured and the likelihood of different events assigned. Significant challenges in acquiring and using hazard data remain, however. Consensus is emerging on the urgent need, particularly in developing countries and high-risk coastal areas, for digital elevation data at the appropriate level (that is, better than the 90m resolution that is currently available). Similarly, lack of historical hydrometeorological data in digital format poses significant challenges in quantifying current and future hydrometeorological risk in low- to middle-income countries. There is also evidence of emerging attempts to integrate climate change scenarios into risk modelling; however, this adds significant additional uncertainty into the modelled results.

Exposure. The growing momentum in efforts to develop exposure data has given rise to new approaches to data collection at various scales, from global to individual-building level. The greater availability of global data sets on population, building types, satellite imagery, and so on is providing significant opportunity to model global exposure at higher and higher resolutions. At national and subnational levels, data and information from government ministries (such as statistics authorities, transportation and infrastructure departments, and education and health departments) are increasingly being liberated[5] and merged in order to understand community, city, and national exposure. At city and community levels, the growing popularity of volunteer geospatial initiatives is seen by authorities as a way to engage communities, particularly youth, in the collection of data that will help everyone to plan and manage disaster risk. The Community Mapping for Resilience program in Indonesia[6] is a prime example of a government-led volunteer geospatial initiative: in a little over a year, more than 160,000 individual buildings were mapped into OSM.

Underpinning these efforts has been the rapid rise of the open data movement, which aims to make data technically open.[7] The Global Facility for Disaster Reduction and Recovery and World Bank launched the Open Data for Resilience Initiative in 2011 to foster and catalyze the open data movement for climate and disaster resilience. Under this initiative, web-based geospatial

---

[5] Liberated data are those that were at one time inaccessible due to format, policies, systems, etc., but are now being made available for use, either as discoverable and useable data sets or (in many cases) as technically open data sets.

[6] This program began in 2011 through a partnership led by the Australia-Indonesia Facility for Disaster Reduction, Indonesia's National Disaster Management Agency (Badan Nasional Penanggulangan Bencana), and the Humanitarian OpenStreetMap Team, with support from the GFDRR and the World Bank.

[7] Technically open generally means that data can be found on the Internet at a permanent address and are available in structured, nonproprietary formats via download or an application programming interface (API).

platforms (GeoNodes) in more than 20 countries have been used to open more than 1,000 geospatial data sets to the public and to catalyze community mapping of buildings and infrastructure. Moreover, satellite imagery is increasingly becoming available for use in assessing and understanding risk. Meteorological data collected using satellite imagery, for example, are increasingly being used to determine flood and drought risks at global and national scales. In addition, release of satellite imagery to the crowd is increasingly being used to map building footprints, roads, and other characteristics of the built environment or disaster-impacted area—often by mappers thousands of kilometers away. However, all these efforts need to achieve scale and sustainability to ensure that exposure data are available to explain the impacts of disasters and climate change at different scales.

Vulnerability. Both structural (i.e., physical) vulnerability and socioeconomic vulnerability are relevant to risk assessment. Concerning structural vulnerability, local engineers are increasingly dedicating themselves to understanding the vulnerability of their local building stock (which varies significantly from country to country and within countries) to different natural hazards. Engineers in the Philippines and Indonesia, for instance, are now developing vulnerability functions relevant to their respective national building stocks. However, opportunities continue to be lost in the collection of damage and loss data following disaster events—data and information critical to understanding future risks. In addition, efforts to quantify socioeconomic vulnerability and poverty remain limited, and information of this kind is rarely integrated into risk assessments.

Risk modelling. The last decade has seen a revolution in open access hazard and risk modelling software packages. Users from beginner to expert can now choose from a range of tools to address a range of problems. The packages vary in complexity from OpenQuake,[8] which is designed for highly advanced users, to multi-hazard risk platforms such as CAPRA,[9] to tools that enable nonspecialists to interact with data sets produced by both experts and volunteers, such as InaSAFE. All these advances and innovations create a need for better standards and transparency, which would enable replicating risk results by other actors, reporting on modelling assumptions and uncertainty, and so forth.

Another area of increased research and innovation has been global and regional risk modelling activities, designed to provide insight into global and regional trends in disaster risk. For example, global flood risk models developed in recent years can quickly provide estimations of potential losses—in monetary or human terms—from flood events with different return periods. With these advances comes a need for clear communication of the limitations of global analysis, in terms of scale, data, and assumptions (e.g., global and regional flood models rarely integrate

---

[8] This tool was developed under the Global Earthquake Model Foundation.

[9] More information about CAPRA can be found at the program’s website at www.ecapra.org.

information on flood protection). While the experts developing these models clearly understand their limitations, especially at subnational levels, those using the information produced by these models may understand their limitations less well.

Risk modelling to quantify evolving and future risk. It is well recognized that risk is not static and that it can change very rapidly as a result of evolving hazard, exposure, and vulnerability (recall Figure 2). Decision makers therefore need to engage today on the risk they face tomorrow. Three case studies included in this publication highlight the potential for quantifying future and evolving risk:

- "A Framework for Modelling Future Urban Disaster Risk" describes the response to rapid changes in exposure and vulnerability in Kathmandu, which have led to extraordinarily rapid growth in earthquake risk.
- "Global River Flood Risk Assessments" describes the capture of global growth in potential flood risk through the downscaled climate models and socioeconomic modelling.
- "Delivering Risk Information for a Future Climate in the Pacific" measures the 250-year loss from cyclones in the Pacific, driven by shifting patterns of cyclonic activity.

Multi-institutional collaboration. Risk assessment is inherently multi-institutional, and no single agency can be solely responsible for generating, communicating, and using risk information. The opportunities for collaboration and dialogue among multi-institutional stakeholders are evident in the successful efforts in Jordan, the Philippines, Indonesia, Bangladesh, and other countries, where agencies responsible for each element of risk assessment worked together with decision makers in finance, planning, and emergency management. Moreover, a number of global collaborative efforts have been formed to bring together practitioners from public, private, academic, and nongovernmental organizations; an example is the Understanding Risk[10] global community of practice. What the case studies make clear in aggregate is that there is no singular "correct" formula for building multi-institutional collaborations around risk assessment; effective approaches are context specific, build on existing institutional mandates, and center on the specific DRM problem being addressed.

Risk communication. The delivery of a risk assessment is now widely recognized as a first step. The completion of the risk assessment marks the beginning of a longer process of broadly communicating risk information to all relevant stakeholders—in a way that is meaningful to them and fit for their purposes. There is no one right way to communicate risk; instead practitioners need to draw on a tool box of approaches, ranging from Excel spreadsheets, maps, and simple interactive tools, to graphical representation of hazard and risk, to clear action-orientated messages from authoritative and respected voices explaining what citizens,

[10] See the Understanding Risk website at www.understandrisk.org.

communities, and countries can do to reduce risk. Much progress has been made in communicating risk—the Padang Build Back Better campaign described in one of the case studies demonstrates this fact, as does the growing use of new interactive geospatial tools such as GeoNode and InaSAFE—but this is an area that needs substantial additional investment in practical and considered research.

Hyogo Framework for Action: Progress under the Indictors Related to Risk Assessment

The current HFA has four indicators that relate to understanding and quantifying disaster risk, either through historical records of disaster events or modelling of potential future events. Based on the contributions received, we comment here on progress made toward and relevance of the specific indicator moving forward.

National and local risk assessments based on hazard data and vulnerability information are available and include risk assessments for key sectors. Significant progress has been made in developing risk information at global, national, and subnational scales—both in the tools and processes that enable such analysis to take place, and in the efforts by governments, the private sector, and nongovernmental institutions. Moreover, advances in remote sensing, global and regional modeling, and volunteer geospatial initiatives mean that risk information can be produced with ever decreasing resource requirements.

Unfortunately, the effort to produce risk information has been patchy from a geographical perspective; cities such as Padang, Indonesia, for example, had access to eight different tsunami inundation maps, in contrast to other communities and cities with no access to hazard or risk information. From a sector perspective, there are only rare examples of risk assessments being clearly targeted at sectors (one is the Costa Rica Water and Sanitation project). Most assessments are too general to be applied to sectoral requirements. Probably the greatest two weaknesses identified under this indicator are first, that too many hazard and risk assessments have been driven by well-intentioned science and engineering experts rather than by the end-users and decision makers who need access to targeted information; and second, that insufficient emphasis has been placed on making fundamental data sets, generated through the risk assessment process, open and accessible for reuse and repurpose—instead, resources have been squandered through the repetitive recreation of the same data sets.

Systems are in place to monitor, archive and disseminate data on key hazards and vulnerabilities. Significant progress has been made under this indictor in some countries; however, progress is by no means universal. With respect to monitoring and archiving data on disaster losses, there are now a number of systems in operation to capture these data, some national and many international.[11] With respect to the dissemination of data on natural hazards, the rapid increase in access to the Internet and use of mobile devices has made an enormous contribution since 2005. Moreover, greater access to open source geospatial tools such as the GeoNode, along with a growing focus on open data, means that information on hazard and risk, once determined, can rapidly be shared.

National and local risk assessments take account of regional/trans-boundary risks, with a view to regional cooperation on risk reduction. Both experience and the contributions to this publication suggest that achievements under this indicator are the lowest. There is some evidence of greater data sharing across some river basins, but generally, data sharing between countries with a common river basin is rare. In the development of riverine flood hazard maps, uncertainty in upstream natural or dam discharge creates severe limitations in the ability of governments to assess and manage flood risks. Many global and regional efforts to assess hazard and risk—some highlighted in this publication—do take into account regional and trans-boundary risks; however, at this stage there is limited evidence of government institutions using data and information from regional and global assessments in their decision making.

Research methods and tools for multi-risk assessments and cost benefit analysis are developed and strengthened. There is a plethora of methods and tools available for an expert aiming to model the risk from single, multiple, or cascading hazards, making this an area of significant progress since 2005. Many of these tools can be readily applied to cost-benefit analysis, and there is much evidence of governments utilizing cost-benefit analysis in prioritization of DRM investments. While not specifically mentioned under this indicator, methods now clearly exist to collect the fundamental data required for risk assessment and cost-benefit analysis. However, these methods are generally resource-intensive and often beyond the capacity institutions in developing countries. The next phase of HFA needs to move away from the development of new methods and tools, to a mature approach that enables genuine, long-term, and sustainable engagements with governments to assist their development of fundamental data sets. Fortunately, this publication highlights some emerging best practices that can be leveraged and scaled over the next 10 years.

Recommendations for Future Risk Assessments

For DRM practitioners, government officials, donors, and nongovernmental organizations considering investing in risk information, we offer key recommendations to ensure that this investment promotes more resilient development and communities. For those undertaking risk analyses, we see an opportunity to promote greater transparency and accountability. Our

[11] See the comparative review of country-level and regional disaster loss and damage databases in UNDP (2013) for a full analysis of the strengths and limitations of different systems.

recommendations, grouped against these two focus areas, are based on submissions received for this publication and on discussions with developers and end-users of risk information.

Recommendations for those commissioning and using risk information:

1. Clearly define the purpose of the risk assessment before analysis starts.

Risk assessments initiated without first defining a question and an end-user often become scientific and engineering exercises that upon completion must find a use case. Moreover, a risk assessment that is not properly targeted may not be fit for its intended purpose or may be over-engineered and/or over-resourced. Where risk assessments have been commissioned in response to a clear and specific request for information, they have tended to be effective in reducing fiscal or physical risk.

2. Promote and enable ownership of the risk assessment process and efforts to mitigate risk.

Ownership is critical for ensuring that knowledge created through a risk assessment is authoritative and therefore acted upon. It is certainly possible for risk specialists to generate risk analysis without ever engaging with local authorities; but regardless of the sophistication or accuracy of their analysis, there will likely be very limited uptake of this information. Experience shows that successful projects often partner risk specialists with country counterparts to design, implement, and communicate the results of the risk assessment. Now that citizens have the ability to map entire cities, it is also important to recognize that the data they generate are more likely to be used when the authorities are also engaged in this process.

3. Cultivate and promote the generation and use of open data.

Experience gained in the last decade strongly speaks to the need to encourage the creation and use of open data. The analysis of natural hazards and their risks is a highly resource- and data-intensive process, whereby the return on expended resources (time and money) can be maximized if the data are created once and used often, and if they are iteratively improved. Current efforts to develop open exposure data on the location, type, and value of assets can continue to be improved, and volunteered geospatial efforts and remote sensing products offer new opportunities to collect and update fundamental data. That said, despite the progress made, some fundamental data gaps prohibit meaningful and accurate assessments of disaster and climate risks—for example, we lack global digital elevation data sets available at resolutions appropriate for analyzing the potential inundation from flood, storm surge, sea-level rise, tsunami, and so on.

4. Make better communication of risk information an urgent priority.

Clear communication throughout the risk assessment process—from initiation of the assessment to delivery of results and the development of plans in response—is critical for successfully mitigating disaster risk.

A case study featured in this publication is a must-read for all risk assessment practitioners and disaster risk managers. An exceptionally planned and implemented "Build Back Better" campaign led by the government of Indonesia in the aftermath of the 2009 Padang earthquake demonstrated conclusively that well-targeted education and communication of risk information can increase awareness of natural hazards and their potential impacts. Analysis also showed, however, that progress from increased awareness to action can be very difficult to achieve, even in a community that has witnessed at first hand the devastation of an earthquake. To put risk knowledge into practice and build more resilient homes, people must be offered the correct combination of timely information, technical training, community supervision, and financial and nonfinancial incentives and disincentives.

A second point about communicating risk information has to do with the type of information communicated, and to whom. Metrics like annual average loss and probable maximum loss, for example, are of interest and relevant to the financial sector, but they are poor metrics for communicating with almost all other decision makers involved in DRM. Far preferable are interactive tools that enable people to answer "what if?" questions robustly and simply ("What if an earthquake/cyclone/other natural hazard hit my community—How many buildings would collapse or be damaged?"). InaSAFE, a recently developed tool, meets this need and is now being used extensively at national and subnational levels in Indonesia. That said, there is still immense opportunity to develop a bigger tool box of interactive, highly graphical visualization tools, which would enable all decision makers, from individuals to national governments, to meaningfully interact with risk information.

5. Foster multidisciplinary, multi-institutional, and multi-sectoral collaboration at all levels, from international to community.

To generate a useable risk assessment product, technical experts and decision makers must consult with one another and reach agreement on the purpose and process of the assessment. The actual development of risk information is clearly a multidisciplinary effort that takes place through collaborations ranging from international efforts to multi-institutional arrangements at national and subnational levels. There are many efforts currently under way that speak to the success of this approach. However, success has been comparatively limited in merging community-level understanding of risk with a national or subnational understanding of risk. This is a missed opportunity wherein a common understanding of the risks and necessary steps to reduce these risks could trigger greater action.

6. Consider multi-risk assessments instead of assessing single risks in isolation.

Rarely do countries, communities, or citizens face potential risks from only one hazard, or even from natural hazards alone. Our complex environments and social structures are such that multiple or connected risks—from financial hazards, multiple or cascading natural hazards, and anthropogenic hazards—are the norm. A risk assessment that accounts for a single hazard may struggle with relevance and will not necessarily speak to a decision maker who is responsible for broader risk management. Moreover, failure to consider the full risk environment can result in maladaptation: heavy concrete structures with a ground-level soft story for parking can protect against cyclone wind, for example, but can be deadly in an earthquake. A particular caution comes with risks in food security and the agricultural sector, which should be considered at all times alongside flood and drought analysis.

7. Keep abreast of evolving risk.

Risk assessments need to account for temporal and spatial changes in hazard, exposure, and vulnerability, particularly in rapidly urbanizing areas or where climate change impacts will be felt the most. A risk assessment that provides an estimation of evolving or future risk is a way to engage stakeholders in carrying out actions now in order to avoid or mitigate the risk that is accumulating in their city or country. For example, analysis can now be undertaken to show the decrease in future risk that arises from better enforcement of building codes, and hence demonstrates the benefit of spending additional funds on building inspectors.

Recommendations for those producing risk information:

8. Understand, quantify, and communicate the uncertainties and limitations of risk information.

Once risk information is produced, all users must be aware of and knowledgeable about its limitations and uncertainties. Failure to consider these can lead to flawed decision making and the inadvertent increase in risk. A risk model can produce a very precise result—it may show, for example, that a 1-in-100-year flood will affect 388,123 people—but in reality the accuracy of the model and input data may provide only an order of magnitude estimate. Similarly, sharply delineated flood zones on a hazard map do not adequately reflect the uncertainty associated with the estimate and could lead to decisions such as locating critical facilities just outside the "flood line," where the true risk is the same as if the facility was located inside the flood zone. It is incumbent upon specialists producing risk information to clearly and simply communicate uncertainties and limitations.

9. Ensure that risk information is credible and transparent.

Risk information must be scientifically and technically rigorous, open for review, and honest regarding its limitations and uncertainties, which may arise from uncertainties in the exposure data, in knowledge of the hazard, and in knowledge of fragility and vulnerability functions. The best way to demonstrate credibility is to have transparent data, models, and results open for review by independent, technically competent individuals. Risk modelling has become very advanced, yet also more accessible, and therefore anyone can feasibly run a risk model—but without the appropriate scientific and engineering training and judgment, the results may be fundamentally incorrect and may mislead decision makers.

10. Encourage innovations in open source software.

In the last 5 to 10 years, immense progress has been made in creating new open source hazard and risk modelling software. More than 80 freely available software packages, many of which are open source, are now available for flood, tsunami, cyclone (wind and surge), and earthquake, with at least 30 of these in widespread use. Significant progress has also been made in improving open source geospatial tools, such as QGIS and GeoNode, which are lowering the financial barriers to understanding risks at national and subnational levels. Yet all this innovation has created challenges around assessing "fitness-for-purpose" interoperability, transparency, and standards. These need to be addressed in a way that continues to catalyze innovation and yet also better supports risk model users.

Looking ahead to the next phase of the HFA, we would encourage international policy makers to consider the recommendations highlighted in this publication. Future HFA indicators centered on risk information should articulate the need for *targeted*, *robust, authoritative, trusted*, *open, understandable*, and *usable* risk information—descriptors which were universally mentioned by contributors to this publication. We also encourage future HFA indicators to highlight the importance of producing risk information that is driven by the needs of end-users and the information and evidence gaps—whether at national, sub-national or community levels—as well as the need for appropriate communication of risk information for different stakeholders.

References

GFDRR (Global Facility for Disaster Reduction and Recovery). 2012. "Managing Disaster Risks for a Resilient Future: A Strategy for the Global Facility for Disaster Reduction and Recovery 2013–2015."
https://www.gfdrr.org/sites/gfdrr.org/files/publication/GFDRR_Strategy_Endorsed_2012.pdf.

IMD (India Meteorological Department). 2013. *Very Severe Cyclonic Storm, PHAILIN over the Bay of Bengal (08-14 October 2013): A Report.* New Dehli: Cyclone Warning Division, India Meteorological Department. http://www.imd.gov.in/section/nhac/dynamic/phailin.pdf.

UNDP (United Nations Development Programme). 2013. A Comparative Review of Country-level and Regional Disaster Loss and Damage Databases. Bureau for Crisis Prevention and Recovery, UNDP.

World Bank and GFDRR (Global Facility for Disaster Reduction and Recovery). 2013. *Building Resilience: Integrating Climate and Disaster Risk into Development—The World Bank Group Experience*. Washington, DC, U.S.: World Bank.
http://www.worldbank.org/content/dam/Worldbank/document/SDN/Full_Report_Building_Resilience_Integrating_Climate_Disaster_Risk_Development.pdf.

I. Introduction

> Earthquakes, droughts, floods and storms are natural hazards, but unnatural disasters are deaths and damages that result from human acts of omission and commission. Every disaster is unique, but each exposes actions—by individuals and governments at different levels—that, had they been different, would have resulted in fewer deaths and less damage.
> —World Bank and United Nations, *Natural Hazards, UnNatural Disasters* [12]

A disaster-related risk assessment[13] provides an opportunity before a disaster event to determine the likely deaths, damages, and losses (direct and indirect) that will result, and to highlight which actions will be most effective in reducing the impacts on individuals, communities, and governments. This ability to model disaster loss and to provide robust analysis on the costs and benefits of risk preparedness, reduction, and avoidance has made disaster risk assessments a powerful tool in disaster risk management (DRM). As a result, the number of risk assessments being undertaken is growing, innovation has flourished, and a vast array of approaches, experiences, and lessons learned now exists.

Experience has shown that a disaster risk assessment does not represent the conclusion of a process, but instead provides a foundation for a long-term engagement focused on the communication and use of the risk information. Proactive responses to new risk information include retrofitting buildings to withstand the assessed seismic risk, developing new land-use plans, designing financial protection measures, and equipping and training emergency responders.

In the context of rapidly growing disaster losses and high-profile catastrophic disasters, it is often difficult to imagine reducing the impact from hazard events. However, societies have successfully overcome similar challenges in the past. For centuries, urban fires were a global concern for the public, private, and finance sectors, as well as for the communities directly affected. Urban fires devastated Rome in 64 CE, London in 1666, Moscow in 1812, Chicago in 1871, and Boston in 1872; the 1906 San Francisco fire destroyed nearly 95 percent of the city, and the Tokyo fire of 1923 killed over 40,000 people. Yet we do not see urban fires any more, and this hazard has largely been consigned to history. The reasons— implementation of modern building codes, land-use planning, establishment and expansion of emergency services, greater citizen responsibility, and insurance regulations—are essentially the same levers that we can apply to consigning natural disaster events to history.

---

[12] World Bank and United Nations, 2010.

[13] UNISDR (2009) defines a risk assessment as “a process to determine the nature and extent of risk by analyzing potential hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed people, property, services, livelihoods and the environment on which they depend.”

We have already seen construction practices evolving in response to cyclones and earthquakes, and some areas have strict urban and land-use planning designed to reduce loss from flood. California, for example, has implemented a series of building code changes in response to earthquake[14]—changes that today represent a reduction in risk. Recent earthquakes in Chile, New Zealand, and Japan have dramatically demonstrated the influence of enforced building codes in reducing death, damage, and loss. These examples show that a society can reduce vulnerability and risk. But for these efforts to succeed, there must be robust and accessible information on hazard, exposure, and vulnerability, models that integrate this information and quantify risk, and the commitment and resources to prioritize actions needed to implement risk reduction.

About This Publication

This publication was developed to reflect on progress made in risk assessment under the 10-year Hyogo Framework for Action and capture the diverse efforts made to improve our awareness and understanding of risk. It is not a technical guide on how to undertake a risk assessment and instead offers a narrative to a nontechnical audience interested in how risk information can lead to more resilient communities, cities, and countries. The authors are aware that this publication does not capture all the engagements and projects on risk assessment across the globe or all the innovations and advancements that have taken place. However, it does provide both a snapshot of use cases for those interested in application of risk assessment and some recommendations for the future.

The report begins with an overview and is then divided in four parts.

Overview: This section summarizes key themes, observations, and recommendations pulled from the entire report to prompt policy dialogue and discussions among funders of risk assessment projects.

I. Introduction: This section describes the history of risk assessment, the recent rise of open data and open risk modelling, and the alignment of risk assessments to different DRM applications.

II. Progress, Achievements, and Remaining Challenges in Risk Assessment: Based on research and on submissions from and discussions with experts, this section captures key achievements and progress in different aspects of risk assessment in the last decade—from availability of fundamental data sets, to modelling tools, to new platforms that facilitate collaboration. This section also articulates remaining challenges that need focus over coming years.

---

[14] See State of California Seismic Safety Commission (2000).

III. Case Studies Highlighting Emerging Best Practices: This section showcases risk assessment initiatives from around the world that are grouped according to their focus on one of the following: data; modelling; risk assessment in practice; institutionalization and communication of risk information; assessment of future risk.

IV. Recommendations: Based on recommendations received from developers and users of risk information and on emerging best practices, this section offer 10 recommendations for future investment in risk assessment.

A Brief History of Risk Assessment

Societies have been dealing with risk for thousands of years. The earliest records related to practices intended to minimize financial risk come from shipping. For example, in the second millennium BCE the Babylonians invented maritime loans that did not require repayment if the ship was lost (Carter, 1979). The origins of modern property insurance practices that are not associated with maritime ventures can be traced back nearly 350 years, to the creation of the first fire mutual companies following the London fire of 1666. Benjamin Franklin started the first U.S. mutual fire insurance company in 1792. The devastating fires in U.S. cities during the 19th century bankrupted many insurance companies and fostered the use of objective assessments of risk using fire insurance maps, which displayed building footprints, construction materials, and location information.

The modern approach to risk assessment—using complex models as well as extensive exposure and hazard data—came into being when computational resources became more common. But even before the advent of computers, insurers seeking to track exposure and avoid unwanted concentrations of risk used pins on a map to mark the location of underwritten properties. Thus tracking risk using data on exposure and vulnerability is not a new practice.

The invention of computers and their adoption by government and industry set the stage for coupling exposure and vulnerability data with hazard models to generate risk estimates. Perhaps the first modern risk models were developed for managing flood risk and designing dams. The U.S. Army Corps of Engineers Hydrologic Engineering Center (HEC) was created in 1964 and released components of the first watershed models in 1966. The components needed to be run separately because of memory limitations in computers. The integrated version of the model, HEC-1 Flood Hydrograph Package, was released in 1968. At that time, releasing the integrated model components as a package was considered a major innovation that allowed linked, related programs to be run without direct handling of intermediate results (HEC, 1989). Other risk assessment–related efforts were also taking place during the late 1960s and early 1970s. During this period, for example, C. Allin Cornell (1968) released a methodology for seismic risk assessment; efforts at assessing hurricane risk for NASA's Apollo project were under way (Jarvinen, Neumann, and Davis, 1984); and the catastrophe risk models for a range of natural hazards were under development for use by insurers (Friedman, 1972).

Risk modelling became more common as computational resources expanded. In 1981 the first catastrophe risk modelling company, EQE International, was founded. The company provided catastrophic risk management consulting, design, and research services to commercial, utility, nuclear, and other high-tech industries. The two other major catastrophe risk modelling firms, Applied Insurance Research (AIR) and Risk Management Solutions (RMS), were formed in 1987 and 1989, respectively. While catastrophe risk models provided objective assessment of risk, until the early 1990s much of the insurance industry still based many business decisions on actuarial approaches using historical data. The use of catastrophe risk models in the insurance industry grew dramatically after Hurricane Andrew struck Florida in 1992. Insured losses from Hurricane Andrew were much greater than those expected based on historical experience. In contrast, shortly after the landfall of Hurricane Andrew, AIR used its hurricane risk model to estimate insured losses that were much larger than any experienced in the past and closer to those actually experienced by the insurance industry. The difference between experience-based and model-derived loss estimates was driven in part by dramatic increases in exposure along the coast and by the limited sample of hurricane events in the historical record.

Emergency management agencies also began to adopt risk models for risk assessment in the 1990s. In 1997 the Federal Emergency Management Agency (FEMA) released Hazus97, the first version of Hazards US (Hazus), a geographic information system (GIS)–based natural hazard loss estimation software package. The output from Hazus includes factors such as shelter needs related to emergency management. The Hazus model has been adopted for use by emergency management organizations outside the United States, in countries such as Singapore, Canada, Australia, and Pakistan.

During the first decade of the 21st century, there was growing awareness that risk assessments could help countries develop tools and strategies to reduce disaster losses, and thus several efforts to develop risk models were initiated. Governments have increasingly started to use risk modelling to assess their exposure to natural events, and in particular to use probabilistic risk modelling techniques, which manage uncertainty by providing a robust measure of risk and which allow for comparisons of risk.

In 2004 New Zealand began to develop RiskScape, a regional multi-hazard risk model; Australia similarly began development of seismic, cyclone, and tsunami risk models; and in 2007 a partnership of Central American governments and development institutions began work on CAPRA (Central American Probabilistic Risk Assessment). Many of these models were developed to be open source and have led to large developer communities. In addition to these initially regional efforts, the decade also saw efforts to develop global models. The Global Earthquake Model (GEM), for example, was conceived in 2006; the GEM Foundation was officially formed in March of 2009; and the first official release of the GEM OpenQuake is slated for 2014. The international development community also joined this effort, beginning with the Global Facility for Disaster Reduction and Recovery (GFDRR)–World Bank, which released its first global risk analysis in 2005 (Dilley 2005), and followed by the United Nations Office for Disaster Risk Reduction (UNISDR), which began work on a new global probabilistic model in 2011.

Today, there are more than 100 freely available risk models across the range of hazards. While many of these remain the domain of the experienced scientist or engineer, and are poorly suited to city or government officials responsible for managing disaster risk, a growing number of more user-friendly models are becoming available, such as the InaSAFE tool developed through a collaboration between the Indonesian and Australian Governments and GFDRR/World Bank. In addition, researchers are beginning to couple probabilistic risk models with predictions of climate change to account for future changes in hazard and risk, an approach that is likely to become the norm in future assessments.

The Rise of Open Models and Data: The Changing Risk Assessment Paradigm

Over the last five years, the field of risk assessment has been increasingly driven by open data and open source modelling. The reasons for this evolution are multifold:

- Producing risk information requires a substantial investment in time, money, and effort, and those commissioning it are no longer satisfied with a published report as the sole end result. The real value is increasingly seen in the data that make the risk analysis possible, and in the various hazard and risk maps and analysis that can be further manipulated and used in a variety of contexts.
- The rapid changes in urban environments, in populations, and in extreme weather events require that risk information be dynamic and updated frequently. Access to open data and modelling tools allows dynamic risk assessment to be carried out by resource-poor governments and communities.
- There is a global movement toward open data, which seeks to increase government transparency and accountability and to broaden participation in governance. This effort can be seen in the establishment of initiatives such as the Open Government Partnership, whose 63 member governments have pledged accountability to their citizens. In addition, development institutions such as the World Bank, the U.S. Agency for International Development (USAID), and the African Development Bank view openness as a means to make the development process more inclusive and transparent.
- Open data and open models promote a level of transparency in risk assessment that represents an appealing change from the past, when assumptions, data sets, and methodologies, along with the associated uncertainties, were invisible to the end-user.
- Driven originally by citizens frustrated by lack of access to fundamental maps in the United Kingdom, there is a surge in interest in community or participatory mapping that has now become a global revolution led by the OpenStreetMap community (see Box 1).

Box 1. OpenStreetMap

OpenStreetMap, often called "the Wikipedia of maps," is an online geospatial database and a global community of over 1.5 million contributors, who are engaged in building a free and open map of the world that anyone can contribute to and that can be used in any tool or analysis.[a] OSM was established in 2004 in the United Kingdom in reaction to restrictions around the use and/or availability of geospatial data across the world.

OSM is a confederation of organizations and technologies. OpenSteetMap.org is a database with over 2.2 billion map "nodes" hosted by University College London, Imperial College London, Bytemark Hosting, and other partners. The OpenStreetMap Foundation is a UK charitable organization that oversees the state of the map. The Humanitarian OpenStreetMap Team (HOT) is a U.S. nonprofit corporation that applies the "principles of open source and open data sharing for humanitarian response and economic development."[b] HOT provides support to emergency operations and training for the collection of mapping data in communities at risk.

The database hosts data on transport networks, buildings, amenities, and natural landscapes across the globe. Data collection ranges from local-level surveys with handheld GPS units and paper maps to tracing satellite imagery.

The repeated discussion of OSM throughout the case studies in this publication attests to the value of this innovative approach and its ability to improve our understanding of risk from natural hazards and climate change.

a. OSM is open data, licensed under the Open Data Commons Open Database License (ODbL); see http://www.openstreetmap.org/copyright for more information on copyright and license.

b. See the HOT website at http://hot.openstreetmap.org/.

In addition, as demand grows for risk information at resolutions appropriate for community and city decision making, the need to collect exposure data at these resolutions has also grown. Crowdsourcing is increasingly being viewed by governments and communities as a solution that enables bottom-up participation in the understanding of risk and a cost-effective solution to an otherwise expensive challenge of data collection. An example of this approach is highlighted in Box 2.

Box 2. Community Mapping in Indonesia

Open data initiatives, combined with bottom-up approaches such as citizen mapping initiatives, can be an effective way to build large-exposure databases.

The Community Mapping for Resilience program in Indonesia is an example of a large-scale exposure data collection system. The program began in 2011 through a partnership led by the Australia-Indonesia Facility for Disaster Reduction, Indonesia's National Disaster Management Agency (Badan Nasional Penanggulangan Bencana), and the Humanitarian OpenStreetMap Team (HOT), with support from the Global Facility for Disaster Reduction and Recovery and the World Bank.

The initiative's main goal is to use OpenStreetMap to collect building-level exposure data for risk assessment applications. OpenStreetMap offers several important features: open source tools for online or offline mapping, a platform for uploading and hosting data with free and open access, and an active global community of users.

In a little over a year, more than 160,000 individual buildings were mapped and new partners—including five of Indonesia's largest universities, local government agencies, international development partners such Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ), and civil society organizations—were trained and are using the platform.

To be considered open, models and data should be both legally and technically open (see Figure 3). As development and use of open tools grows, the need to clarify and standardize the meaning of "open" will become more pressing. Box 3 describes how one initiative, the Global Earthquake Model, resolved differences of opinion about "open."

Figure 3. What makes data "open."
Note: The quoted material in the first box is from http://opendefinition.org/.

Box 3. Defining "Open"

The members of the Global Earthquake Model, a public-private partnership, share an interest in credible, accessible risk information that is widely used and understood. Although the principle of "open" data was central to GEM's mission and self-understanding, over the course of GEM's first six years members differed widely on what "open" meant and implied.

These differences became obvious and somewhat contentious when concrete licensing policies were proposed for the data and software developed under GEM: public sector participants typically viewed "open" to imply "free of charge," while private sector participants, who sought an ongoing business advantage from their sponsorship of GEM, did not want GEM data and software to be made available free of charge to their competitors. In their view, "open" did not necessarily entail "free."

GEM's governing board convened a task group to study this issue further and make a recommendation to the board. The task group, made up of seven members representing both the public and private sector, proposed a compromise: data and model licenses would be embargoed for 18 months. Under this arrangement, GEM initially releases any given version of a GEM data set or model with a license restricting commercial use for 18 months;[a] after this period the same product is rereleased under a license without commercial restriction.

a. The license type is CC BY-NC-SA 3.0 (Creative Commons Attribution–Noncommercial-ShareAlike 3.0 Unported). See http://creativecommons.org/licenses/by-nc-sa/3.0/.

Source: Helen Crowley, Nicole Keller, Sahar Safaie, and Kate Stillwell (GEM Foundation).

Aligning and Targeting Risk Assessments

Risk assessment as applied to DRM can easily be framed around the formula *risk = hazard X exposure X vulnerability*. Under this single formula, however, there is considerable variation in the types of and purposes for risk assessment. Generally, risk assessments are undertaken for one of four reasons: to raise awareness of disaster risk; to direct and inform policies, investments, and measures intended to reduce risk; to develop financial applications so that risk can be managed or transferred; or to inform risk planning and preparedness at various levels.

Determining what constitutes a suitable risk assessment product depends not only on the purpose of the assessment, but on a number of other factors as well: which decision makers and stakeholders are involved, how the results will be used, the scale at which the assessment will be carried out, the data requirements for the assessment, and the complexity of the analysis. Table 1 suggests a range of assessment products and their different attributes.

Experience has shown that a risk assessment that is well targeted to a purpose and end-user will have a greater chance of success, wherein success is measured in the use of the risk information for decision making. It is therefore critical that there be consensus on the objective of the risk assessment, that it be designed to meet the project's basic requirements and standards, and that it not exceed available resources (money, personnel, time.)

To understand how various factors influence risk assessment design, consider two different risk assessment products, one a community-based assessment that aims to engage communities in disaster risk reduction, to communicate risk, and to promote local action (first row of Table 1), and the other a catastrophic risk assessment for financial planning (second row from the bottom). The community-based assessment involves local stakeholders—communities and local government—and can be used in building community preparedness, supporting contingency planning, and identifying vulnerable assets. On the other hand, it cannot be used in developing financial applications and will seldom be used in planning significant investments in risk reduction, or in carrying out land-use planning. In contrast, a catastrophic risk assessment for financial planning involves a different set of stakeholders—ministries of finance, international and domestic financial markets, modelling companies, and insurance and reinsurance companies—and is carried out on a larger (national to multi-country) scale using high-quality, high-resolution data. This type of analysis is rarely used for local DRM or community preparedness.[15]

[15] However, data in this type of assessment can sometimes serve as the foundation for local applications, as was the experience with the Pacific Catastrophic Risk and Financing Initiative.

Table 1. Comparison of Risk Assessment Products

Product	Purpose	Decision makers	Uses	Limitations	Scale	Requirements	Analytical complexitya	Examples
Community-based disaster risk assessment	Engage communities, communicate risk, and **promote local action**	Communities and local government	Build **community preparedness** and support contingency planning, identification of vulnerable assets	Not suited for design of risk reduction infrastructure / urban land-use planning	Community level	Low: Typically based on historical disaster events	Simple: Includes promotion of participatory mapping	Bhutan
Asset-level risk assessments, including cost-benefit and engineering analysis	Inform design of building / **asset-level risk reduction** activities and promote **avoidance of new risk**	Government officials, subnational authorities, and engineering / construction firms	Serve as input into risk reduction **interventions at asset level** (retrofitting buildings and strengthening infrastructure), and **ensure resilience of new infrastructure** (building code enforcement and site selection)	Not suited for influencing financial applications / informing urban and contingency planning	Building / infrastructure level	Moderate to high: Requires high-resolution local data sets	Moderate: May require probabilistic risk modelling	Malawi, Maldives, Turkey, Indonesia, Morocco, CAPRA – Costa Rica
Macro-level risk assessment for risk reduction, including cost-benefit analysis	Inform urban / regional risk reduction measures	Government officials and subnational authorities	Inform risk-sensitive land-use planning, input into cost-benefit analysis of macro-scale risk reduction	Not suited for influencing financial applications / informing engineering decisions on retrofitting /	Urban, regional, national	Moderate to high: Requires moderate- to high-resolution data across large spatial	Moderate: Requires probabilistic risk modelling	Philippines, Morocco, Jordan

			interventions at urban / regional level (flood protection, etc.)	rebuilding at the asset level		areas		
Risk identification to identify critical infrastructure and establish early warning systems	Inform **preparedness and risk reduction**, based on understanding of potential damage at the regional to local level	Government officials, subnational authorities, and NGOs supporting preparedness and communities	**Identify high-risk critical infrastructure** (schools, hospitals, and government buildings) and the potential impacts of different hazard events	Not suited for influencing financial applications / informing engineering decisions on retrofitting / rebuilding at asset level	Urban, regional, national	Moderate to high: Requires asset-level information across large spatial areas	Moderate: Typically requires probabilistic risk modelling	CAPRA–Peru
Qualitative (preliminary) national risk profile	Aid in **advocacy** and initiation of DRM dialogue	Government officials, international organizations	**Initially illustrate disaster risks** for dialogue and cross-country comparison	Not suited for determining quantitative losses / risk reduction prioritization / urban planning	National	Low: Requires global, regional, and /or national data sets	Simple	Maldives, work in Middle East and North Africa, Indonesia, Nigeria
Quantitative (comprehensive) national risk profile	Aid in advocacy and **initiation of DRM dialogue** based on quantitative assessment	Government officials, international organizations	**Illustrate potential disaster losses** if DRM interventions are not prioritize / inform national development planning,	Not suitable for informing preparedness/ risk reduction strategies / financial decision making	National	Low to moderate: Requires global, regional, and/or national data sets	Moderate: Requires probabilistic risk modelling	Malawi

			investments, social protection policies, DRM strategies, and coordination mechanisms.					
Catastrophic risk assessment for financial planning	Aid in **financial and fiscal risk** assessment of disasters / serve as catalyst for **catastrophe risk insurance market** growth	Ministries of finance, international and domestic financial markets, modelling companies and (re)insurance companies	Provide detailed distribution of **annual average and probable maximum losses** and analysis of uncertainty as an **input into sovereign disaster risk financing and insurance strategies** for managing fiscal exposure to disasters	Not suitable for detailed local planning for investments to reduce risk or community preparedness	National to multi-country	High: Requires high-resolution and high-quality data for large spatial areas with clear articulation of uncertainty	High: Requires probabilistic risk modelling typically undertaken by internationally recognized firms	PCRAFI, Morocco, Mexico
Global risk assessments	Aid in advocacy and initiation of DRM dialogue	Government officials, international organizations	Provide support to high-risk countries to **understand emerging patterns of risk**	Not suitable for informing national or subnational decision making	National to multi-country	Low: Requires global data sets	Simple	Global Assessment Report on Disaster Risk Reduction; global / regional flood risk modelling (Nigeria)

Source: World Bank and GFDRR (2013).

Note: The table reflects consultations among GFDRR, World Bank, United Nations Development Programme, and UNISDR about how DRM challenges can be aligned with risk assessment approaches.

References

Carter, R. L. 1979. *Reinsurance.* Brentford, Middlesex, UK: Kluwer Publishing Ltd. and Mercantile & General Reinsurance Co. Ltd.

Cornell, C. A. 1968. Engineering Seismic Risk Analysis. *Bulletin of the Seismological Society of America* 58(5): 1583–1606.

Dilley, M. 2005. *Natural Disaster Hotspots: A Global Risk Analysis*. Washington, DC, U.S.: World Bank.

Friedman, D. G. 1972. Insurance and the Natural Hazards. *ASTIN Bulletin International Actuarial Association* 7(1): 4 –58.

HEC (Hydrologic Engineering Center). 1989. Hydrologic Engineering Center—A Quarter Century, 1964–1989. http://www.hec.usace.army.mil/publications/AdministrativeDocument/HEC_A_QuarterCentury_1964-1989.pdf.

Jarvinen, B. R., C. J. Neumann, and M. A. S. Davis. 1984. A Tropical Cyclone Data Tape for the North Atlantic Basin, 1886–1983: Contents, Limitations, and Uses. NOAA Technical Memorandum. NWS NHC 22. http://www.nhc.noaa.gov/pdf/NWS-NHC-1988-22.pdf.

State of California Seismic Safety Commision. 2000. The History of the California Seismic Safety Commission: Living Where the Earth Shakes, 1975–2000. http://www.seismic.ca.gov/pub/CSSC_HISTORY.pdf.

UNISDR (UN Office for Disaster Risk Reduction). 2009. *2009 UNISDR Terminology on Disaster Risk Reduction.* Geneva, Switzerland: UNISDR. http://www.preventionweb.net/files/7817_UNISDRTerminologyEnglish.pdf.

World Bank and United Nations. 2010. *Natural Hazards, UnNatural Disasters*. Washington, DC, U.S.: World Bank.

World Bank and GFDRR (Global Facility for Disaster Reduction and Recovery). 2013. *Building Resilience: Integrating Climate and Disaster Risk into Development—The World Bank Group Experience*. Washington, DC, U.S.: World Bank. http://www.worldbank.org/content/dam/Worldbank/document/SDN/Full_Report_Building_Resilience_Integrating_Climate_Disaster_Risk_Development.pdf.

II. Progress, Achievements, and Remaining Challenges in Risk Assessment

Risk assessments require hazard, exposure, and vulnerability data at the appropriate scale and models with the appropriate resolution to address the problem of interest. Moreover, it is impossible to develop a risk information product that can be used successfully without a considered approach to building multidisciplinary, multi-institutional platforms and nontraditional partnerships around the technical analysis. In this section, we discuss these aspects by reviewing promising innovations in risk assessment over the last decade and highlighting some of the greatest remaining challenges.

Hazard Assessment

Essential steps required to quantify risk are the identification of the relevant hazard(s) and the collection of hazard-related data. Although these steps usually occur at the start of a risk assessment, they are often not easy or straightforward. Often, this process includes deciding whether to undertake a single hazard or multi-hazard assessment of the primary hazards and then deciding whether consider secondary (or cascading) hazards that may be triggered by a primary hazard event—for example, fire or tsunami after earthquake.

This is not a simple decision. Since it is a rare country or community that is affected by only a single hazard, assessments that consider the full range of hazard events often achieve greater traction; on the other hand, the level of investment for considering all hazards may be too great, or momentum following a disaster event may be driving interest in single hazard. Adding the complexity of secondary hazards will further increase the resource and data requirements and may significantly broaden the institutions involved in a risk assessment. For example, considerations of fire after an earthquake require additional data sets, engagement with fire authorities, energy and water companies, and so on. These challenges are discussed further in Box 4.

Box 4. Multi-risk Assessment: An Overview

In spite of growing interest in and use of multi-risk assessment approaches, devising an integrated multi-risk assessment scheme remains a major challenge. It implies adopting a quite different perspective from that of a classical single-risk analysis. A multi-risk analysis does not merely consider more than one type of risk. It deals with the various spatial and temporal interactions that may arise between risks (European Commission, 2010). For example, cascading or domino effects may include cases in which one event directly triggers another (such as the 2011 Great East Japan earthquake, where the earthquake triggered a tsunami, and the ensuing tsunami resulted in catastrophic failures at the Fukushima nuclear facility). Cascading or domino effects may also include cases in which the occurrence of one event modifies the likelihood of another (such as drought and wildfires) and/or increases the vulnerability of an area to later events. There are also situations where more than one event may occur at around the same time, without any actual physical link (e.g., an earthquake just after a windstorm).

Another example of cascading effects from a hazard is combustion of a building by fire caused by an explosion of gas released from a pipeline ruptured by an earthquake. This scenario occurred following the 1994 Northridge earthquake, when approximately 110 earthquake-related fires were reported within 24 hours of the earthquake (Scawthorne, 1997). A slightly different scenario occurred following the 1995 Kobe earthquake, when a similar number of fires was ignited. Damage to structures from fire caused by the Northridge earthquake was well contained; however, nearly 5,500 buildings were lost to fire caused by the Kobe earthquake.

The results provided by a full multi-risk approach would need to include a harmonized quantitative assessment of the different risks and the effects of the possible interactions. Thus, while a multi-risk assessment may make it possible to establish a hierarchy of risks, it can also be used to identify areas where efforts to mitigate one hazard may conflict with, or create synergies with, the response of the system to a second type of hazard, or where planned adaptation and mitigation activities may potentially increase or decrease the risk from other hazards. An example of this potential risk is the challenge of building for cyclone wind and earthquake—wherein the strongest concrete building may decrease vulnerability in a cyclone, but create additional vulnerability in an earthquake (as happened in Haiti in 2010).

Source: Anna Scolobig, Alexander Garcia-Aristizabal, Nadejda Komendantova, Anthony Patt, Angela Di Ruocco, Paolo Gasparini, Daniel Monfort, Charlotte Vinchon, Mendy Bengoubou-Valerius, Roger Mrzyglocki, and Kevin Fleming, "From Multi-Risk Assessment to Multi-Risk Governance: Recommendations for Future Directions," input paper prepared for the 2015 Global Assessment Report on Disaster Risk Reduction, available at www.preventionweb.net/gar.

Once the hazards of interest are defined, the next step often involves acquiring a variety of hazard-related data. The most fundamental data define historical events, in particular their date, geographical location and extent, and maximum intensity. Historical events are often used in deterministic analyses that assess the impact of past events with current exposure. Additionally, historical event information is used to estimate the probability of a hazard occurring at a location with a specific intensity.

An *event set* comprises a suite of stochastic or computationally generated synthetic hazard events with statistical characteristics consistent with the historical record. Such event sets can typically include thousands or tens of thousands of potential events and are intended to define the full range of potential events for a hazard. Event sets are used with other information to quantify probabilities of loss and risk from a hazard.

Additional information is used to define the spatial distribution of the forces (e.g., the wind field from a tropical cyclone or the ground motion from an earthquake) associated with a hazard event. Such information is often incomplete or unavailable and in most cases must be derived from a very limited set of observations. Typically, a combination of observational data and theory is used to define the spatial and temporal characteristics of an event. A collection of the spatial, intensity, and temporal characteristics for events in an event set is termed a *hazard catalog*.

Hazard catalogs and event sets can be used with risk models in a deterministic or probabilistic manner. Deterministic risk models are used to assess the impact of specific events on exposure. Typical scenarios for a deterministic analysis include renditions of past historical events, worst-case scenarios, or possible events at different return periods.[16] For example, a deterministic risk (or impact analysis) will provide a robust estimation of the potential building damage, mortality/morbidity, and economic loss from a single hazard scenario. Risk models are used in a probabilistic sense when an event set contains a sufficient number of events for the estimate of the risk to converge at the longest return period, or the smallest probability, of interest. In other words, a probabilistic risk model contains a compilation of all possible "impact scenarios" for a specific hazard and geographical area. Note that hazard catalogs are generally associated with rapid onset hazards. Risk assessments for slow onset hazards, such as drought, are typically undertaken using deterministic approaches. Additional issues associated with modelling drought risk and impacts are discussed in Box 5. For a cost-benefit approach to risk that deals with the effects of drought on livestock, see Box 6).

Box 5. Assessing Damage and Loss Caused by Drought: Example of a Deterministic Assessment

Most studies that evaluate drought damage look at past drought events on an ex post basis. They use self-reports or media accounts, or compare production for drought and non-drought years (Martin-Ortega and Markandya, 2009). These ex post approaches may fail to determine susceptibility to drought, due to predefined relations between certain drought hazard and resistance parameters and expected damage. Moreover, they also fail to deal with the dynamics of drought risk and damage over time. Specific problems with these ex post approaches include potential bias from self-reports and media accounts of damage, and significant uncertainty in comparisons between drought and non-drought agricultural production. Additionally, these comparisons fail to account for factors other than drought that influence production. They do not distinguish between direct drought effects that damage crops and indirect effects spreading through the economy.

A further problem with current drought damage models is that they are not designed to account for drought mitigation measures. This means that the damage-reducing effects of drought mitigation measures are largely unknown, a situation that makes choosing among the different mitigation measures difficult. This lack of information about mitigation strategies is especially problematic in the case of drought-related soil subsidence. Existing studies suggest that soil subsidence (which can severely damage buildings) can be as destructive as other large-scale natural disasters, such as floods, yet little is known about how to best reduce its impact.

Deficiencies in current approaches to assessing damage and loss caused by drought could be ameliorated using the following:

---

[16] A 100-year event represents something with a probability of occurrence equal to 0.01 per year. In general, an X-year event has a 1/X probability of occurrence per year. The number of years represented by X is termed the "X-year return period."

- *Ex ante evaluation methods.* Properly designed, these will help to address the projected increase in frequency and intensity of droughts, make it possible to learn about changes in drought damage over time, and facilitate evaluating and prioritizing mitigation strategies for drought damage.
- *More sophisticated drought damage models that are based on assessments of losses to economic flows*—that is, models that account for indirect losses of sector-specific added value, wage losses, or relocation expenses. These could significantly improve current cost assessments.
- *Models that capture the effect of drought mitigation measures.* Existing databases on drought-induced soil subsidence and its effect on different building types could provide a basis for this future work.

Source: Heidi Kreibich and Philip Bubeck, "Natural Hazards: Direct Costs and Losses Due to the Disruption of Production Processes," input paper prepared for the 2015 Global Assessment Report on Disaster Risk Reduction, available at www.preventionweb.net/gar.

Box 6. A Cost-Benefit Analysis of Livestock Protection in Disaster Risk Management

Animal-related income streams are critical to underlying causes of risk and provide economic and social well-being in the world's poorest and most vulnerable regions. Protecting livestock is crucial because it protects the livelihoods of livestock producers and guarantees food security for millions of people.

To learn more about the role of livestock protection in DRM, the World Society for the Protection of Animals (WSPA) commissioned Economists at Large Pty Ltd to conduct a cost-benefit analysis of a WSPA intervention in the Mwingi District in Kenya. The intervention began in 2011, in response to long-lasting drought conditions, and involved treating livestock brought to WSPA's Mwingi operation to increase the likelihood that the animals would survive until the next rainy season.

The analysis focused on the household income impacts to owners of livestock who brought their animals for treatment. Beyond this, the analysis sought both to understand the economic impact of livestock operations on local and regional economies and to create an applicable and scalable risk reduction model that would assess vulnerabilities and return on investment strategies within livestock-dependent communities.

To assess the number of animals reached and the total cost of WSPA's intervention, WSPA post-intervention response reports were used. The potential income derived from animals treated was considered the benefit of the intervention. For the sake of this preliminary analysis, it was assumed that half of the animals treated would have died had they not received treatment.

The intervention is estimated to have generated $2.74 of benefits in the form of avoided losses for every $1.00 spent. If the time period for potential income generated by the livestock is extended to three years and the cumulative effect of secured livelihoods is taken into account, the benefit-cost ratio increases to $6.69 in benefits for every $1.00 spent. Based on the research described here, WSPA is developing a framework for estimating the impacts on communities and households of losing livestock in a disaster.

Source: Nicole Fassina, World Society for the Protection of Animals, "Cost-Benefit Analysis of Livestock Protection in Disaster Risk Management," input paper prepared for the 2015 Global Assessment Report on Disaster Risk

Reduction, available at www.preventionweb.net/gar; based on Economists at Large, *Cost-benefit Analysis of WSPA's Mwingi Intervention in Kenya* (Melbourne: World Society of the Protection of Animals, 2013).

Convergence of results is a concern when using a risk model probabilistically. As a simple example, consider a simulation of 100 years of hazard events. This simulation is too short to determine the 100-year return period. A random sample of 100 years of events could easily omit events, or include multiple events, that on average would occur every 100 years and therefore dramatically affect determination of return period.

Figure **4** illustrates this challenge. If the sample size (1900 and after) is the historical record, then it would appear that extreme flood and drought are not a concern. Similarly, if the period 1800–1900 is considered, flood would be seen as a risk, but not drought. Herein lies the challenge of determining the return period for rare and extreme hazard events. In the case of hydrometeorological cycles, determining the return period is difficult; for geophysical hazards such as volcanic eruptions and large earthquakes, which may occur every 1,000, 10,000, or 100,000 years, it is incredibly complex.

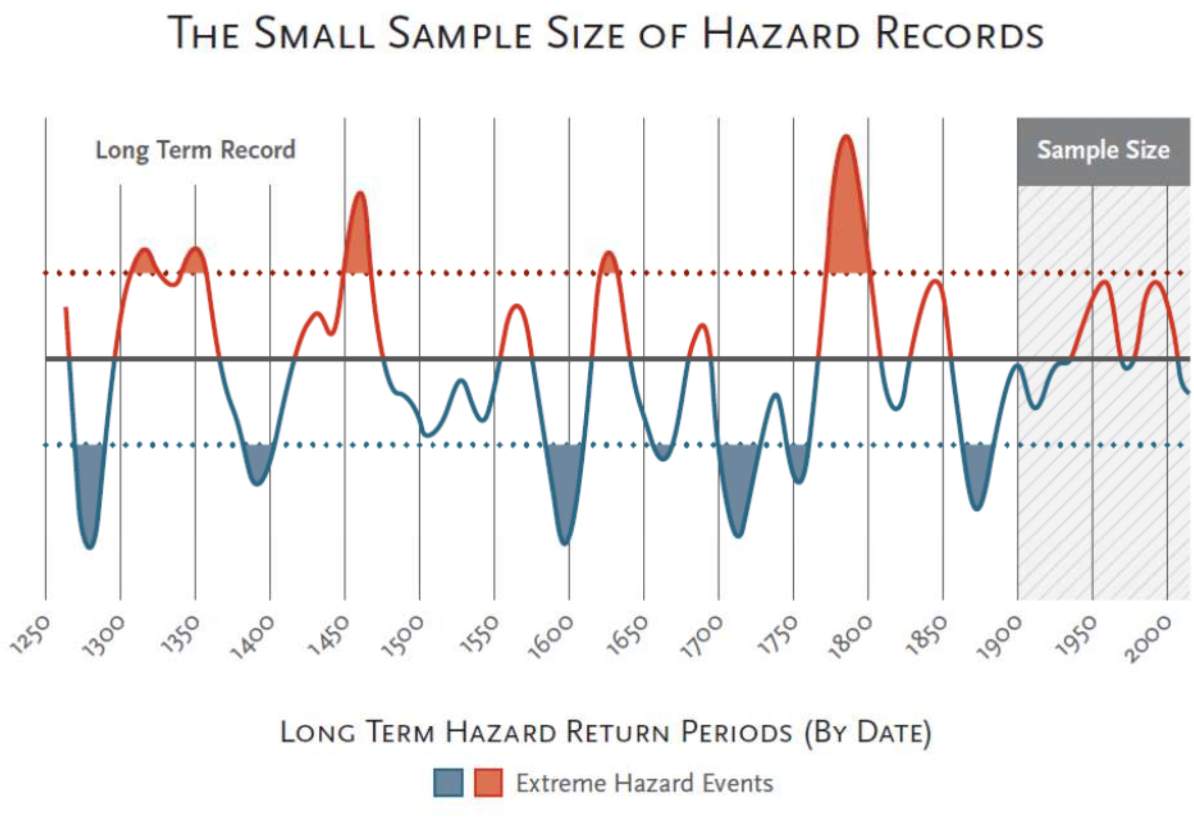


Figure 4. The challenge posed by short historical records for determining return period of drought (red) and flood (blue).

A variety of hazard-dependent data are required to generate a hazard catalog. Knowledge of the distribution of soil types, for example, is required to model the spatial variation of ground acceleration (shaking) from an earthquake; values for surface roughness are needed to define the distribution of wind speed from a tropical cyclone; and a digital elevation model (DEM) is needed to determine flood depth. Fortunately, some data can be common to multiple perils. For example, topography as defined by a DEM is required for modelling floods, tsunamis, sea-level rise inundation, landslide susceptibility, storm surges, and detection of earthquake fault lines.

Hazard data can be open, proprietary, or (if they have yet to be collected) unavailable. Moreover, even if available, the data may be not be digitized, may lack necessary metadata, and/or may require substantial improvement before use. A compilation of publicly available hazard-related data with global coverage is given in Table 2. Some of these data sets, such as the records for the location and intensity of earthquakes and tropical cyclones, provide global coverage and are considered authoritative records that compile the best available data.[17] Other global data sets may not be of optimal quality for risk assessment. For example, openly available topographic data are not optimal for modelling hydrometeorological hazards because of their relatively coarse resolution. Poor resolution of elevation data has a significant impact on flood risk, since small changes in elevation can involve huge changes in the predicted inundation area in many relatively flat floodplains and coastlines.

Table 2. Examples of Globally Available Hazard-related Data

Data	Use	Source
Earthquake events	Define date, intensity, and location of earthquakes	http://www.globalcmt.org
Earthquake events	Earthquake date, location, and intensity	http://www.ncedc.org/anss/
Quaternary fault maps	Assess distance from known faults and define fault motion	http://earthquake.usgs.gov/hazards/qfaults/download.php
Attenuation relationships	Calculate propagation of seismic waves	http://www.opensha.org/glossary-attenuationRelation
30m shear velocity (Vs30)	Determine seismic wave attenuation	http://earthquake.usgs.gov/hazards/apps/vs30/

[17] Information on the moment tensors for all earthquakes globally with moment magnitudes greater than 5 can be obtained through the Global Centroid-Moment-Tensor (CMT) Project (http://www.globalcmt.org). Best-track information for tropical cyclones includes the location (latitude and longitude), central pressure, and maximum sustained wind at six-hour intervals for all tropical cyclones. A collection of these data from a variety of sources can be obtained from the IBTrACS archive (http://www.ncdc.noaa.gov/ibtracs/).

Topography—digital elevation data (~90m resolution)	Define elevation and slope for floods, tsunamis, landslides, etc.	http://eros.usgs.gov/elevation-products
Tropical cyclone best-track data[a]	Determine location and intensity of tropical cyclones	http://www.ncdc.noaa.gov/ibtracs/
Land cover	Assign roughness for calculating winds from gradient-level winds	http://due.esrin.esa.int/globcover/ US: http://www.mrlc.gov/
Bathymetry	Define behavior of waves from storm surge and tsunamis	http://www.ngdc.noaa.gov/mgg/inundation/tsunami/
Tornado and hail paths	Develop event sets for tornadoes and hail from severe convective storms	http://www.spc.noaa.gov/wcm/#data
Volcanic eruptions	Catalog of all known historical (and in some cases geological) eruptions with indicative impacts (where known)	http://www.volcano.si.edu/search_eruption.cfm#
Tsunami events and run-ups	Tsunami hazard	http://www.ngdc.noaa.gov/hazard/tsu_db.shtml
Flood events since 1985	Flood hazard	http://floodobservatory.colorado.edu/Archives/index.html
Fire events 1997–2011	Wildfire hazard	http://due.esrin.esa.int/wfa/
Atmospheric reanalysis data	Reconstruct atmospheric winds, precipitation, temperature, etc.	http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html
Hurricane satellite data (HURSAT)	Homogeneous estimates of hurricane intensity	http://www.ncdc.noaa.gov/hursat/

a. Best-track data are defined as "a subjectively-smoothed representation of a tropical cyclone's location and intensity over its lifetime." National Hurricane Center, "Glossary of NHC Terms," http://www.nhc.noaa.gov/aboutgloss.shtml.

The spatial characteristics of an event are usually defined by combining theoretical and empirical knowledge with other observational hazard-related data because of the sparseness of the relevant observations. For example, quantifying the wind field for a tropical cyclone as it travels inland highlights the difficulty of estimating the spatial distribution of a hazard. Wind speed and pressure measurements from observing stations can be used to estimate two parameters, a cyclone's maximum wind and the radius of maximum wind. However, there are typically few quality measurements available due to a limited number of observational platforms, suboptimal siting of existing observation stations, power failures during the cyclone, and/or damage to anemometers by flying debris. Surface pressure measurements of the cyclone are easier to collect, and the minimum central pressure has a large influence on maximum wind speeds, but these surface pressures must be converted to surface wind speeds for risk modelling purposes, and this is where the theoretical and empirical knowledge is critical.

Most hazard event sets and catalogs are developed region by region. Exceptions include the global earthquake event set generated by the Global Earthquake Model (GEM), and tsunami, volcanic eruption, cyclone, and drought hazard event sets developed as part of the global risk model under the leadership of the UN Office for Disaster Risk Reduction. There are also a number of efforts to develop global flood models, which will use a global flood catalog; one model, GLOFRIS (GLObal Flood Risk with IMAGE Scenarios), is already in use (see part III for a more detailed discussion).

A critical requirement acknowledged by all experts working in hazard modelling is the need for a high-resolution, open DEM. Currently, the 90m Shuttle Radar Topography Mission (SRTM) is the only global open DEM, with 30m resolution available in some countries. Satellite-based Interferometric Synthetic Aperture Radar (InSAR) appears to be one promising approach for generating these data on a global scale; one satellite currently using InSAR is the TerraSAR/Tandem-X of DLR (German Aerospace Center) and Astrium Geo-Information Services. A growing alternative to a satellite-based collection of elevation data is the use of airplanes and/or helicopters to derive high-resolution surface data on a smaller scale via LiDAR[18] or airborne InSAR. Both of these "active" methods, while expensive, are capable of generating very accurate and high resolution surface and terrain elevations. Collection of LiDAR DEM is growing across the globe; however, the cost, time, and technical processing aspects of this approach prohibit its widespread accessibility.

There are two types of DEMs: a digital surface elevation model and a digital terrain model. A digital surface elevation model provides surface elevations that describe the elevations of features such as buildings and treetops. A digital terrain model provides elevations of the bare ground surface and neglects objects such as buildings and trees. The impact of the different models on hazard and risk assessments can be significant—see Box 7—but the combination of these different DEMs offers opportunities for better characterizing the built environment.[19]

Box 7. The Importance of Accurate Elevation Data for Understanding Tsunami Hazard

Tsunami inundation models provide fundamental information about coastal areas that may be inundated in the event of a tsunami. This information has relevance for disaster management activities, including evacuation planning, impact and risk assessment, and coastal engineering. A basic input to

---

[18] For more on LiDAR (Light Detection and Ranging), see the National Oceanic and Atmospheric Administration website at http://oceanservice.noaa.gov/facts/lidar.html.

[19] For more information, see Geoscience Australia, "New Building Assessment Tool Supports Better Risk Analyis," February 12, 2014, http://www.ga.gov.au/about-us/news-media/news-2014/new-building-assessment-tool-supports-better-risk-analysis.html.

tsunami inundation models is a digital elevation model—that is, a model of the shape of the onshore environment. Onshore DEMs vary widely in resolution, accuracy, availability, and cost. Griffin et al. (2012) assessed how the accuracy and resolution of DEMs translate into uncertainties in estimates of tsunami inundation zones. The results showed that simply using the "best available" elevation data, such as the freely available global SRTM elevation model, without considering data accuracy can lead to dangerously misleading results.

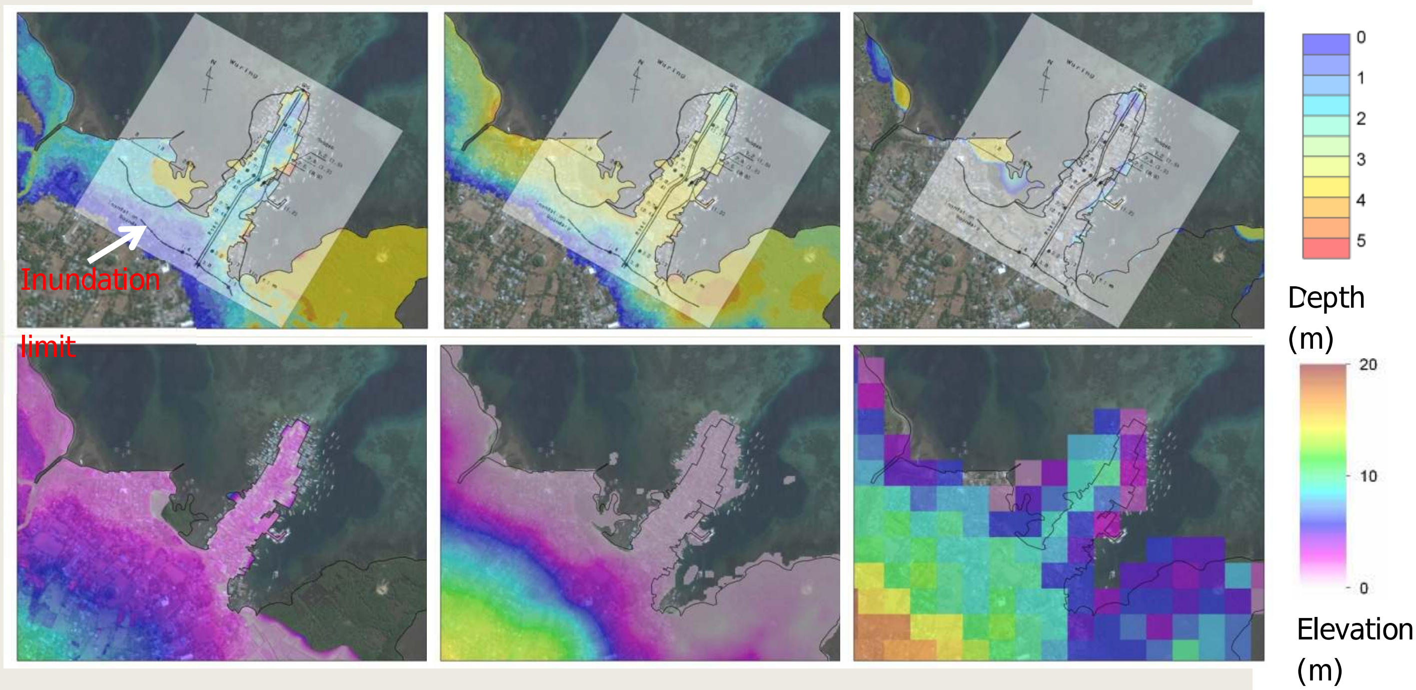


Figure 5. Modelled inundation for the 1992 tsunami in Flores, Indonesia (top) and underlying elevation data used in the model (bottom).
Source: Griffin et al., 2012.
Note: Top images show inundation estimates from the 1992 tsunami in Flores, Indonesia, with arrow pointing to black line showing the observed inundation limit. Bottom images show elevation data for LiDAR (left), airborne InSAR (middle), and SRTM (right).

The top part of Figure 5 shows tsunami inundation models for the 1992 tsunami in Flores, Indonesia (Griffin et al., 2012). For each model all parameters are the same except for the elevation data, shown in the bottom of the figure. Inundation model results are overlain with field observations of the actual inundation.[a] LiDAR and airborne InSAR give inundation area extents that are comparable with historical data. However, results obtained using the SRTM data set, with lower vertical accuracy,[b] show negligible tsunami inundation.

Two main inferences can be drawn from the results:

1. The most accurate and expensive data are not always needed, depending on the purpose. Airborne InSAR, which is an order of magnitude cheaper to acquire than LiDAR, may be suitable for tsunami evacuation planning.[c]
2. SRTM and ASTER[d] data sets, although freely available with near global coverage, should not be used for modelling onshore tsunami hazard, since the results can be dangerously misleading.

This study makes clear that accurate elevation models are crucial for understanding tsunami hazard. Investing in high-quality, accessible elevation data in tsunami-prone areas will underpin better risk reduction planning at the local level.

a. The observation data are from Tsuji et al. (1995).

b. See E. Rodriguez, C. S. Morris, J. E. Belz, E. C. Chapin, J. M. Martin, W. Daffer, and S. Hensley, "An Assessment of the SRTM Topographic Products," Jet-Propulsion Laboratory D-31639. http://www2.jpl.nasa.gov/srtm/SRTM_D31639.pdf.

c. However, further testing of tsunami inundation sensitivity to underlying DEM may be required in other coastal environments with different geomorphology before this inference becomes a widespread recommendation.

d. ASTER elevation data also significantly underestimate the wet area. See Griffin et al. (2012) for the full analysis.

Source: Jonathan Griffin (Australia-Indonesia Facility for Disaster Reduction, Geoscience Australia); Hamzah Latief (Bandung Institute of Technology); Sven Harig (Alfred Wegener Institute); Widjo Kongko (Agency for Assessment and Application of Technology, Indonesia); Nick Horspool (Geoscience Australia).

To assess risk from multiple meteorological hazards on a global scale, one should consider their spatial and temporal correlations and how they vary as a function of climate. For example, the probability of tropical cyclone landfall varies as a function of the El Niño-Southern Oscillation (ENSO) along the Queensland coast of Australia, the U.S. coastline, and in the northwest Pacific. Generally, warm El Niño years are associated with a reduced rate of landfall, and cool La Niña years are associated with a higher rate of landfall (e.g., Flay and Nott, 2007; Elsner and Jagger, 2006; Wu, Chang, and Leung, 2004). There are also possible cross-peril correlations. For example, flood and drought risk in many areas are strongly correlated with ENSO.

The response of meteorological hazards to natural climate variability highlights the possibility that the risk from these hazards will respond to future changes in climate. It is difficult to specify with certainty how hazard occurrence and intensity will change by region, and this is an area of significant research and modelling.[20] In part III, a case study highlights the changing risk associated with future changes in tropical cyclone activity in the Pacific region. Regardless of the uncertainties associated with quantifying future changes in meteorological hazards, sea level is certain to rise in response to melting of continental ice caps and thermal expansion of seawater. Higher sea levels will exacerbate coastal flooding from storm surge, intense precipitation events, and tsunami inundation.

Climate change and sea level rise are not the only future threats for coastal regions. Many coastal regions suffer from (severe) subsidence. In some locations the (increase in) subsidence is much larger than the sea-level rise. For example, in Jakarta the subsidence is currently over 10cm per year. According to Brinkman and Hartman (2008), Jakarta is heading toward a disaster with the juxtaposition of the high sea tides and the subsidence rate. Up to 4 million

[20] For a more in-depth discussion of how climate extremes may change in the future, see IPCC (2012).

people and approximately 25 percent of the city will be affected by inundation from the sea within the next 15 years if urgent action does not occur.

Exposure[21]

Exposure modelling has a critical role to play in risk assessment. Empirical studies suggest that exposure data, as compared to hazard or vulnerability data, have the most influence on the output loss estimates from risk models.

The process of exposure modelling identifies the elements at risk in areas that could potentially be affected by natural hazard events (UNISDR, 2009; Ehrlich and Tenerelli, 2013; van Westen, 2012). In other words, if a hazard occurs in an area with no exposure, there is no risk. This is the case, for example, with an earthquake in an unpopulated area of Alaska.

Exposure modelling techniques have been developed at various scales, from global to local. Significantly, global-scale and local-scale modelling use different methodologies: the former tends to take a top-down approach, with work being carried out by governments or large institutions, whereas the latter works from the bottom up by methods such as crowdsourcing and in situ surveys. At least four homogeneous inventory regions—urban residential, urban nonresidential, rural residential, and rural nonresidential—are usually defined to capture the differences in occupancy and construction. Data sources also vary by resolutions.

At the local scale, high-resolution exposure data have been developed on an ad hoc basis, in areas where risk modelling has been carried out. Crowdsourcing has become a common and valuable tool for collecting detailed bottom-up data, but this approach has limits, both in the type of data it can collect and in the quality of those data. In addition to being used to develop exposure data at a local scale, crowdsourcing has also been used to validate global-scale data. At the national scale, complete geospatially linked inventories that include public infrastructures are rare and not publicly available in most developing countries, where exposure model development is most needed for risk assessments. At the global scale, initiatives that aim to generate globally consistent exposure data sets in terms of quality and resolution have grown. Experience has shown that efforts to develop exposure data sets must employ innovative, efficient methodologies for describing, collecting, validating, and communicating data, while also accounting for the inherent spatiotemporal dynamics associated with exposure—that is, the dynamics by which exposure evolves over time as a result of (unplanned) urbanization, demographic changes, modifications in building practices, and other factors.

---

[21] The discussion of exposure here draws heavily on the GAR15 input paper by Massimiliano Pittore, Marc Wieland, and Kevin Fleming, "From Remote Sensing to Crowdsourcing: Perspectives of a Global, Dynamic Exposure Model for Georisk Assessment," available at www.preventionweb.net/gar.

The information used to develop exposure data sets can be derived from various sources and methods. At a local level, common data sources are council and local government agencies, household surveys, aerial photos, and individual architectural/structural drawings. At a regional level and above, state-based agencies, statistical offices, census data, investment and business listings, employment figures, and existing geographic information system (GIS) data are common sources of exposure information. At the coarsest level of resolution, national statistical agencies, census data, global databases, and remote sensing are used for developing exposure data.

Commercial risk models have developed the so-called industry exposure databases for regions where risk models are offered. These exposure data can include detailed information on construction as well as estimates of the value of the contents within a structure. The resolution of the exposure data is typically at the postal code level with varying levels of occupancy types. However, these data are almost always proprietary.

The classification (taxonomy and ontology) used to generate these exposure data varies from data set to data set; this variation is problematic for efforts to merge independently developed data sets. Nor is there is a commonly agreed upon taxonomy that accounts for features such as construction attributes and asset valuation across different hazards.

In recent years, several data sets with global coverage have made the first step in overcoming these obstacles. The first such global exposure data set was developed in 2010 for PAGER (Prompt Assessment of Global Earthquakes for Response), a global near-real-time earthquake loss estimation system, by the U.S. Geological Survey (Jaiswal, Wald, and Porter, 2010a). In addition, three global exposure databases are slated for publication in 2014, the global risk model by UNISDR (De Bono, 2013), the GEM4GEM by the Global Earthquake Model (Dell'Acqua, Gamba, and Jaiswal, 2012)[22] and the World Bank exposure database, which will be completely open and suitable for multi-hazard analyses (Gunasekera et al., 2014).[23] Many of these newer exposure models take advantage of aspects of building typology taxonomy originally compiled in the PAGER database. Several examples of global exposure data sets are given in Box 8.

Box 8. Global Exposure Data Sets

Global human exposure. Global models of human exposure mostly describe population data either on a regular grid or in specific settlement coordinates or geographical boundaries. A widely used product is the Gridded Population of the World (GPWv3), a gridded data set that provides a spatially disaggregated

[22] For more on GED4GEM, see "Global Earthquake Model" in part III. For more on the global risk model, see "Global Probabilistic Risk Assessment" in part III.

[23] Many global exposure models make use of commercial available data sets such as Landscan (http://web.ornl.gov/sci/landscan/) and as a result the final exposure model may not be completely open.

population layer constructed from national or subnational input units of varying resolutions.[a] The native grid cell resolution is 2.5 arc-minutes. Population estimates are provided for the years 1990, 1995, and 2000, and are projected to 2005, 2010, and 2015. Other global human exposure models include commercially available LandScan (Bhaduri et al., 2007) and the open WorldPop. These models are based on the integration of several information sources, including census and remote sensing, and are affected by a significant range of uncertainties (Potere et al., 2009; Mondal and Tatem, 2012).

Characterization of global built-up area. The Global Human Settlement Layer (GHSL) is developed and maintained by the Joint Research Centre of the European Commission. GHSL integrates several available sources about human settlements with information extracted from multispectral satellite images. The underlying automatic image information extraction work flow makes use of multi-resolution (0.5m–10m), multi-platform, multi-sensor (pan, multispectral), and multi-temporal satellite image data (Pesaresi and Halkia, 2012). The Global Urban Footprint is being developed by the German Aerospace Center (DLR) and is based on the analysis of Synthetic Aperture Radar (SAR) and optical satellite data. The project intends to cover the extent of the large urbanized areas of megacities for four time slices: 1975, 1990, 2000, and 2010 (Taubenböck et al., 2012).

Global description of building stock. Several global exposure databases include physical exposure information; examples include PAGER, the Global Exposure Database for the 2013 Global Assessment Report on Disaster Risk Reduction (GED-13), and the Global Exposure Database for GEM (GED4GEM).[b] Using the CAPRA platform (Cardona et al., 2012), GED-13 aims to create an open global building and population inventory suitable mainly for earthquake and cyclone probabilistic risk modelling. It employs building type classifications for different size categories of settlements as developed by the World Agency of Planetary Monitoring and Earthquake Risk Reduction (Wyss et al., 2013). The goal of the GED4GEM (Dell'Acqua, Gamba, and Jaiswal, 2012) is to create an open homogenized database of the global building stock and population distribution, with spatial, structural, and occupancy-related information at different scales, as input to the GEM risk platform OpenQuake.[c] Its building type classifications follow the GEM taxonomy, which is designed primarily for earthquake vulnerability assessments, and its multi-scale database structure contains information on buildings and populations from the country scale down to the per-building scale. The initial version of GED4GEM will contain aggregate information on population, built area, and reconstruction costs of residential and nonresidential buildings at 1km resolution. Detailed data sets on single buildings will be integrated for a selected number of areas and will increase over time.

a. See the Gridded Population of the World website at http://sedac.ciesin.columbia.edu/data/collection/gpw-v3.

b. For PAGER, see Wald et al. (2008) and the website at http://earthquake.usgs.gov/earthquakes/pager/; for GED13, see De Bono (2013); for GED4GEM, see http://www.nexus.globalquakemodel.org/ged4gem/posts.

c. For OpenQuake, see http://www.globalquakemodel.org/openquake/about/.

Source: Massimiliano Pittore, Marc Wieland, and Kevin Fleming, "From Remote Sensing to Crowdsourcing: Perspectives of a Global, Dynamic Exposure Model for Georisk Assessment," input paper prepared for the 2015 Global Assessment Report on Disaster Risk Reduction, available at www.preventionweb.net/gar.

Categories of information included in exposure models. There are several categories of assets that need to be included in a comprehensive exposure model (Table 3). The broad variety of categories illustrates the necessity of combining efforts from different disciplines, such as geographical science, statistics, engineering, mathematics, economics, remote sensing, and socio-demographics.

Table 3. Categories of a Comprehensive Exposure Model

Asset categories	Description
Population	Demographic characteristics
Property (buildings, etc.)	Various occupancy types such as residential, commercial, public, administrative, industrial classes. Also includes various different structural building types such as exterior wall and roof types.
Agriculture	Crop and land-use characteristics
Transportation	Road, rail, air, and other transport-related networks
Large loss facilities	Sports stadiums, marketplaces, churches/temples/mosques, schools and other high population density infrastructure
Critical/high-risk loss facilities	Hospital and health care facilities, public buildings, telecommunications, airports, energy systems, bridges and other facilities critical to the recovery of a disaster
Other lifelines—utilities, pipelines	Oil, gas, and water supply pipelines/distribution systems, nuclear and chemical power plants, wastewater, and electricity systems

Source: Adapted from GFDRR (2011).

It is clear that as more data are integrated, modelled, and jointly analyzed, *uncertainties* propagate in the model and in the subsequent results. A choice needs to be made about whether slightly more-detailed data will improve a model or merely add to the noise and confusion. The impossibility of eliminating uncertainty in hazard and vulnerability modelling is widely recognized. After all, every model constitutes a simplified approximation of reality. Depending on geospatial data characteristics (including resolution aspects) and integration factors, uncertainty may increase. It is therefore essential for uncertainties to be conceptually integrated into the framework of the risk analysis, and consequently into the loss estimates. The uncertainties and associated limitations in the final risk assessment then need to be communicated to the end-users of this information.

Information required for the modelling of physical damage. On a national scale, reliable data on physical exposure are less available than population data. Information is often missing or incomplete, and few governments have developed national exposure databases of buildings and infrastructure that are open and can be used to understand the impacts of multiple hazards (Turkey, Australia, the United States, and New Zealand are exceptions). Thus it is not surprising that most exposure data sets at the national scale or above use the spatial distribution of population as a proxy for developing exposure estimates. This is a rapidly evolving area, however, and more governments are seeing the widespread value of developing exposure information.

The basic information needed to model the response of a structure to a hazard event includes its location, occupancy, construction type, length or density (for road and railway), and replacement value. The response of a structure to a hazard event can be more realistically simulated using additional structural information such as its square footage, shape, height, age, roof type, irregularities, and material and mechanical properties, as well as building codes applicable to it. For hydrological hazards, additional details useful for vulnerability assessments include information on the height above ground of the first occupied floor, distance from water channels, and the presence of basements. Knowledge of the replacement value makes it possible to estimate the direct loss associated with an event.

Modelling economic losses. Valuation data are critical for quantitatively assessing economic loss from disasters. The re/insurance industry uses claims and other economic data sets to calibrate its exposure models. However, this information is often proprietary and limited to insured risks. Obtaining comprehensive loss data for uninsured property is much more difficult. Proxy data such as socioeconomic surveys, labor statistics by economic sector, floor area per employee by type of activity, etc. are used to determine nonresidential building stock values. Accounting for a structure's contents becomes particularly significant when modelling nonresidential occupancy classes.

Incorporating the temporal variation in human exposure. Other important factors related to exposure data are population and demography characteristics that highlight the movement of population through the course of a day. Consider, for example, the swelling of populations in major metropolitan areas during the work day, or the varying population characteristics of areas of cultural or religious value depending on the day and/or time of the year. Temporal variability in human exposure can be a key factor in determining the impact of rapid onset events such as earthquakes, landslides, or tsunamis. Models of building occupancy that consider daily patterns have been proposed (Coburn and Spence, 2002; Coburn, Spence, and Pomonis, 1992), but collecting the necessary data to update such models can be very time- and resource-intensive. A promising alternative approach takes advantage of cellular phone data provided by telephone companies (Wesolowski et al., 2013; Lu et al., 2013).

Exposure data collection approaches—full enumeration, sampling, or disaggregation using proxy data. In general terms, top-down and bottom-up approaches are used to collect exposure data. Approaches that use bottom-up methods commonly employ direct observation, which relies on two principle strategies: full enumeration or sampling. With the *full enumeration* approach, each exposed asset in the study area is detected and defined. This approach can be very accurate and detailed but also requires a greater expenditure of time and other resources. *Census data* are commonly used to fully enumerate human populations, though this approach is best suited to developed countries, which are likely to have slow or moderate population growth and up-to-date census data. *Volunteered geographic information* (VGI), another approach to full enumeration, derives data from the joint efforts of many individuals who voluntarily collect and submit data. VGI may be either structured or unstructured—the latter applies to unsystematic, non-authoritative initiatives such as OpenStreetMap, which rely on participants' interest and motivation. The structured approach also involves volunteers but has an authoritative component that directs volunteers' efforts toward certain tasks (Chapman, 2012), such as a government-led participatory mapping program to collect exposure data for risk assessment.

With a *sampling* approach, summary statistics for a large area are estimated based on smaller subset areas. Increasingly, census methodologies are turning to sampling and statistical modelling rather than full enumeration because they provide more up-to-date and more accurate information with less effort than traditional methods. A rolling census approach—in which only small areas are fully enumerated and other, highly populous areas are continuously sampled at the rate of around 10 percent a year—makes it possible to update data annually instead of every 5 to 10 years (UN Statistical Division, 2008).

Remote sensing is on occasion used in conjunction with these sampling methodologies (Adams and Huyck, 2006; Müller, Reiter, and Weiland, 2011; Geiß and Taubenböck, 2013). For instance, urban areas can be classified according to their density using satellite images, followed by a sampling approach where high-resolution imagery (manual or automatic extraction of features) or direct observation is used to fully enumerate assets (buildings, roads, bridges) and their geometric characterization (footprint, shape, height) within each of the sampling areas that represent the common density pattern classified during the first step. Alternatively, if time and resources permit, optical satellite or aerial images can be used to extract all of the footprints for buildings in an exhaustive manner. To provide a complete description of the exposure, however, the footprints should be combined with in situ direct observations or other data sets (such as national statistics information) that provide additional data that cannot be captured from above (e.g., construction features or building use).

In recent years, digital *in situ data capturing systems* have started to emerge, which allow the user to collect and generate exposure information using handheld direct observation tools in combination with other disaggregation or extrapolation methodologies (FEMA, 2002). An example includes the open source suite of tools called the Inventory Data Capture Tools (IDCT) developed under GEM. IDCT takes information generated from the analysis of satellite images to characterize built-up areas and combines it with sampled direct field observations on individual buildings using handheld devices or paper survey forms. This information is then integrated through the use of mapping schemes to generate exposure information.

Indirect, top-down disaggregation approaches use exposure proxies to develop exposure data sets when direct observation alone is not feasible. Information on the spatial distribution of population and built-up areas allows the exposure to be disaggregated into finer resolutions. Some examples of this approach are described in Box 9.

Box 9. Indirect Characterization of Exposure

Population: A global distribution of population data, in terms of counts or density per unit area, is considered the primary source of information for exposure assessment. For instance, the GAR13 exposure database uses the commercial global LandScan population database to obtain a spatial distribution of buildings' structural types (de Bono 2013). Analogously, the GED4GEM database exploits population data to disaggregate exposure estimation (Dell'Acqua, Gamba, and Jaiswal, 2012). In both cases the knowledge of the percentage of population living in each building type, or the estimated average dwelling occupancy, is used to link the population to the physical exposure. Global population models also allow use of empirical vulnerability functions, where direct estimates of loss are obtained directly in terms of population exposed, and the main loss metrics account for fatalities (Jaiswal and Wald, 2010). Many global models use human exposure as a basic ingredient to define a more refined "hazard-specific exposure" (Dilley, 2005; Peduzzi et al., 2009; Allen et al., 2009).

***Built-up areas*:** A further step with respect to population distribution is the spatial delineation of built-up areas, that is, impervious surfaces mostly characterized by artificial structures, including roads and buildings. Built-up areas are often described by binary masks that clearly outline the boundary of settlements. This can be considered an intermediate description of exposure, where the characterization of the built-up environment is improved with respect to a simple population layer. Built-up masks can be reliably obtained by processing different remote-sensing data, thus effectively addressing global-scale mapping. Examples of global built-up area products include the Global Rural-Urban Mapping Project (GRUMPv1),[a] the Global Human Settlement Layer (Pesaresi and Halkia, 2012), and the Global Urban Footprint (GUF) (Esch et al., 2010).

a. See the GRUMP website at http://sedac.ciesin.columbia.edu/data/collection/grump-v1.

Source: Massimiliano Pittore, Marc Wieland, and Kevin Fleming, "From Remote Sensing to Crowdsourcing: Perspectives of a Global, Dynamic Exposure Model for Georisk Assessment," input paper prepared for the 2015 Global Assessment Report on Disaster Risk Reduction, available at www.preventionweb.net/gar.

Multi-source integration. The growing variety of possible exposure information sources requires the flexible *integration of existing information* from different acquisition techniques, scales, and accuracies, so that no available information is discarded. An example for a probabilistic integration approach is given in Pittore and Wieland (2013). This method is based on Bayesian networks and allows for the sound treatment of uncertainties and for the seamless merging of different data sources, including legacy data, expert judgment, and inferences based on data mining.

There are clearly many approaches to collecting exposure data; however, for best results the decision on the approach must be aligned with the scale and purpose of the risk assessment (see Box 10).

Box 10. How Study Scale Drives Exposure Data Collection Methods

Assessing how a community will be affected by natural hazards requires a fundamental understanding of the elements at risk. The *type* of data needed for a hazard impact assessment depends on the nature of the problem that is being addressed and is independent of the location or scale of the problem. In direct contrast to this, the *methods* used for exposure data collection depend on the scale of the study.

If the goal of a natural hazard impact assessment is to understand whether a particular feature will be affected by a certain level of hazard, then it will be enough to simply know the location of that feature, and whether the location lies in a zone of potential hazard. For example, landowners who want to know whether their land is likely to be inundated by a flood will only need to locate their land within published flood hazard information. This example demonstrates scale independence: if the entire population sought this information, it would still be necessary to know only the location of land relative to zones of hazard.

In contrast, if the aim of a study is to understand the potential economic losses and casualties that could result from a natural hazard, then it is necessary to understand more than just the location of a single feature. For the quantitative estimates of risk, it is necessary understand the type of construction materials, the age of construction, and the number of people within a building. Note that while additional information is required in this example, the information is still independent of the scale of the study: whether data are for a single household or every household in a megacity, assessing the possible economic losses from flooding requires information about the number of stories in a building and the building's construction type and age.

The same example that demonstrates scale independence for the type of data collected demonstrates scale dependence for data collection methods. For the individual landowner/household, firsthand observation is the most effective method for collecting relevant data, regardless of whether they are for a simplistic "wet/not wet" assessment or a quantified estimate of risk to inform an insurance policy. However, undertaking either of these types of assessments through firsthand individual data capture at a megacity, national, or regional scale is impractical and likely impossible.

Source: Australian Department of Foreign Affairs and Trade (DFAT), Australia-Indonesia Facility for Disaster Reduction (AIFDR), Indonesian National Disaster Management Agency (BNBP), Collective Strengthening of Community Awareness on Natural Disasters (CSCAND), and Geoscience Australia (GA).

Vulnerability and Loss

Vulnerability is typically described in terms of damage and/or loss. Damage and loss to a structure are assessed using functions that relate hazard intensity to damage; see Figure **6** for an illustration. A variety of adjectives are used to describe the functions, including "fragility," "damage," and "vulnerability." Engineers use fragility functions to quantify damage and vulnerability functions to quantify loss caused by a hazard. However, it is not uncommon to use the term vulnerability function when discussing damage. Damage is often quantified using a damage ratio where 0 is equivalent to no damage and 1 is equivalent to complete destruction. Multiplying value by the damage ratio gives an estimate of direct loss.

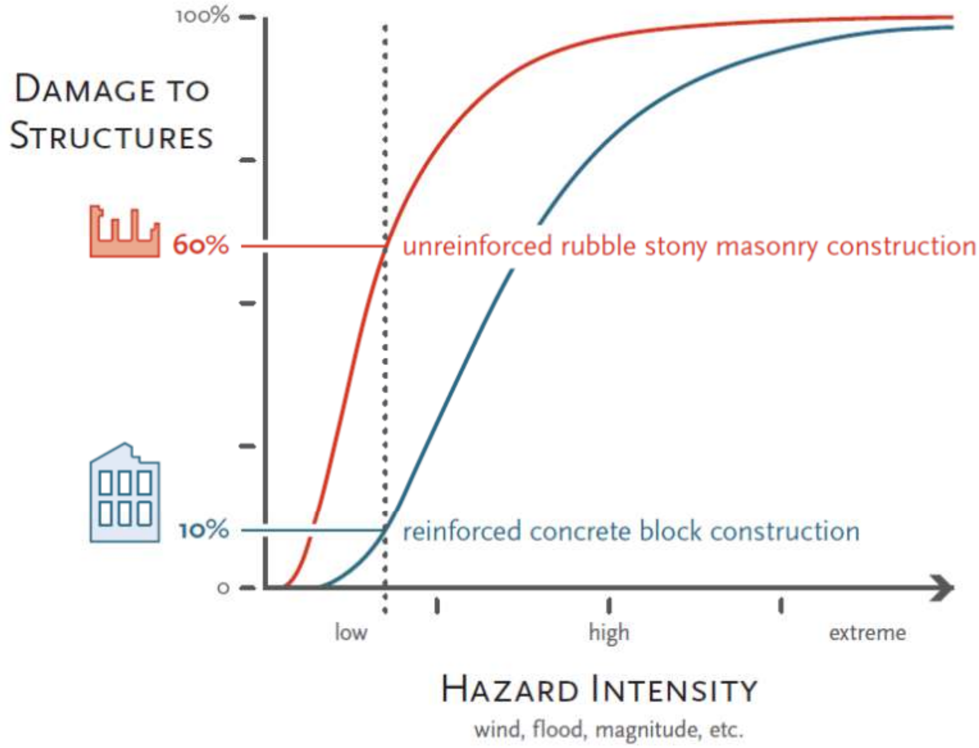


Figure 6. The relationship between hazard intensity and damage to structures: the same earthquake results in significantly different damage to a reinforced concrete block construction building than a unreinforced rubble stony masonry construction building.

The resolution of loss estimates will vary by model. For a global- or regional-scale model, the losses may resolve only total direct loss, whereas detailed site-specific models may estimate loss to a structure, its contents, and outlying buildings and include time-dependent losses such as business interruption. Site-specific fragility and vulnerability functions can account for differences in structural characteristics, such as roof covering and how it is attached. Loss estimates for contents, business interruption, and outlying structures tend to be just a simple function of loss to the main structure. Fatality estimates tend to be based on knowledge of local population and empirical relationships based on structural damage or hazard characteristics. For example, PAGER estimates fatality rates based on ground-shaking intensity and a region-specific fatality rate (Jaiswal and Wald, 2010). A somewhat similar approach is used for floods where the fatality rate is a function of flood depth (Boyd et al, 2010).

Generally, functions are defined using mean values and a coefficient of variation (CV) for a range of hazard intensities (three-second gust wind speed at 5km/hr intervals, peak ground acceleration at intervals of 0.1g, flood depth at 50cm intervals, etc.) The CV tends to decrease with more information. For example, a relatively precise (small CV) estimate of damage would be expected if one had a vulnerability function that accounted for the structural details of a building designed and built to withstand the expected hazard intensities. The damage estimate would have considerable uncertainty (large CV) if the structure were part of aggregate occupancy data. An alternative to a function that provides a mean and a CV is to use a damage probability matrix.

Methods of assessing damage vary greatly depending upon the type of exposure under consideration (e.g., people, buildings, livestock), the resolution of the exposure information (e.g., site specific or aggregate data at postal code resolution or lower), and the details available for a given resolution (e.g., is just occupancy known, or is detailed structural information available for a structure). In addition, the choice of whether to use a mean value or a sampled value for damage depends on the details of a risk analysis. A sampled value is generated using the mean and CV from the vulnerability function at the requisite hazard intensity. Other factors that can be incorporated into damage and loss estimates include when the structure was built, given that building practices and codes have changed over time, and the timing of an event, given that the use of a structure varies over the course of a day.

Often losses are adjusted for a variety of additional factors, such as having to replace a structure if damage exceeds a certain threshold; accounting for business interruption costs for commercial or industrial properties or additional living expenses for residential properties; incorporating the effects of demand surge on large or sequential disasters; and including damage to a structure's contents. A good overview of loss calculations is provided in "Risk Assessment for Risk Financing and Insurance" in part III.

Losses can be estimated ex ante and ex post. Modelled losses often differ from observed losses for a variety of reasons. One reason is that modelled losses represent only losses that are captured by the model, and these losses are dependent upon the quality (in terms of resolution and detail) of the exposure data. Another reason is that loss inventories are typically collected in an ad hoc manner. Better records of disaster losses would provide a range of benefits (see Box 11).

Box 11. The Uses of Loss Inventories

The terms "loss" and "damage" are often used interchangeably in reference to the adverse impacts of disasters on society, economies, and the environment. In the context of disaster loss inventories, losses are quantifiable measures expressed in either monetary terms (e.g., market value, replacement value) or counts such as number of fatalities and injuries. Damage is a generic term without quantitative characteristics, which does not mean that damage cannot be measured and expressed as a loss. The damage to a roof, for instance, can be translated into monetary terms (the cost of repairs), which in turn can be included in loss inventories.

Loss inventories are tools of accountability and transparency for disaster risk management (DRM). Despite their shortcomings (such as quality issues), they are provide a process for documenting a country's disaster losses. Loss inventories establish an historical baseline for monitoring the level of impact on a community or country. They make it possible to quantify the impact of individual hazards so that communities can focus disaster risk reduction efforts on frequently occurring hazards rather than the last disaster. Inventories allow governments to allocate resources by community or by hazard—that is, to prioritize areas of heightened risk (hot spots) or to focus on a particular hazard.

Loss information can also be harnessed for, and integrated into, risk assessments as part of efforts to promote community resilience. Loss and hazard profiles can inform land-use planning, zoning, and development decisions; local ordinances on building codes and housing density; taxation and budget decisions; and policy setting at local to national levels. A sound understanding of the drivers and causes of losses, as well as their societal, environmental, and economic implications, enables communities to manage hazards and disasters proactively rather than reactively.

Where loss inventories are consistently updated, the expanded historical record provides the basis for temporal studies and trend analysis of losses. High-quality loss data of good temporal and spatial resolutions can be coupled with ancillary data like DRM expenditures or demographic information. Combining these data makes it possible to evaluate the effectiveness of policies and to determine whether DRM expenditures are making a difference in loss trends, whether DRM efforts are effective, whether the mere presence of more people is driving the rise in losses, and whether climate change is affecting losses.

Source: Text is from Melanie Gall, Christopher T. Emrich, and Susan L. Cutter, "Who Needs Loss Data," input paper prepared for the 2015 Global Assessment Report on Disaster Risk Reduction, available at www.preventionweb.net/gar.

The historical record of loss mainly represents direct tangible losses produced by an event. Examples of direct tangible loss include damage to public and private infrastructure, commercial and industrial facilities, dwellings, and the contents of a structure. The cost of business interruption and the expense of housing a structure's inhabitants while a dwelling is repaired or replaced are considered indirect losses. Indirect losses generally arise from disruptions in the flow of goods and services, though such disruptions can produce positive as well as negative impacts. An example of a positive impact would be the increased demand for construction material. In contrast to tangible losses that are relatively easy to value, such as damage to structures or contents, intangible losses are associated with assets that are difficult to value. Examples include the loss of a life, damage to ecosystem services, and damage to sites related to cultural heritage. (Box 12 describes efforts to increase the resilience of heritage sites in Bhutan.) A full consideration of all direct, indirect, and intangible losses would produce much higher loss estimates than the more easily quantified and commonly seen records of direct loss.

Box 12. Incorporating Disaster Resilience into Cultural Heritage Buildings in Bhutan

Cultural heritage sites in Bhutan are considered "living" heritage sites because they continue to play an active role in the daily lives of the society. In addition to their architectural, aesthetic, historical, and archaeological significance, most of the cultural heritage sites in Bhutan have deep spiritual and cultural significance. In Bhutan, sites are deemed to be part of the country's cultural heritage based on their use as religious and communal centers as well as their antiquity.

Disasters have physically affected Bhutan's cultural heritage sites and have also disrupted centuries-old communal and social traditions. The great vulnerability of Bhutan's unique cultural heritage sites can be seen in the effect of events over the last 20 years, starting in 1994, when the Punakha Dzong (a huge structure built as a fortress in the 17th century) was severely damaged by a glacial lake outburst flood, through to earthquakes in 2009 and 2011, which damaged over 200 cultural heritages sites and thousands of rural dwellings.

It was estimated that the physical loss of the structures—mainly *lhakhangs* (temples) *and dzongs* (fortresses)—was US$13.5 million USD for the 2009 earthquake and US$6.96 million for the 2011 earthquake. These are large losses for a small developing country. The actual loss however, is much larger, since it goes beyond the loss of the physical structures and includes the loss of interior assets known as *nangtens* (paintings, sculptures, carvings, etc.). In many cases, these were one of a kind and irreplaceable. Moreover, the loss to spiritual values and traditions brought about by such disasters cannot be estimated in terms of monetary value.

Bhutan has a variety of programs and policies in place designed to protect its cultural heritage, but these have tended to be reactive rather than proactive. There are signs that this reactive approach is beginning to change, however. Several programs and trainings have been conducted to proactively address disaster resilience in cultural heritage sites, and good construction guidelines have been formulated by the national government to help prevent or minimize damage to cultural heritage sites during disaster events. A study of indigenous construction practices, begun after the 2009 earthquake, has been ongoing, and hundreds of carpenters and masons in the affected districts have been trained in safe construction practices to facilitate reconstruction of the damaged cultural heritage buildings and rural houses.

One positive and surprising outcome of this training program was the discovery that most of the local carpenters and masons already had the knowledge and skills needed for traditional—and more disaster-resilient—construction, though this knowledge had deteriorated over time as the traditional construction practices grew less popular and as the rapid completion of buildings was made a priority. It also appeared that in the interest of saving time and money, compromises were being made in the quality of materials as well as construction techniques, leaving structures even more vulnerable to disasters. The safe construction training program has highlighted the importance of safety for both homeowners and builders during the post-earthquake reconstruction phase.

The government of Bhutan faces some clear challenges as it seeks to improve the understanding of disaster management and the resilience of cultural heritage sites, with access to appropriate technical skills and financial resources to monitor and sustain the program the greatest challenge.

Source: Dechen Tshering (World Bank)

It can be difficult to anticipate and quantify the potential for indirect losses despite their size. The 2011 Tohoku earthquake and tsunami in Japan and flooding in Thailand offer an example of the global indirect impacts from local events. The Japanese tsunami was much more spectacular and had dramatic news coverage; however, the Thailand floods caused much more damage to industrial supply chains on a global basis.

The 2011 Tohoku earthquake and tsunami slowed the Japanese and global economies. For the full year of 2011 the GDP of Japan was 0.7 percent lower than in 2010 (Trésor-Economics, 2012). The largest quarterly decline (1.8 percent) occurred in the first quarter when the earthquake and tsunami struck. There was a rebound in the third quarter followed by a decline in the fourth quarter that was associated with the Thailand floods. On a global basis there was negligible impact on full-year GDP because of a rebound in the second half of 2011. In addition, spending on public sector reconstruction resulted in a positive impact in 2012.

In contrast to the Japanese disaster, the 2011 flooding in Thailand was estimated to have reduced global production by 2.5 percent (UNISDR, 2012) and reduced Thailand's GDP growth rate from 4.0 percent to an expected 2.9 percent.[24] The reason Thailand's flooding had such a dramatic impact on the global economy is that industrial parks outside of Bangkok were a critical node in the global supply chain for the production of automobiles and electronics (Haraguchi and Lall, 2013).

As Box 11 suggests, collecting and analyzing damage and loss data from previous disasters provides valuable insight into the understanding of physical, social, and economic vulnerability. Collecting information post-disaster can build damage scenarios to inform planning processes, assess the physical and financial impact of disasters, develop preparedness measures, and facilitate dialogue for risk management. A number of global and national disaster loss systems, some open and some proprietary, record the losses associated with disasters; these are listed in Table 4. For more detailed information, see the United National Development Program survey of loss databases (UNDP, 2013).

[24] See World Bank (2012). Information on Thai floods is from Haraguchi and Lall (2013).

Table 4. Sources of Disaster Loss Data

Database name	Description	Direct link
Regional		
Andean Information System for Disaster Prevention and Relief (SIAPAD)	http://www.gripweb.org/gripweb/?q=countries-risk-information/databases-information-systems/andean-information-system-disaster	http://www.siapad.net/
DesInventar	http://www.desinventar.org/	See countries at http://www.desinventar.org/en/database
Armenia Emergency Management	Stand alone	CMC Nikolay Grigoryan (nik@emergency.am)
Australia Disasters Database	http://www.emknowledge.gov.au/disaster-information/	http://www.emknowledge.gov.au/disaster-information/
Disaster Incidence Database (DIDB) of Bangladesh	http://www.gripweb.org/gripweb/?q=countries-risk-information/databases-information-systems/disaster-incidence-database-didb-bangladesh	http://www.dmic.org.bd/didb
Canadian Disaster Database	http://www.publicsafety.gc.ca/cnt/rsrcs/cndn-dsstr-dtbs/index-eng.aspx	http://cdd.publicsafety.gc.ca/
Caribbean Disaster Events Database	http://www.cdema.org/index.php?option=com_content&view=article&id=110&Itemid=88	
Calamidat	http://calamidatph.ndrrmc.gov.ph/dm/web/	
Sheldus	http://webra.cas.sc.edu/hvri/products/sheldus.aspx	http://webra.cas.sc.edu/hvriapps/sheldus_web/sheldus_login.aspx
US Billion Dollar Weather/Climate Disasters	http://www.ncdc.noaa.gov/billions/overview	http://www.ncdc.noaa.gov/billions/events
Damage and Needs Assessment system (DANA) of Vietnam	http://www.gripweb.org/gripweb/?q=countries-risk-information/databases-information-systems/damage-and-needs-assessment-system-dana	http://www.ccfsc.gov.vn/KW6F2B34/Disaster-Database.aspx
Global		

Database name	Description	Direct link
GLIDE	http://www.glidenumber.net/glide/public/about.jsp	http://www.glidenumber.net/glide/public/search/search.jsp
EM-DAT	http://www.emdat.be/about	http://www.emdat.be/database
NatCatSERVICE	https://www.munichre.com/touch/naturalhazards/en/natcatservice/default.aspx	https://www.munichre.com/touch/portal/en/service/login.aspx?cookiequery=firstcall
Sigma	http://www.swissre.com/sigma/	http://www.swissre.com/sigma/
Aon Benfield	http://catastropheinsight.aonbenfield.com/Pages/Home.aspx	http://thoughtleadership.aonbenfield.com

Tools for Risk Modelling[25]

Since 2005, the number of nonproprietary hazard and risk modelling tools has grown rapidly as part of the global movement to understand and manage risk. These tools allow users to calculate risk and better understand, prepare for, and mitigate the likely impact of potential disasters.

Given the plethora of tools available, and the variety of reasons for seeking to assess risk, users may find it challenging to choose the appropriate tool for their purposes and capacities. Some attempts have been made to evaluate the many modelling tools that are available to users at no cost, but these efforts did not include in-depth review or testing. Thus the evidence base to differentiate tools for different purposes and end uses has been lacking.

To address this gap and meet the need for a systematic review of tools against a set of established criteria, the Global Facility for Disaster Reduction and Recovery (GFDRR) and World Bank undertook testing and evaluation of free hazard and risk modelling software using a consistent approach. The review considered over 80 open source[26] or freely available software packages in a preliminary analysis, and then undertook in-depth analysis of 30 packages.[27]

The overall objective of the review was to improve the capacity of national and local governments and international development professionals working in DRM to objectively select the right computational modelling tool for the hazard and risk question being addressed. Recognizing that each package has advantages and disadvantages depending on its use, the evaluation aimed to determine the suitability of the different tools for different objectives and end-users. For example, a model that allows for a very robust calculation of hazard may be difficult for an entry-level user, or user without a science or engineering background, to understand and operate; and a model that aims to provide a qualitative assessment of risk may not be appropriate for users seeking information based on precise hazard parameters.

The review carried out an evaluation of freely available computational hazard and risk modelling tools for four main groups of perils: earthquakes (including secondary effects such as liquefaction, landslide, and fire); floods (hydraulic and hydrologic models; flow, water modelling); cyclones/hurricanes/wind cyclones (wind modelling); and tsunamis and cyclone surge (wave modelling).

---

[25] This section describes, and is based heavily on, the review of risk modelling tools in James Daniell, Alanna Simpson, Abigail Baca, Oscar Ishizawa, Andreas Schäfer, and Rashmin Gunasekera, "Open Source Software Package Review for Risk of Natural Hazards," GFDRR, 2013. The figure and all the tables that illustrate the findings of the review are from this source.

[26] "Open source" can mean many things under the large array of GNU and Creative Commons licensing combinations. For further discussion on this point, see Box 1 and the section on risk modelling in part IV.

[27] Software was expected to be suitable for running on a PC.

The evaluation of software packages included the following steps:

1. Evaluation criteria were developed for open access software packages based on Daniell (2009) and through consultations.

2. A preliminary review of available open source packages worldwide in the four peril types was undertaken. More than 80 software packages were downloaded and initial checks made concerning availability, source code, active or inactive status, and so on.

3. An initial multi-criteria analysis was undertaken in order to select the packages to review in depth for each peril.

4. The 30 selected packages were installed and tested using tutorials, data sets, and examples in order to create outputs. This step included noting advantages and disadvantages of these software packages, and then filling out a detailed final set of about 180 criteria under 11 key classification themes (open source, GUI [graphical user interface], software documentation, technology, exposure component, vulnerability, hazard, risk, post-event analysis, scenario planning, and output). A sample page of the review (for MAEvis/mHARP) is shown in Figure 7.

5. The answers to these criteria were then converted to a numeric system that used between two and five rating levels for each of the 180 different criteria. This approach used fuzzy logic to rank the software for different users, from basic to advanced.

6. A preliminary assessment was undertaken in order to rank each software package as a whole for general use. The results can be adapted for specific needs and situations, and—given the subjective element to some of the criteria—the criteria and answers can be changed.

MAEviz/mHARP

Software Name	Peril	License	Curr. Version	Open Source	Operating Systems
MAEviz	**Earthquake**	**Single User**	**V3.1.1 Build12**	Yes, svn	Win, Mac, Linux

Preferred Specific Information:

Coding Language	Software Modules (see below in appendix for more info)	Manual	GUI	Help
Java using Eclipse RCP	**Many risk modules – NCSA GIS, Eclipse RCP, MAEviz.**	YES	**YES**	**YES**

Goal of the software

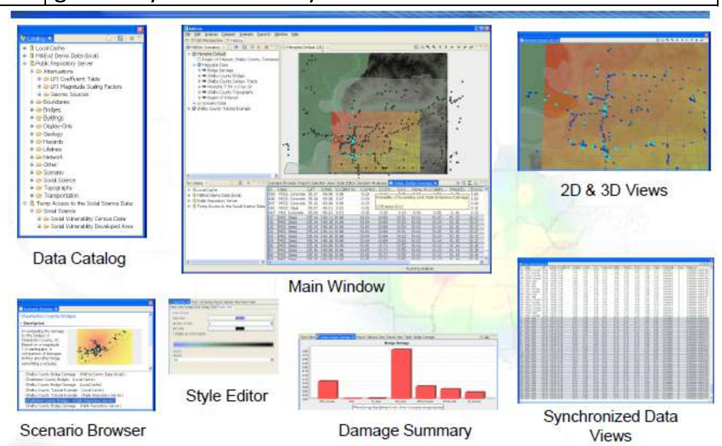
MAEViz was developed to perform seismic risk assessment in the Mid America region by the Uni. Illinois. Another HAZUS-based application, but applied to the middle states of the U.S., is MAEViz (Mid America Earthquakes visualization). At first glance, it seems specialised; however, the huge potential is shown by the flowchart of analysis procedures (48 and counting) and its complete HAZUS system, including more detailed algorithms. The visual driven system of MAEViz uses a combination of Sakai (an open source web portal), NEESgrid (a framework of tools to allow researchers to collaborate) and SAM (Scientific Annotation Middleware) in order to allow for users to add their own hazard data. It is easily extendable, with the EU project SYNER-G adding a large fragility function manager to it, in addition to other tools.

File types used:-

Hazard	Vulnerability	Exposure	**Key Hazard Metrics**
.txt, .csv	.xml	*.shp	Spectral ordinates are used in terms of PGA and Sa. This is calculated using GMPEs and source-site distance, source geometry and seismicity.

Description of Software Risk Outputs

Damage estimates can be established with options for multiple mitigation strategies, testing of scientific and engineering principles and also estimating the earthquake hazard impact on lifelines, social or economic systems based on HAZUS and extra analysis.
The outputs are all types of economic losses (direct, indirect, downtime, business interruption), social losses (social vulnerability, fatalities, injuries, homeless and management options. A detailed list of the modules is shown in the appendix. Simple reports, and data views are given. It creates all scenario outputs (disaggregated and not).



An overview of the MAEviz options (McLaren et al., 2008)

!

Advantages and Disadvantages

- ✓ It is completely open source and features inbuilt GIS - good format of software with the GIS user interfaces.
- ✓ Is easily the best software for scenario risk assessment and decision support (mitigation, benefit-cost).
- ✓ It has an outstanding array of modules that provide end analysis such as shelter needs or business interruption.
- ✓ Easy to use for basic users with a large array of infrastructure types which can be from hazard to loss.
- ✓ Easily extendable, combining detailed hazard, detailed vulnerability and then management and risk modelling.
- It is currently only tuned for deterministic analysis but the extension of this to probabilistic is the key.

Recommendations for improvements for greater utility

mHARP will give this fantastic software an additional use. It should be integrated with Deltares or other risk software, given the common structure. It has already been integrated in HAZturk and SYNER-G.
A combination with EQRM in terms of probabilistic modelling would be useful.
An InaSAFE style command system could simplify it even further for the most basic of users, but it is user friendly enough to not necessarily need to be changed.

Evaluation (followed by rank using the criteria in Section 3) – 1 = top rank, 2 = 2nd in rank etc.

Name	**OS**	**GU**	**SW**	**TE**	**EX**	**VL**	**HE**	**RK**	**PS**	**FC**	**OU**
Rank	**1**	**1**	**2**	**7**	**1**	**1**	**6**	**1**	**1**	**3**	**1**

Figure 7. Sample software package review.

Some key results from the evaluation are summarized in Table 5–Table 8. For each of the four hazards, the tables show how selected software packages scored in each of the 11 classification areas. Given that most packages are under continuous development, however, specific scores (and the rankings derived from them) will likely change over time as new features are added. For example, the tropical cyclone risk model TCRM is currently under construction with extension to a risk module, and OpenQuake will add a user-friendly GUI to broaden its appeal to basic and intermediate users. Once these changes are in effect, both packages will be ranked higher.

Table 5. Earthquake Modelling Tools: Results against Evaluation Themes

Evaluation Theme (total possible points)	CAPRA	RiskScape	Hazus-MH	InaSAFE[a]	OpenQuake[b]	EQRM	SELENA	MAEViz / mHARP
Open source (120)	111	90	70.5	108	102	106.5	105	114
GUI (9)	6.75	8	9	6	1	0	5	9
Software documentation (56)	47	46	44	52	45	48	44	48
Technology (10)	8	7	5	8	6	7	6	5
Exposure component (68)	51	53	50	49	48	56	42	56
Vulnerability (68)	46	40	51	47	50	47	46	58
Hazard (156)	103.5	79.5	90	61.5	126	111	79.5	81
Risk (56)	30	48	44	26	43	37	36	47
Post-event analysis (12)	4	5	4	4	4	4	3.5	7
Scenario planning (6)	3	5	4	4	4	5	3	4
Output (24)	16	18	22	8	8	14	12	24
Total	426	400	394	374	437	436	382	453

a. Some components of InaSAFE were modelled using the 2013 version.
b. Some components of OpenQuake were modelled using the 2014 version.

Table 6. Cyclone Modelling Tools: Results against Evaluation Themes

Evaluation Theme (total possible points)	Hazus-MH hurricane model	RiskCape	ERN-Hurricane	TCRM
Open source (120)	64.5	91.5	106.5	93
GUI (9)	7.5	8	7	8.5
Software documentation (56)	42	40	47	45
Technology (10)	5	8	7	5

Exposure component (60)	37	42	40	0
Vulnerability (64)	50	44	43	0
Hazard (126)	108	81	81	99
Risk (56)	43	30	28	0
Post-event analysis (12)	8.5	6.5	4.5	3
Scenario planning (6)	4	5	3.5	1
Output (24)	20	20	17	13
Total (543)	390	376	385	268

Table 7. Flood Modelling Tools: Results against Evaluation Themes

Evaluation Theme (total possible points)	ERN-Flood	Kalypso	HEC-RAS/ HEC-HMS	BASE MENT	NoFDP IDSS	Sobek 1D/2D HIS-SSM	Delft-3D-FLOW	Risk Scape Flood	Hazus Flood	InaSAFE	TELEMAC
Open source (120)	97.5	112.5	76.5	76.5	100.5	115.5	114	93	76.5	103.5	112.5
GUI (9)	5.5	9	8.5	4.5	8.5	7	7	7.5	8.5	7.5	7
Software documentation (88)	67	78	74	50	56	74	72	58	60	73	68
Technology (6)	6	5	6	5	4	6	6	6	5	6	5
Exposure component (68)	44	44	52	30	51	48	48	51	49	49	16
Vulnerability (72)	53	65	67	0	45	45	37	58	60	37	0
Hazard (174)	140	150	168	108	124.5	160.5	154.5	103.5	135	54	136.5
Risk (56)	27	40	48	8	33	38	38	29	40	22	0
Post-event analysis (18)	6.5	10	10	4.5	11	10	10	6	11	6	5
Scenario planning (6)	3	6	5	0	5	6	6	6	5	5	3
Output (24)	20	20	24	12	22	22	22	18	24	14	8
Total (641)	469	540	539	299	461	532	515	436	474	377	361

Table 8. Overall Wave/Storm Surge/Tsunami Modelling Tools: Results against Evaluation Themes

Evaluation Theme (total possible points)	SLOSH	Delft-3D-WAVE (SWAN)	InaSAFE Tsunami	OsGEO Tsunami	AnuGA (Tsudat)	RiskScape (Tsunami)	CAPRA - Surge/Tsunami	TOMAWAC
Open source (120)	101	106.5	112.5	73.5	88.5	88.5	109.5	112.5
GUI (9)	7	8.5	8.5	6	8	8	7	7
Software documentation	49	48	50	38	46	40	47	46

(56)								
Technology (10)	5	6	7	5	6	8	7	5
Exposure component (60)	0	0	46	28	38	42	38	12
Vulnerability (64)	0	0	40	18	0	44	42	0
Hazard (108)	57	45	46.5	36	76.5	54	60	60
Risk (56)	0	4	39	7	8	30	28	0
Post-event analysis (14)	6.5	4.5	7.5	6	8.5	5.5	4.5	5
Scenario planning (6)	5	2	4	2	2.5	5	3	4
Output (24)	12	10	18	14	16	18	16	10
Total (527)	242	235	379	234	298	343	362	262

One benefit of the fuzzy logic approach to ranking was that it allowed testing and evaluation of the modelling tools for different users. The most suitable packages for each of the four peril types are shown for advanced users in Table 9, for intermediate users in Table 10, and for inexperienced users in Table 11.

Table 9. Most Appropriate Modelling Tools for Advanced Users

Rank	Earthquake	Cyclone	Flood	Tsunami
1	MAEViz / mHARP	Hazus-MH	Kalypso	InaSAFE Tsunami
2	OpenQuake	ERN-Hurricane	HEC Suite	CAPRA - Surge/Tsunami
3	EQRM	RiskScape	Sobek Suite 1D/2D w/HIS-SSM	RiskScape (Tsunami)
4	CAPRA	TCRM*	Delft-3D-FLOW	AnuGA (Tsudat)
5	RiskScape		Hazus Flood	TOMAWAC

Table 10. Most Appropriate Modelling Tools for Intermediate Users

Rank	Earthquake	Cyclone	Flood	Tsunami
1	MAEViz / mHARP	ERN-Hurricane	Sobek Suite 1D/2D with HIS-SSM	InaSAFE Tsunami
2	CAPRA	Hazus-MH Hurricane Model	Kalypso	CAPRA - Surge/Tsunami
3	OpenQuake	RiskScape	Delft-3D-FLOW	RiskScape (Tsunami)
4	RiskScape	TCRM*	Hazus Flood	AnuGA (Tsudat)
5	Hazus-MH		ERN-Flood	TOMAWAC

Table 11. Most Appropriate Modelling Tools for Inexperienced Users

Rank	Earthquake	Cyclone	Flood	Tsunami
1	InaSAFE	RiskScape	NoFDP IDSS	InaSAFE Tsunami
2	RiskScape	ERN-Hurricane	Kalypso	AnuGA (Tsudat)
3	MAEViz / mHARP	Hazus-MH Hurricane	RiskScape Flood	RiskScape (Tsunami)

		Model		
4	CAPRA	TCRM*	InaSAFE	CAPRA - Surge/Tsunami
5	Hazus-MH		Sobek Suite 1D/2D with HIS-SSM	TOMAWAC

The evaluation also determined which hazard-only modelling tools were strongest. These are shown in Table 12.

Table 12. Top Five Hazard-Only Modelling Tools

Rank	Earthquake	Cyclone	Flood	Tsunami
1	OpenQuake	Hazus-MH	Sobek Suite 1D/2D with HIS-SSM	AnuGA (Tsudat)
2	EQRM	TCRM	HEC-RAS/HEC-HMS	CAPRA - Surge/Tsunami
3	CAPRA	ERN-Hurricane	Delft-3D-FLOW	TOMAWAC
4	MAEViz / mHARP	RiskScape	Kalypso	SLOSH
5	Hazus-MH		ERN-Flood	InaSAFE Tsunami

Essentially, all these rankings are simply a way to aid users in selecting suitable software packages. It is highly recommended that users test as many packages as possible in order to make an informed decision about which software is right for their purposes. Users at all levels should understand the sensitivity of models to changes in inputs and would probably benefit from training; see Box 13 and the case studies in Part III that focus on training around risk assessment.

Box 13. Training in Use of Risk Models: The GEM Perspective

While specific risk modelling software packages may be more or less appropriate depending on the experience level of the end-user, users at any level may benefit from training. It is important for users of hazard and risk models to understand the sensitivity of the models they are using and to be aware of the large impact on assessment results that changes in the input parameters can have. Figure 8 shows that the OpenQuake engine may produce two different hazard maps for Japan depending on the user-defined modelling decisions (in this case related to the probability of a Tohoku-like event occurring in the next 50 years).

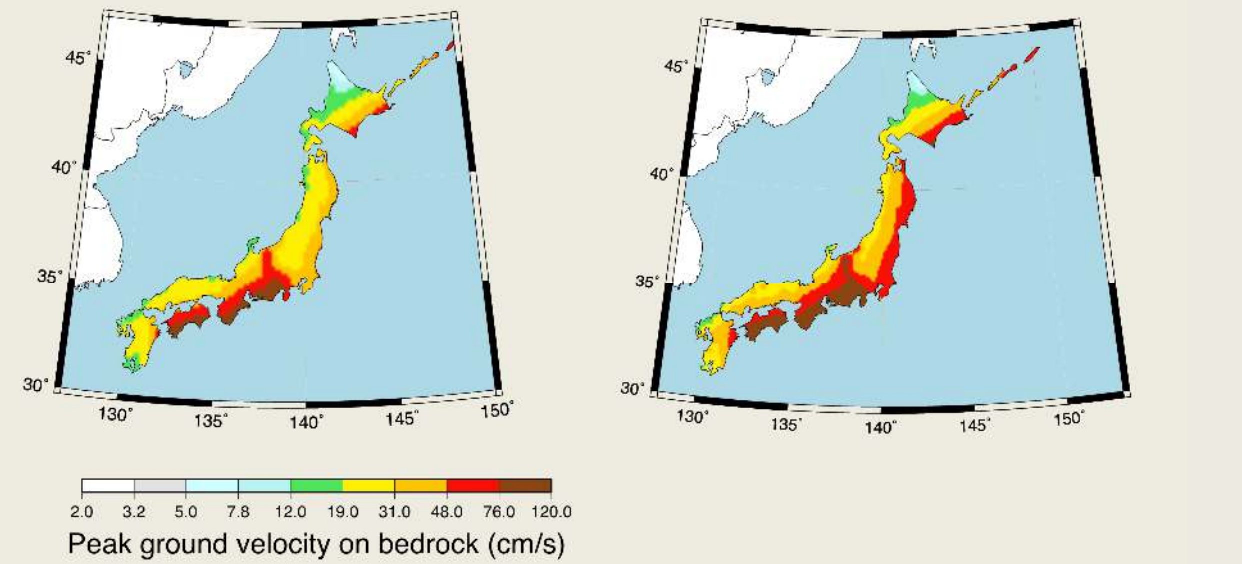


Figure 8. The sensitivity of hazard results to input model modifications, illustrated with a preliminary OpenQuake engine implementation of the Japan 2013 model.

Source: GEM Foundation, using data from http://www.j-shis.bosai.go.jp/en/. ©GEM Foundation. Used with permission; further permission required for reuse.

Note: The left plot shows a 475-year return period hazard map based on the original Japan 2013 model (based on a 0 percent probability of occurrence in the next 50 years for a Tohoku-like earthquake); the right shows the same results after the probability of occurrence for a Tohoku-like earthquake in the next 50 years was increased from 0 percent to 10 percent.

In governments of developing countries, where capacity in conducting seismic hazard and risk assessment, using probabilistic modelling, and understanding results tends to be especially low and sporadic, training could be most beneficial. But even governments in developed countries need access to technical advice, including the expertise of their own specialists.

The Global Earthquake Model has developed a variety of approaches to training users in its tools. It holds workshops targeted to users at the same level of experience and education, and it hosts professionals at the GEM secretariat for hands-on training that may last for weeks or months. For local experts in developing countries, GEM has found that “learning by doing” has been the most effective way to gain necessary skills and to develop needed capacity. Offering training of this type requires a few years of ongoing engagement and is possible only through strong partnerships at both the institutional and individual levels. Through its Earthquake Model for the Middle East (EMME) project, for example, GEM offered local technical experts their first exposure to probabilistic earthquake modelling. Although the speed of developing hazard and risk assessment might suffer initially under the “learning by doing” approach, the newly built local capacity for maintaining, understanding, and advising governments is invaluable.

Source: Helen Crowley, Nicole Keller, Sahar Safaie, and Kate Stillwell (GEM Foundation).

Creating Platforms and Partnerships to Enable the Development of Risk Assessments

The move to collect, analyze, and produce risk information for current and future climates is gaining momentum among various actors at various levels, from the individual to the global. One consequence of this trend is a growing need for all actors involved with risk to cooperate, communicate, and form partnerships across geographic, institutional, and disciplinary boundaries. Fortunately, much progress has been made in this regard.

The recognition that cooperation and partnership are crucial for building resiliency motivated the formation in 2010 of the Understanding Risk community, whose more than 3,000 members span the globe and include experts and practitioners across many professions and disciplines (see Box 14 for more detail). Information sharing is critical to this community, which meets every two years to discuss best practices and promising innovations in disaster risk assessment and to give members an opportunity to build and strengthen partnerships and spur further innovations.

Box 14. The Understanding Risk Community

Understanding Risk (UR) is an open and global community of experts and practitioners in the field of disaster risk assessment. UR community members include representatives of government agencies, the private sector, multilateral organizations, nongovernmental organizations, community-based organizations, research institutions, and academia. Every two years, the Global Facility for Disaster Reduction and Recovery convenes the UR Forum—a five-day event designed to showcase best practices and the latest technical know-how in disaster risk assessment. The forums provide organizations with the opportunity to highlight new activities and initiatives, build new partnerships, and foster advances in the field.

The first UR Forum, held in Washington, DC, in June 2010, was attended by 500 practitioners representing 41 countries. The goal of the forum was to showcase progress in the field of disaster risk assessment and to promote the sharing of ideas and the exchange of knowledge through a series of technical sessions led by experts. During the forum, the GEM held its annual outreach meeting, and Random Hacks of Kindness (RHoK)—a group that brings together software programmers to develop applications for DRM challenges—organized its first global hackathon.[a] Based on the success of the forum, the UR series was launched.

UR 2012, held in Cape Town from July 2 to July 6, was attended by 500 risk assessment experts from more than 86 countries. The forum showcased new tools for decision makers, strengthened regional and global partnerships, and built technical capacity in the Africa region through a series of training events. UR 2012 was also a testimony to the tremendous progress in understanding risk since 2010: crowdsourcing, a new topic in 2010, by 2012 was being mainstreamed and used to support risk assessment for financial applications intended to make governments, businesses, and households more financially resilient to risk. A consensus about the need for data that are more open also emerged, with many initiatives demonstrating that the trend toward open data would be broadly beneficial. The forum also highlighted new tools and methodologies for building resilience, and in particular called attention to the extent to which these tools are now available to nonspecialists.

As a result of the 2012 UR Forum, participatory mapping projects have been implemented in Nepal and Malawi, and open geospatial data platforms have been launched in the Horn of Africa, Haiti, and Sri Lanka. The 2012 forum also lead to the first national UR event, held in Brazil in November 2012. This event brought together Brazilian experts and practitioners to discuss the challenges the country faces in understanding its disaster risk and to raise the profile of the topic nationally. In May 2014, Haiti will hold a national UR Forum to bring together nontraditional partners and tackle the challenge of economic, social, and environmental vulnerability in the country.

The next global UR Forum, in London between June 30 and July 4, 2014, takes "Producing Actionable Information" as its theme; it will focus on how to translate and communicate scientific information into actionable decisions on the ground. UR 2014 will continue to foster the growth of partnerships and spur the advances in risk assessment needed for achieving sustainable development and building resilience.

The UR Forums are clearly meeting a need. Participants report that the mix of backgrounds, interests, and types of expertise they encounter, along with the opportunity to share ideas and information, stimulate their thinking and promote creative solutions to problems. Discussions taking place at the forums are being shared beyond the UR community by means of a post-conference publication (*Understanding Risk: Best Practices in Disaster Risk Assessment*). The UR community website (www.understandrisk.org) also serves as a platform for incubating innovation and forging partnerships in the disaster risk assessment field. Membership in the community has grown from about 1,000 in 2010 to more than 3,000 in 2014.

a. RHoK is a partnership of Google, Microsoft, Yahoo, the National Aeronautics and Space Administration (NASA), and the World Bank. See the website at http://www.rhok.org/.

Source: Emma Phillips (GFDRR).

The Global Earthquake Model suggests some of the benefits that arise when developing and applying knowledge is treated as a cooperative endeavor.[28] GEM was created specifically as a public-private partnership because its founders judged that structure to be optimal for its purposes. They recognized that risk holders reside in both sectors; that advocacy, models, and information are necessary for mitigating earthquake risk; that the project could achieve its goals only by combining funds from both sectors; and that the involvement of both sectors would lend the project credibility and momentum. GEM's formal partners include 13 private companies, 15 public organizations representing nations, and 9 international organizations. Various other associate participants and organizational members of international consortia also deliver global projects.

One notable aspect of GEM as a public-private partnership is its success in unifying diverse perspectives under a common interest. The partnership works because both sectors seek the same outcome: credible, accessible risk information that is widely used and understood. At the same time, the two sectors have somewhat different focuses. Private sector partners generally seek to reduce future financial losses (through strict building codes and through open data that ensure common expectations of loss); to create new markets for insurance products (requiring worldwide intercomparable loss data and accessible risk information); and to build customer demand (through increased engagement among trusted local experts and increased understanding of risk by the public). Public sector partners, including nongovernmental organizations, seek to reduce future casualties, economic loss, and disruptions (through DRM

---

[28] This account of GEM's institutional structure was provided by Helen Crowley, Nicole Keller, Sahar Safaie, and Kate Stillwell of GEM.

and land-use policies and retrofitting of public buildings); to implement policy (requiring broad awareness of risk and hence accessible data); to base decisions on scientifically defensible hazard and risk estimates; and to reduce the need for post-disaster aid (requiring free, open information to support markets for financial risk transfer mechanisms and lower losses as a result of risk reduction).

The perspectives and positions of the two sectors do not differ as widely as GEM's founders initially anticipated. In practice, differences in perspective varied within each sector as much as or more than they did across sectors.

Yet another collaboration that aims to build better risk information is the Willis Research Network, which links more than 50 international research institutions to the expertise of the financial and insurance sector in order to support scientists' quantification of natural hazard risk. More detail on the network is in Box 15. For an account of another kind of collaboration—one in which scientists, engineers, and developers of building codes collaborated with officials in planning, governance, and public service to promote a more earthquake-resilient city—see the account of participatory earthquake risk assessment in Dhaka in Box 16.

Box 15. Willis Research Network

The Willis Research Network was launched in 2006 to better integrate science, insurance, and resilience.[a] Starting with a partnership of seven UK universities, the network has now grown to include more than 50 international research institutions, making the Willis Research Network one of the world's largest collaborations between science and the financial sector.

The network's research program is organized across four pillars: economic capital and enterprise risk management; natural hazard and risk; man-made liability risks; and core technologies and methods. A focus on accurately quantifying natural hazard risk is a priority for Willis Re and the insurance sector as a whole, given that the solvency capital of most non-life insurance companies is strongly influenced by their exposure to natural catastrophe risk.

Research supported by the network has resulted in hundreds of peer-reviewed academic articles; it has also led to improved insurance sector models, methodologies, and transactions that enable the financial market to better understand and cover risk. Moreover, by openly sharing research findings, the network has made it possible for other private and public institutions to improve their efforts to identify, evaluate, and manage disaster risk.

The Willis Research Network's principles and practices—its clear articulation of critical research requirements, its protection of academic and scientific independence, and its recognition of the time frames consistent with academic achievement—explain its ability to catalyze improvements in risk assessment, and exemplify the strengths of academic and private sector partnerships.

a. The network was formed to support the academic and analysis focus of Willis Group Holdings.

Source: Willis Research Network website (www.willisresearchnetwork.com), ©Willis Group Holdings. Used with permission; further permission required for reuse.

Box 16. Participatory Earthquake Risk Assessment in Dhaka

While Bangladesh can rightfully claim major accomplishments in flood and cyclone risk reduction, its urban earthquake risk has not been adequately considered. Bangladesh lies on the seismically active northeastern Indian plate, which is subject to moderate- to large-magnitude earthquakes. The nearest major fault line is believed to run less than 60km from the capital city of Dhaka. Research suggests that an earthquake of up to magnitude 7.5 is possible in the area. Earthquake risk in Bangladesh is increasing with rapid and uncontrolled urbanization, particularly in and around Dhaka, which with 26,000 residents per square kilometer is one of the world's densest cities.[a]

There has been no major earthquake in living memory, which has frustrated efforts to build consensus around the need to invest in measures to increase urban resilience to earthquake. Moreover, the governance of cities in Bangladesh, particularly Dhaka, is very complex. Responsibility for urban planning, governance, and public service provision is spread out across among many different agencies. Agencies' roles are not clear and often overlap. Moreover, political affiliations can affect capacity to implement policy and govern the city. Thus any initiative intended to address Dhaka's vulnerability to earthquake required engagement with multiple stakeholders and a common understanding of risk.

A participatory earthquake risk assessment over the last two years in Bangladesh[b] has successfully built consensus on disaster risk across agencies, institutions, and technical experts in their pursuit of earthquake risk reduction and is now being leveraged to develop specific investments to enhance urban resilience. The program has increased the collective understanding of risk, promoted collaboration in identifying major disincentives for resilient development, supported planning for prevention, and has gradually shifted the country toward a more proactive approach to resilient development.

A successful aspect of this program involved ensuring that stakeholders from over 40 different agencies working in Dhaka guided each step of the project and assessed the collective progress toward achieving project goals. Participants in the project were assigned to one of three groups depending on their job and type of expertise: a focus group, an advisory committee, or a scientific consortium. Focus group members included representatives from key national and local organizations involved in planning or in developing and implementing construction codes; therefore their role involved engaging in data collection, analysis, and validation. The advisory committee is made up of policy makers and decision makers from various government and nongovernment institutions who provide overall guidance and oversight to project participants. The scientific consortium is made up of local experts in earthquake engineering, geology and geophysics, land use and regional planning, DRM, law and business administration, environmental management, and other closely related fields; collectively they provide guidance on scientific and technical matters.

Next steps include the development of multiyear process that will develop several decision-making tools for mitigating the impact of earthquake hazards by reducing structural and nonstructural vulnerability. Diverse working groups will mobilize resources and implement the project; existing earthquake hazard and vulnerability data will be compiled; a uniform data platform will be developed; and an information, education, and communication program will be established. Building on this foundation, the project will produce (a) an earthquake hazard, vulnerability, and risk analysis; (b) an assessment of legal and institutional arrangements; and (c) a guide to incorporating earthquake risk management into land-use planning.

a. Data are for Dhaka City Corporation; if the entire Dhaka Metropolitan Area is taken into account, Dhaka's population density is 13,500 residents per square kilometer (World Bank, 2012a).

b. The assessment is called the Bangladesh Earthquake Risk Mitigation Program and is a World Bank program supported by the GFDRR.

Source: Swarna Kazi (World Bank).

References

Adams, B., and C. Huyck. 2006. Remote Sensing Technologies for Disaster Emergency Response: A Review. In: *Acceptable Risk Processes: Lifelines and Natural Hazards*, edited by Craig E. Taylor and Erik Vanmarcke. New York: ASCE Publications.

Allen, T. I., D. J. Wald, P. S. Earle, K. D. Marano, A. J. Hotovec, K. Lin, and M. G. Hearne. 2009. An Atlas of ShakeMaps and Population Exposure Catalog for Earthquake Loss Modeling. *Bulletin of Earthquake Engineering* 7: 701–18.

ATC (Applied Technology Council). 1985. *ATC-13: Earthquake Damage Evaluation Data for Californi*a. Washington, DC, U.S.: ATC.

Bhaduri, B., E. Bright, P. Coleman, and M. L. Urban. 2007. LandScan USA: A High-resolution Geospatial and Temporal Modeling Approach for Population Distribution and Dynamics. *GeoJournal* 69: 103–17.

Boyd, E., M. Levitan, and I. van Heerden. 2010. Improvements in Flood Fatality Estimation Techniques Based on Flood Depths. In: *Wind Storm and Storm Surge Mitigation*, edited by Nasim Uddin, 126–39. ADCE Libraries. doi:10.1061/9780784410813.ch11.

Brinkman, Jan Jaap, and Marco Hartman. 2008. Jakarta Flood Hazard Mapping Framework. World Bank. (unpublished). http://www.hkv.nl/documenten/Jakarta_Flood_Hazard_Mapping_Framework_MH.pdf.

Cardona, O. D., M. G. Ordaz, E. Reinoso, L. E. Yamin, and A. H. Barbat. 2012. CAPRA–Comprehensive Approach to Probabilistic Risk Assessment: International Initiative for Risk Management Effectiveness. In: *Proceedings of the 15th World Conference on Earthquake Engineering*, Lisbon, Portugal. http://www.iitk.ac.in/nicee/wcee/article/WCEE2012_0726.pdf.

Chapman, K. 2012. Community Mapping for Exposure in Indonesia. Humanitarian OpenStreetMap Team. http://hot.openstreetmap.org/sites/default/files/CM4E-Indo-en.pdf.

Coburn, A., and R. Spence. 2002. *Earthquake Protection*. Chichester, UK: Wiley.

Coburn A. W., R. J. S. Spence, and A. Pomonis. 1992. Factors Determining Human Casualty Levels in Earthquakes: Mortality Prediction in Building Collapse. In: *Proceedings of the First International Forum on Earthquake-Related Casualties.* Madrid, Spain.

Daniell, J. E. 2009. *Open Source Procedure for Assessment of Loss Using Global Earthquake Modelling (OPAL Project)*. CEDIM Earthquake Loss Estimation Series, Research Report No. 09-01. CEDIM. Karlsruhe, Germany.

De Bono, A. 2013. Global Exposure Database for GAR 2013. *Global Assessment Report on Disaster Risk Reduction—GAR 2013*. Geneva, Switzerland: UNEP-GRID.

Dell'Acqua, F., P. Gamba, and K. Jaiswal. 2012. Spatial Aspects of Building and Population Exposure Data and Their Implications for Global Earthquake Exposure Modeling. *Natural Hazards* 68: 1291–1309.

Dilley, M. 2005. *Natural Disaster Hotspots: A Global Risk Analysis*. Washington, DC, U.S.: World Bank.

Ehrlich, D., and P. Tenerelli. 2013. Optical Satellite Imagery for Quantifying Spatio-temporal Dimension of Physical Exposure in Disaster Risk Assessments. *Natural Hazards* 68(3): 1271–89.

Elsner, J. B., and T. H. Jagger. 2006. Prediction Models for Annual U.S. Hurricane Counts. *Journal of Climate* 19: 2935–52.

Esch, T., M. Thiel, A. Schenk, A. Roth, A. Müller, and S. Dech. 2010. Delineation of Urban Footprints from TerraSAR-X Data by Analyzing Speckle Characteristics and Intensity Information. *IEEE Transactions on Geoscience and Remote Sensing* 48: 900–916.

European Commission. 2010. *Risk Assessment and Mapping Guidelines for Disaster Management*. Commission Staff Working Paper, SEC(2010) 1626 final. European Commission. Brussels, Belgium.

FEMA (Federal Emergency Management Agency). 2002. *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook*. FEMA 154. 2nd ed. https://www.fema.gov/media-library/assets/documents/15212.

Flay, S., and J. Nott. 2007. Effect of ENSO on Queensland Seasonal Landfalling Tropical Cyclone Activity. *International Journal of Climatology* 27: 1327–34 (2007) DOI: 10.1002/joc.1447.

Geiß, C., and H. Taubenböck. 2013. Remote Sensing Contributing to Assess Earthquake Risk: From a Literature Review towards a Roadmap. *Natural Hazards* 68(1): 1–42.

GFDRR (Global Facility for Disaster Reduction and Recovery). 2011. World Bank Distance Learning Natural Disaster Risk Management Program. World Bank/ GFDRR.

Griffin, J. G., H. Latief, W. Kongko, S. Harig, N. Horspool, R. Hanung, A. Rojali, N. Maher, L. Fountain, A. Fuchs, J. Hossen, S. Upi, S. E. Dewanto, and P. R. Cummins. 2012. An Evaluation of Onshore Digital Elevation Models for Tsunami Inundation Modelling. *American Geophysical Union Fall Meeting Abstracts*. http://fallmeeting.agu.org/2012/files/2012/12/Griffin-et-al-AGU-2012-NH21C-1598.pdf.

Gunasekera, R., O. A. Ishizawa, C. Aubrecht, G. Pita, A. Pomonis, K. Fane, S. Murray, and B. Blankespoor. 2014. Developing an Adaptive Exposure Model to Support the Generation of Country Disaster Risk Profiles. EGU (European Geosciences Union) General Assembly 2014. *Geophysical Research Abstracts*, 16, EGU2014-16168. Vienna, Austria.

Haraguchi, Masahiko, and Upmanu Lall. 2013. Flood Risks and Impacts: Future Research Questions and Implication to Private Investment Decision-Making for Supply Chain Networks. Background Paper prepared for the 2013 Global Assessment Report on Disaster Risk Reduction. UNISDR. Geneva, Switzerland.

IPCC (Intergovernmental Panel on Climate Change). 2012. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. A special report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge and New York: Cambridge University Press.

Jaiswal, K. S., and D. J. Wald. 2010a. Development of a Semi-empirical Loss Model within the USGS Prompt Assessment of Global Earthquakes for Response (PAGER) System. *Proceedings of 9th US and 10th Canadian Conference on Earthquake Engineering: Reaching Beyond Borders.* Ottawa, Canada.

Jaiswal, Kishor, and David Wald. 2010b. An Empirical Model for Global Earthquake Fatality Estimation, *Earthquake Spectra* 26(4): 1017–37.

Jaiswal, K. S., D. J. Wald, and K. A. Porter. 2010. A Global Building Inventory for Earthquake Loss Estimation and Risk Management. *Earthquake Spectra* 26(3): 731–48.

Lu, X., E. Wetter, N. Bharti, A. J. Tatem, and L. Bengtsson. 2013. "Approaching the Limit of Predictability in Human Mobility." *Nature Scientific Reports* 3: Article no. 2923. doi:10.1038/srep02923.

Martin-Ortega, J., and A. Markandya. 2009. *The Costs of Drought: The Exceptional 2007–2008 Case of Barcelona*. Basque Centre for Climate Change, Bilbao, Spain.

Mondal, P., and A. J. Tatem. 2012. Uncertainties in Measuring Populations Potentially Impacted by Sea Level Rise and Coastal Flooding. *PloS ONE*. doi:10.1371/journal.pone.0048191.

Müller, A., J. Reiter, and U. Weiland. 2011. Assessment of Urban Vulnerability towards Floods Using an Indicator-based Approach: A Case Study for Santiago de Chile. *Natural Hazards and Earth System Science* 11: 2107–23.

Peduzzi, P., H. Dao, C. Herold, and F. Mouton. 2009. Assessing Global Exposure and Vulnerability towards Natural Hazards: The Disaster Risk Index. *Natural Hazards and Earth System Science* 9: 1149–59.

Pesaresi, M., and Halkia, M. 2012. *Global Human Settlement Layer Urban Atlas Integration: Feasibility Report*. Luxembourg: Joint Research Centre European Union.

Pittore, M., and M. Wieland. 2013. Toward a Rapid Probabilistic Seismic Vulnerability Assessment Using Satellite and Ground-based Remote Sensing. *Natural Hazards* 68: 1–31.

Potere, D., A. Schneider, S. Angel, and D. Civco. 2009. Mapping Urban Areas on a Global Scale: Which of the Eight Maps Now Available Is More Accurate? *International Journal of Remote Sensing* 30: 6531–58.

Scawthorn, C. 1997. Fires Following the Northridge and Kobe Earthquakes. In: *Thirteenth Meeting of the UJNR Panel on Fire Research and Safety, March 13-20, 1996*, vol. 2, edited by K. A. Beall, 325–35. NISTIR 6030. National Institute of Standards and Technology.

Taubenböck, H., T. Esch, A. Felbier, M. Wiesner, A. Roth, and S. Dech, S. 2012. Monitoring Urbanization in Mega Cities from Space. *Remote Sensing of Environment* 117: 162–76.

Trésor-Economics. 2012. The Impact of Japan's Earthquake on the Global Economy. No. 100. April. http://www.tresor.economie.gouv.fr/File/371985.

Tsuji, Y., H. Matsutomi, F. Imamura, M. Takeo, Y. Kawata, M. Matsuyama, T. Takahashi, and P. Harjadi. 1995. Damage to Coastal Villages Due to the 1992 Flores Island Earthquake Tsunami. *Pure and Applied Geophysics* 144(3): 481–524.

UNDP (United Nations Development Programme). 2013. A Comparative Review of Country-level and Regional Disaster Loss and Damage Databases. Bureau for Crisis Prevention and Recovery, UNDP.

UNISDR (United Nations Office for Disaster Risk Reduction). 2009. *UNISDR Terminology on Disaster Risk Reduction*. Geneva, Switzerland: United Nations.

———. 2012. Towards a Post-2015 Framework for Disaster Risk Reduction. http://www.unisdr.org/we/inform/publications/25129.

UN (United Nations) Statistical Division. 2008. *Principles and Recommendations for Population and Housing Censuses*. New York, U.S.: United Nations Publications.

Van Westen, C. J. 2012. Remote Sensing and GIS for Natural Hazards Assessment and Disaster Risk Management. In: *Application of Space Technology for Disaster Risk Reduction: International Training Course Lecture Notes*, 307–75. Dehradun, India: Indian Institute of Remote Sensing (IIRS) and Centre for Space Science and Technology Education in Asia and the Pacific.

Wald, D. J., P. S. Earle, T. I. Allen, K. Jaiswal, K. Porter, and M. Hearne. 2008. Development of the US Geological Survey's PAGER System (Prompt Assessment of Global Earthquakes for Response). *Proceedings of the 14th World Conference on Earthquake Engineering.* Beijing, China.

Wesolowski, A., C. O. Buckee, D. K. Pindolia, N. Eagle, D. L. Smith, A. J. Garcia, and A. J. Tatem. 2013. The Use of Census Migration Data to Approximate Human Movement Patterns across Temporal Scales. *PLoS ONE.* doi:10.1371/journal.pone.0052971.

World Bank. 2012. Thai Flood 2011: Rapid Assessment for Resilient Recovery and Reconstruction Planning. World Bank. Washington, DC, U.S.

Wu, M. C., W. L. Chang, and W. M. Leung. 2004. Impacts of El Niño–Southern Oscillation Events on Tropical Cyclone Landfalling Activity in the Western North Pacific. *Journal of Climate* 17: 1419–28. doi:http://dx.doi.org/10.1175/1520-0442(2004)017<1419:IOENOE>2.0.CO;2.

Wyss, M., S. Tolis, P. Rosset, and F. Pacchiani. 2013. Approximate Model for Worldwide Building Stock in Three Size Categories of Settlements. Background paper prepared for the 2013 Global Assessment Report on Disaster Risk Reduction. UNISDR. Geneva, Switzerland.

III. Case Studies Highlighting Emerging Best Practices

Demonstrated success is one of the best ways to illustrate the benefits associated with risk assessment and how emerging efforts can contribute to further success. This section reviews a variety of case studies demonstrating ongoing and emerging open efforts that support risk assessments and successful examples of completed risk assessments. The contributions are roughly grouped into those focused on data; those focused on modelling; those that describe risk assessments; those that focus on participation, collaboration, and communication; and those that address the future of risk. Given that many case studies speak to some or all of these aspects, however, there is a fair amount of overlap across categories.

Data for Risk

Open Data for Resilience Initiative (OpenDRI)

John Crowley, Vivien Deparday (GFDRR); Robert Soden, Abigail Baca, Ariel Nunez (World Bank)

Risk assessments never start from a blank slate; instead they build on existing data, analysis, and historical experience. All too frequently, the data sets that are required are incomplete, out-of-date, and ill-suited to the analysis required. Moreover, data are often in forms that prevent them from being shared widely, and they therefore remain latent and inaccessible (even across ministries and municipalities within the same country). Some are blocked by technologies that lock data into proprietary ecosystems. Most are stoppered by policies that prevent release beyond small groups or are simply fragmented into bureaucratic silos that require significant investment to assemble back into a whole picture.

Yet even fusing these existing data stocks into a useable form is not be enough as the data needs to capture a dynamic reality. Rapid urbanization, population growth and increasingly climate change means that the analysis of the potential impacts of natural needs to updated more frequently and at higher resolutions than ever before. In a time of economic hardship and unequal globalization, few governments possess the resources to collate existing data or collect new data, or to analyze data and communicate the results to decision makers able to implement projects that get ahead of the disaster cycle.

Because individual governments may not currently have the capacity to take on this work, however, does not mean that it cannot be accomplished. The task of stewarding data about shared risks should be understood as a collective effort, one engaging governments, civil society, industry, and individuals. That understanding is behind the Open Data for Resilience Initiative (OpenDRI), a growing partnership of institutions that was launched by the Global Facility for Disaster Reduction and Recovery (GFDRR) and the World Bank in 2010, and designed to make data available to those who need information about disaster risks in order to make decisions. OpenDRI offers governments and their partners a process for cataloging their existing stocks of data and placing certain types of data under open licenses that still enable ministries to retain stewardship. The initiative also offers an inexpensive method of engaging at-risk communities in the process of mapping about their changing exposure to natural hazards. Finally, it offers a way to build ecosystems of entrepreneurs, researchers, and international institutions around data that a nation manages for itself.

The OpenDRI approach to managing risk data. Since 2010, the GFDRR has worked with the World Bank to implement OpenDRI in over 20 countries, including Indonesia, Haiti, Nepal, Sri Lanka, and Malawi. The program is designed to build the necessary data for quantifying and mapping risk and for communicating the results to a wide range of decision makers— from national to community levels. The OpenDRI team works with governments to harness the value of open data practices in the service of more effective disaster risk management (DRM) and climate change adaptation.

OpenDRI projects offer a menu of approaches for building and using risk data and information:

- *Collation and sharing of data and information through open geospatial catalogs.* Here local partners are supported to identify, prepare, and release existing hazard, exposure, and risk data via an online geospatial catalog. Recognizing a need to move away from proprietary software platforms, GFDRR and the World Bank have been active in leading and developing the open source platform GeoNode (http://geonode.org/), which provides tools that allow users to upload, visualize, and share data as well as simply produce maps. The platform also enables clients to federate multiple GeoNodes so that each ministry can retain custody of the data and choose which data sets are made available through open licenses. Figure 1 highlights GeoNodes supported by GFDRR and the World Bank.
- *Collection of exposure data with participatory mapping.* Participatory mapping, also known as crowdsourcing and volunteer geospatial information, provides a way for countries and cities to create fundamental data on their infrastructure, including attributes such as building vintage, construction materials, elevation, use, and number of stories—information critical for quantifying risk. Here support is provided to communities and governments to build this asset database from the bottom up, such as the collection of data by local communities or government officials through open platforms like OpenStreetMap (OSM). Under this approach OpenDRI has sought to build the capacity of national OSM chapters and train them to collect data about the exposure of the built environment to natural hazards. OpenDRI has supported the collection of millions of buildings to analysis during its programs.
- *Catalyzing open data ecosystems*. The development of a community around DRM data is critical for fostering information sharing, providing training, and creating the network of decision makers who apply data to understanding their risks from natural hazards and climate change. This work includes establishing a community of technologists and organizers who build applications and tools using risk data at "hackathons"—such as the 2014 Code for Resilience, which builds on previous Random Hacks of Kindness activities.[1] Moreover, there is a realization that the OpenDRI program requires many actors all striving for a collective vision and goal, so efforts to engage with a wide range of public, private, academic stakeholders around

[1]See the institutions' websites at www.codeforresilience.org and http://www.rhok.org/.

collective challenges are fundamental part of this program – for example improving access to appropriate resolution digital elevation model.

- *Creating tools for communication of risk.* It has long been recognized that the communication of risk results to different users is a significant challenge in the global effort and one that has received insufficient attention. Support to the development of InaSAFE—see X—is one example of efforts to overcome this challenge.

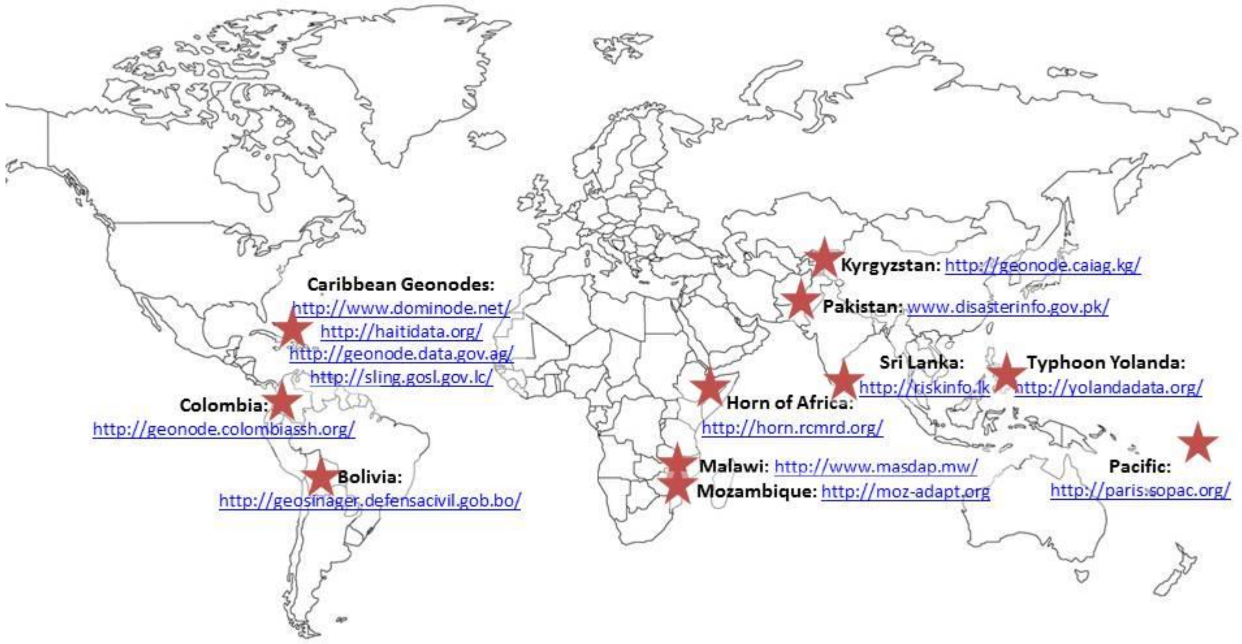


Figure 1. Locations of GeoNodes supported by the World Bank and GFDRR.

Box 1 offers an example of the collaborative effort possible under OpenDRI—specifically, the efforts mobilized in the aftermath of Typhoon Yolanda (Haiyan).

Box 1. Typhoon Yolanda GeoNode: An Example of the Collaborative Effort Possible under OpenDRI

Super Typhoon Yolanda (international name Haiyan), with 305km/hr sustained winds and 6m storm surge, made landfall in Guiuan (central Philippines) in November 2013 as one of the strongest cyclones on record. Yolanda subsequently made landfall on four more islands before heading back to sea and weakening into a tropical storm, eventually dissipating over China.

Damage across the central Philippines was severe. UN agencies estimate that approximately 11 million people were displaced and over 6,200 killed. Entire sections of cities were leveled by wind and water. Understanding the extent and magnitude of the damage was core to both the response effort and the planning for recovery and reconstruction.

Working together, the GIS team from the American Red Cross's International Department and the team from the GFDRR Labs set up a GeoNode data catalogue to collect all geospatial data that were technically and legally open. Over the course of three weeks, the Yolanda GeoNode team collected over 72 layers of geospatial data, including damage assessments performed by the EU Joint Research Centre, UNOSAT, the U.S. National Geospatial Intelligence, and the Humanitarian OpenStreetMap team. The GeoNode also hosted hundreds of situation reports and PDFs from the Red Cross and United Nations Office for the Coordination of Humanitarian Affairs (OCHA), many of which contained geospatial data. Importantly, the GeoNode also collated data from collective efforts of the OSM community, which made over 4.5 million edits from 1,600 mappers working from 82 countries.

A technical team—BoundlessGeo and LMN Solutions, working under the U.S. Army Corps of Engineers—developed a technique to extract footprints of damaged buildings from these OSM data, place them under version control in a tool called GeoGit, and made daily snapshots available. In the process, the technical team prototyped new approaches to tracking the growing volumes of damage assessment data generated by the OSM community. This technique will continue to be explored for future efforts.

The Yolanda GeoNode is an example of a GeoNode for a specific event. This approach can be used to make specific subsets of data available to a community that needs them to support the specialized use cases of response operations and recovery planning. Over the long term, the data in event GeoNodes can be rolled back into national GeoNodes or databases, allowing agencies to curate data for their general operations. This scenario recently played out with haitidata.org, which has been transferred to national government ownership.

Additional information is available at Yolanda GeoNode, http://yolandadata.org; OpenStreetMap Yolanda, http://wiki.openstreetmap.org/wiki/; Typhoon_Haiyan, GeoGit Version Control for GeoData: http://geogit.org/.

Challenges remain. Many governments have worked with partners to aggregate and centralize some portion of the data that they generate through comprehensive stock takings. However, these efforts have often failed or faltered, with two of the most common reasons being: a need for control and to collect revenue. Government officials may perceive data sets that are shared widely as data over which they have lost control and for which they can no longer negotiate monetary or other benefits. When data are shared rather than sold, there is no longer a potential for revenue. Revenue is often a greater concern for the small GIS consultancies that make a living selling their data to local, provincial, and national government officials.

Risk assessment and the need for data about potential disasters represent an easier entry point into discussions about open data than many other thematic areas (such as budget accountability), because there are often more champions where disasters are concerned, and it is easier to appeal to stakeholders' altruism. This ongoing work is rarely easy or straightforward. Opening data for wider use can raise fears, create uncertainty, and break power structures that control data flows. For this reason, OpenDRI works to empower local champions and help them build a community of leaders to advance the principles of open data, which in turn contribute to making societies more resilient. An OpenDRI field guide (Crowley, 2014), which captures the experiences and lessons learned over four years of implementation and provides a practical guide for other partners, was launched in March

2014. A case study of the local application of OpenDRI is given in the subsequent section on Open Cities.

Open Cities: Application of the Open Data for Resilience Initiative in South Asia and the Lessons Learned[2]

Robert Soden, Nama Raj Budhathoki, Marc Forni (World Bank); Vivien Deparday (GFDRR)

South Asia is one of the most rapidly urbanizing regions in the world. Growing populations, unplanned settlements, and unsafe building practices all increase disaster risk in the region. As urban populations and vulnerability grow, promoting urban growth that is resilient to natural hazards and the impacts of climate change becomes an ever-greater challenge.

The Open Cities project constitutes one effort to meet this challenge. Launched by the World Bank and the GFDRR in November 2012, it aims to create open data ecosystems that will facilitate data-driven urban planning and DRM in South Asian cities and builds on the practices and tools developed under OpenDRI. Open Cities has brought together stakeholders from government, donor agencies, the private sector, universities, and civil society groups to create useable information through community mapping, build applications and tools to inform decision making, and develop the networks of trust and social capital necessary for these efforts to become sustainable. This process has been evolutionary, with opportunities for experimentation, learning, failure, and adaptation incorporated into the project planning.

Open Cities approaches risk assessment differently from catastrophic risk modelling firms, whose data are typically used by the insurance industry or for specific portfolio analysis. Professional assessments often involve computationally intensive modelling analysis, but they also tend to rely on statistical representations, proxies, or estimations of the exposed assets, which are expressed in monetary terms. These data are insufficient for driving specific investments to reduce disaster risk, because individual assets are typically not accurately located, described, and valued. By contrast, the Open Cities platform engages local expertise and stakeholders in identifying all building structures in a city and assigning vulnerability attributes to each. In this way, a risk assessment that identifies particular structures at risk can be completed. An assessment with this degree of precision is able to identify structures based on importance and risk level, and can therefore guide plans to reduce disaster and climate risk through physical investments.

Drawing upon experiences from Haiti and Indonesia. Open Cities was inspired by two other projects involving community mapping, the OpenStreetMap response to the 2010 Haiti earthquake (described in Section X), and the Community Mapping for Exposure effort by the Australian and Indonesian governments (described in Section X). Like these efforts, Open Cities made use of the OSM platform to harness the power of crowd and community to

[2] Parts of this paper also appear in Soden, Budhathoki, and Palen (2014).

create accurate and up-to-date spatial data about the location and characteristics of the built and natural environments.

Using lessons learned from these projects in Haiti and Indonesia, Open Cities employs a scalable approach to understanding urban challenges and disaster risk in South Asian cities. Three cities were chosen for the initial work: Batticaloa, Sri Lanka; Dhaka, Bangladesh; and Kathmandu, Nepal. These cities were chosen for their high levels of disaster risk, the presence of World Bank activities related to urban planning and disaster management that would benefit from access to better data, and the willingness of government counterparts to participate in, and help guide, the interventions. Open Cities has sought to support the creation of new data in each of these projects, but has also supported broader ecosystems of open data production and use in each of the cities. Leveraging data to improve urban planning and DRM decisions requires not just high-quality information, but also the requisite tools, skills, and willingness to commit to a data-driven decision-making process. With this in mind, Open Cities also sought to develop partnerships across government ministries, donor agencies, universities, private sector technology groups, and civil society organizations to ensure broad acceptance of the data produced, facilitate data usage, and align investments in risk reduction across projects and sectors. With the first phase of Open Cities complete in each of the projects, these partnerships will be critical for continuing the work and expanding into new cities in the region.

Case study: Batticaloa, Sri Lanka. Batticaloa, a major city in Sri Lanka's Eastern Province severely affected by the Sri Lankan civil war and the 2004 Indian Ocean tsunami, is located in a hazard-prone area that has suffered near-annual droughts, floods, and cyclones. Some limited hazard maps were available for the area, but no detailed digital geographic data of the built environment were available for use in risk studies or for informing potential infrastructure and risk mitigation projects. To fill this gap, Open Cities started a pilot project to map the building stock, including critical assets of the Manmunai North Divisional Secretariat (DS), which covers an area of 68 km^2 and includes about 90,000 people around the town of Batticaloa. The work began with a series of meetings with the Batticaloa local authorities. In part, these were designed to establish the close collaboration needed to carry out the actual mapping. But they were also meant to ensure local understanding of and trust in the mapping process and in the data produced, so as to encourage local authorities to use the tools and data for their own DRM and urban planning projects.

A team of four technical experts (three recent GIS and IT graduates and one experienced GIS analyst) was hired and trained in OSM techniques in order to supervise and support the overall mapping process. Team members worked directly with the staff from local partners, including the Batticaloa Municipal Council, the Batticaloa District, the Manmunai North DS, and the 48 Grama Niladhari (GN) that make up the Manmunai North DS. A small group began by tracing all building outlines into OSM using satellite imagery and then added landmarks, road and road names, and points of interests using local paper maps provided by the DS. This effort created a solid reference map for the surveying work. The work was then split into two components: buildings were surveyed by 48 recent graduates hired to work on the GN local planning and development, and surveyed data were entered by government workers who were also responsible for fixing the maps and refining the point of interests.

Both groups were trained in OSM and surveying techniques by the Open Cities team, and all the staff involved in the data collection received a stipend for the extra work.

Data on basic characteristics (number of floors, usage, and construction materials of walls and roof) were collected for all 30,000 buildings in the area. These data are now freely available in OSM and in the government geospatial data-sharing platform RiskInfo (www.riskinfo.lk) for easy use by many stakeholders. To publicize the benefits of these techniques at the national level and promote their adoption, high-level managers of the relevant national agencies were briefed regularly and given final results when available. Two week-long training courses, one dealing with OSM techniques and the other with use of data for decision making (specifically the combination of data with existing hazard maps through GIS tools and the InaSAFE tool) were conducted at the national level with all relevant national agencies. Discussions are ongoing with various ministries concerning the next phase of the project. There is a strong interest in scaling up the project to cover a greater geographic area and in streamlining the use of the data in more DRM applications and sectors.

Case study: Dhaka, Bangladesh. Dhaka's Old City is a crowded and complex area of immense historical value and an important locus of social and economic activity. In consultation with Dhaka Water and Sanitation, seismic risk experts from Bangladesh University of Engineering and Technology (BUET), and a local nongovernmental organization (NGO) working on heritage preservation and restoration in Old Dhaka, the Dhaka Open Cities pilot sought to create detailed maps of three of the Old City's 15 wards. These maps would provide data useful for planning of evacuation routes, managing water and sanitation infrastructure, and understanding the location and characteristics of heritage buildings. In partnership with BUET, which provided technical support and a working space, 20 engineering and planning undergraduates were hired as mappers and were trained for in a series of workshops over a three-month period. A local nonprofit GIS consulting organization, CEGIS, was contracted with to provide management and quality control for the work. The Humanitarian OpenStreetMap Team (HOT), a nonprofit specializing in the use of OpenStreetMap in development and humanitarian relief situations, also provided training and technical oversight to the project.

The effort began by importing building footprint data for the three wards—created by CEGIS as part of a different project but until that point unavailable to the public—directly into OSM. This allowed the mapping team to focus on field surveying, in which basic characteristics, such as building height, usage, construction materials, and age were collected through visual survey of each building. They also mapped road characteristics (width and surface type) along with important water and sanitation infrastructure. The data were added to OSM during times when conditions prohibited field surveys (e.g., poor weather conditions). Two weeks of training at the beginning of the project and a final two weeks of data entry and quality assessment at the end of the project left two months in the middle for fieldwork. During this period, the team was able to finish complete maps of the three wards.

In total, 8,500 buildings, 540 of which were deemed to have historical significance, were surveyed. Sections of roads measuring 43km and drainage works measuring over 50km were also assessed. This information is now available to the public through the OSM platform. Several training courses and presentations on OSM were also given to university students, government partners, and private sector technology companies during the project period in order to help the OSM community in Dhaka grow. The results of the pilot were presented to the government and other key stakeholders in December 2013. Consultations are ongoing concerning the next phase of the project.

Case study: Kathmandu, Nepal. Kathmandu, the capital city of Nepal, has very high potential for significant loss of human life during a major earthquake event.[3] In November 2012, in partnership with the government of Nepal, the World Bank and GFDRR launched a project to build seismic resilience in the Kathmandu Valley's education and health infrastructure, in part by creating a disaster risk model to determine the relative vulnerability of the relevant buildings. Once complete, the model will be used to prioritize plans for retrofits of schools and health facilities to improve structural integrity in the face of earthquake. However, a critical input into this model is building-related exposure data.

World Bank staff and consultants began the year-long project by assembling a team of mappers and community mobilizers. The team was responsible for a variety of tasks, from field surveying to software development to training of community groups in OSM. The core team comprised six graduates of Kathmandu University who were recruited based on their prior contribution to Nepal's then-nascent OSM community. They were paid full-time salaries at rates commensurate with the local salary structure for recent graduates in technical disciplines. The project also recruited six part-time interns from Kathmandu University and 11 volunteers from Tribhuvan University. Office space for the team provided access to meeting rooms, reliable Internet service, and opportunities to interact with other technologists and entrepreneurs, some of whom later became active in OpenStreetMap.

Open Cities Kathmandu surveyed 2,256 schools and 350 health facilities in the Kathmandu Valley. In addition to collecting a comprehensive list of structural data for health and school facilities, the team worked to create a comprehensive base map of the valley by digitizing building footprints, mapping the road network, and collecting information on other major points of interest. The Open Cities team also conducted significant outreach to universities, technical communities, and government in order to expand the OSM community. Over 2,300 individuals participated in OSM trainings or presentations during the first year of the project. The data have been used in plans to retrofit school and health facilities and in applications for transportation planning; moreover, USAID has incorporated the data into disaster preparedness planning exercises. The American Red Cross has also made substantial contributions to the OSM project in Kathmandu, suggesting the opportunities for partnerships between development organizations. A local NGO called the Kathmandu Living Labs, staffed by participants in the first phase of the Open Cities project, has been created in order to continue the work.

Lessons learned and recommendations. Although the Open Cities project is ongoing, several key lessons have already emerged which can be applied to other initiatives.

---

[3] In the 20th century alone over 11,000 people lost their lives to earthquakes in Nepal. The 1934 Bihar-Nepal earthquake destroyed 20 percent of Kathmandu's building stock and damaged 40 percent. Geohazards International, ''Kathnandu Valley Earthquake Risk Management," http://geohaz.org/projects/kathmandu.html.

1. Government ownership is important.
Although many Open Cities partners and participants will be from civil society and the private sector, government counterparts in line ministries must be involved in projects' development and execution. Engaging governments early in the planning process and ensuring close involvement throughout is an essential component of a successful Open Cities project. Governments are primary stakeholders for many DRM and urban planning projects and provide necessary legitimacy to Open Cities work. In Kathmandu, the involvement of the Department of Education in the mapping work will be critical for developing the department's confidence in and use of the data to prioritize seismic retrofitting activities. An official letter in support of the project carried by mapping team members helped them gain the access to schools and health facilities that was needed for conducting their assessments. In Sri Lanka, the project deliberately involved local authorities directly in the mapping activities as a way to ensure government ownership of the project and the use of the data in various applications.

2. Universities make good partners.
Universities have been valuable allies during the first year of Open Cities work. Outreach to university departments of engineering, geography, computer science, and planning has provided projects with critical connections and support. In Dhaka and Kathmandu, university students have played an important role in mapping activities and software development. Students from technical departments are frequently able to quickly learn OSM, and some students in Kathmandu fulfilled a requirement to complete internships or volunteer projects through participating in Open Cities. University faculty have also provided useful support. In Dhaka, professors from the BUET Civil Engineering Department and Planning Department contributed to the design of the mapping project. Professors in the Geomatics Department at Kathmandu University provided guidance to the project on quality control techniques for surveying, and they also incorporated OSM into their courses. Training future classes of university students will help the OSM community in Kathmandu continue to grow after the formal project period has ended.

3. Access to imagery is critical.
As the work of Haiti's OSM community made clear, access to high-resolution satellite imagery is extremely useful for efficient mapping of infrastructure. However, such imagery is often prohibitively expensive or available only under licenses that prohibit digitization by the public. With this in mind, the U.S. State Department's Humanitarian Information Unit launched an initiative in 2012 called Imagery to the Crowd, which makes high-resolution imagery owned by the U.S. government accessible to humanitarian organizations and the volunteer communities that support them. Open Cities Kathmandu partnered with USAID and Imagery to the Crowd to release 2012 satellite photography for the Kathmandu Valley and to organize volunteers in Nepal, the United Kingdom, Germany, and the United States to digitize building footprints. The data created by these volunteers have been incorporated into USAID disaster response planning, and they provided a solid foundation upon which the Nepali OSM community can continue to expand and improve.

4. Data must be trustworthy and credible.

Data quality is a frequently raised issue in community and volunteer mapping projects. Numerous measures were taken by the Open Cities project to ensure that partners and intended users of the data would trust its accuracy and completeness. In Kathmandu, partner organizations—including the National Society for Earthquake Technology, a respected NGO working on seismic resilience, and the Kathmandu University Geomatics Department—provided technical guidance to the project as well as independent quality assessments throughout the process to provide credibility. In Dhaka, key stakeholders, including BUET and representatives of government and civil society, were consulted throughout the project, and many were given basic training in OSM in order to familiarize them with the platform.

5. Sustained engagement is required for success.
For these projects to be successful, sustained engagement with local partners is necessary. Too often technology and data projects of this sort are discrete and short-term endeavors. A workshop or a weeklong training course is simply not enough time to trigger the kinds of change that Open Cities hopes to support. Although OSM makes mapping more accessible to non-specialists, collecting and interacting with geographic information remains a complex technical undertaking, one that requires more training and involves a longer learning process than is often assumed. It also takes time to build technical communities of OSM mappers and software developers who are familiar enough with the platform to comfortably deploy it in their own tools and applications—and creating these communities is an important part of sustaining Open Cities projects. Finally, Open Cities seeks to contribute to cultural and policy shifts within technical groups and government that will prioritize open data and broad participation in development challenges. When projects of this kind are planned, the parties involved must understand and commit to sustained investment in their success.

In its early phase, Open Cities has demonstrated success in engaging non-traditional institutions and community groups in the process of creating high-resolution spatial data that can be used in support of urban planning and resilience building programs. There is still work to be done to establish direct links between the OSM data set and target users in and out of government, but the initial reception has been positive, and there is strong interest from a number of other development institutions in learning from the early experience and in partnering on future work. In the future, Open Cities will also seek to scale through expansion of the range of organizations involved in the work and explore launching new programs in cities in South Asia and other regions.

Preliminary Survey of Government Engagement with Volunteered Geographic Information

Muki Haklay (University College London), Sofia Basiouka (National Technical University of Athens), Vyron Antoniou (Hellenic Military Geographical Service), Robert Soden (World Bank)

When data and information are shared and part of open systems, they promote transparency and accountability, and ensure that a wide range of actors can participate in the challenge of building resilience. Arguably, one of the greatest revolutions in this open data space has been the increasingly active involvement of local people in geospatial data collection and maintenance—a process known as volunteered geographic information (VGI).

A preliminary survey of government engagement with VGI was undertaken in order to strengthen governmental projects that incorporate voluntary and crowdsourced data collection and to provide information that can support wider adoption of VGI.[4] The survey compiles and distributes lessons learned and successful models from efforts by governments at different levels. The survey project began from the following premises:

- Sources of VGI data such as OpenStreetMap are growing increasingly important across a range of thematic areas and user communities.
- Concerns about the quality, consistency, and completeness of VGI data have been assessed by a range of studies and overall have been found not serious enough to prevent exploration of VGI data as a valuable data source.
- For governments, interacting with VGI communities is different and potentially more complex then interacting with typical sellers and resellers of GIS data.
- Designing strategies to encourage governments to engage with VGI efforts is not straightforward, and we are still learning from early experience what opportunities exist and what methodologies work well.

The survey project focuses on cases that demonstrate a synergy between government and citizens or civic society organizations. "Synergy" means a government authority's clear use of contributed information to make decisions and take actions. Four case studies are highlighted: Canada's interaction with OSM, Haiti's interaction with the Humanitarian OSM Team, Indonesia's experience with community mapping, and the U.S. State Department's interaction with HOT.

Canada. In Canada, the main duty of National Mapping Agencies is to provide up-to-date topographical maps and a range of spatial products to public and private sector. Likewise, the role of Mapping Information Branch at Natural Resources Canada is to provide accurate geographic information on landmass at the scale of 1:50,000. This task involves regularly covering an area of 10 million km^2 divided into 13,200 map sheets.

Taking into account the results of ongoing research regarding VGI quality, Canadian authorities choose to cooperate with the OSM community to see if and how the updating process could profit from the evolution of VGI. As Beaulieu, Begin, and Genest, 2010 describe, the first step to this synergy was made by the Centre for Topographic Information in Sherbrooke which released the digital topographic map of Canada in the native OSM format. This move enabled further integration of the Canadian authoritative data into OSM and gave the OSM community a chance to interact with—that is, complete, correct, or update—the authoritative data. In addition, authorities are now able to regularly compare the OSM database with the original data to pinpoint the differences. Those differences are

[4] Funding for this research is provided by the Global Facility for Disaster Reduction and Recovery. For more information on VGI, see http://crowdgov.wordpress.com/.

treated as potential changes and are verified using the authoritative channel at the field. Verified changes are propagated to the authoritative database.

On the positive side, the titanic work of keeping the data sets up-to-date has been facilitated by the OSM community. Leveraging the OSM crowdsourcing mechanism, the Canadian authorities have developed a much-needed change-detection process, which helps the authorities concentrate resources and effort on areas with identified changes. Given that the authoritative database had failed to update all the originally designed spatial entities, this contribution in valuable.

Engaging with OSM has also presented challenges. Among the issues that must be addressed are the imperfect compatibility of the two data sets (in terms of semantic and attribution differences), the virtual nonexistence of metadata for OSM data, and the differences in coverage (OSM is concentrated in urban areas compared to the uniform authoritative coverage). All these differences stem from the differences in the two geographic information–generating processes—that is, the bottom-up and looser OSM process versus the top-down authoritative process. Yet another issue involves a conflict between license and use terms of OSM and the intellectual property rights of Canadian authorities.

The Canadian and OSM synergy rests mainly on two pillars: the authorities' recognition that they have been unable to keep the national data up-to-date, and their willingness to acknowledge and trust the quality of the OSM data. Yet another factor contributing to the synergy is that Canadian authorities are well organized and equipped and therefore have a standard process regarding spatial data collection, change detection, and spatial data quality control and quality assurance. They can easily handle the addition of OSM data in their processes, and the results are visible, understandable, and tangible. In other words, in this case, the context in which authoritative and non-authoritative entities interact is an important influence on how easy it is to integrate the two different spatial data sets.

The Canadian experience suggests several important lessons:

- An authority's recognition that it needs assistance to meet its target can trigger the turn to VGI.
- VGI data sets can be used by authoritative and governmental bodies to supplement or facilitate their standard operational procedures.
- Differences in structure and operation mean that updates to geographic information do not move freely between the two systems.
- Different terms of use and license options for the two data sets can create connectivity problems.

Haiti. Haiti was dramatically affected by the 7.0 magnitude earthquake of January 12, 2010. Estimates of deaths range from 100,000 to 159,000, with Haitian government reports of over 200,000 fatalities. More than 250,000 residents were injured and more than 30,000 buildings were collapsed or severely damaged. The Haitian government and the numerous nongovernmental organizations seeking to respond to the disaster lacked accurate and up-to-date maps to help guide their work. The only available spatial data were poor in content and had last been updated in the 1960s; moreover, the local mapping agency collapsed in the earthquake and many of the skilled employees were lost. An updated map was urgently needed to enable distribution of supplies, attention to collapsed buildings, repair of damaged infrastructure, and provision of medical services.

The Haiti disaster response constitutes an example of a successful project in which geographic information was released from partners to the crowd for enhancement and then returned back to government for activation—although government was rather reluctant to involve volunteers. Historical maps, CIA maps, and high-resolution imagery in Yahoo were used for tracing in OSM so that the basic maps could be improved. Within 48 hours, new imagery from the World Bank, Google, and others, was also made available for tracing in OSM. According to HOT, within a month, 600 volunteers had added spatial information to OSM and OSM was used as a default base map for the response to the Haiti earthquake. Figure 2shows volunteers involved in the mapping.

Figure 2. OSM volunteers in Haiti.
Source: ©Humanitarian OpenStreetMap Team, http://hot.openstreetmap.org/projects/haiti-2. Used with permission; further permission required for reuse.

Four factors explain the success of this project: the quick creation of the data, the low cost, the numerous contributions of volunteers from the OSM community, and the public release of high-resolution satellite imagery. The two first factors were summarized by view that the United Nations "would have taken tens of thousands of pounds and years to do what OpenStreetMap did in 3 weeks."[5] The third factor was the remote volunteers who acted quickly, coordinated their efforts, and disseminated the appeal for help all over the world. As Tim Waters puts it, "It is the first time where individuals from the comfort and safety of their

[5] This view is attributed to Schulyer Erle in Tim Waters, "OpenStreetMap Project & Haiti Earthquake Case Study, slide presentation, 2010, http://pt.slideshare.net/chippy/openstreetmap-case-study-haiti-crisis-response.

own home can literally help other people save lives in a disaster zone."[6] A final key factor in the success of the project was the willingness of partners to provide spatial data and imagery free of license restrictions.

Despite the project's overall success, several challenges should be highlighted. First, despite the efforts of the HOT and others, the Haitian national mapping agency (CNIGS) was never fully involved in the project. This represented a missed opportunity to establish a richer connection between the Haitian government and the OSM community. Second, the number of volunteers involved in the digitization and the speed with which it occurred caused coordination difficulties, which in turn led to duplication of data and effort.

Undeniably, what OpenStreetMap did in Haiti changed both disaster response and perceptions of VGI forever.[7] Overall, the Haitian experience suggests several important lessons:

- Crowdsourcing of mapping is a valuable ex post disaster response.
- Volunteers from the OSM community and the access to high-resolution imagery made the project a success.
- Coordination among distributed volunteers involved in mapping is a challenge that needs to be addressed in order to ensure efficient use of their time.

Indonesia. The Indonesian community mapping of exposure project began in early 2011 and is still active—see section X for more details. The project's goal was to use OSM to collect previously unavailable data, including structural data, for both urban and rural buildings and use the data in appropriate models to estimate the potential damage from natural hazards. The combination of these two components and the use of realistic data led to the development of InaSAFE tool—discussed in section X. Figure 3 shows the Indonesian community mapping project under way.

[6] Tim Waters, "OpenStreetMap Project & Haiti Earthquake Case Study, slide presentation, 2010, http://pt.slideshare.net/chippy/openstreetmap-case-study-haiti-crisis-response.

[7] This point was made by Jeffrey Johnson, Where 2.0 conference, March 30–April 1, 2010, San Jose, CA, http://hot.openstreetmap.org/updates/2013-12-17_imagery_for_haiyan.

Figure 3. Community mapping project in Indonesia.
Source: ©Humanitarian OpenStreetMap Team, http://hot.openstreetmap.org/projects/indonesia-0. Used with permission; further permission required for reuse.

The project was seen as successful from a human, technical, and financial point of view. It has enabled local government to use spatial data to visualize where people are most in danger (Chapman, Wibowo, and Nurwadjedil, 2013). The community mapping component had clear leadership, specific guidelines in data manipulation, and great coordination of the different contributors. The crowd was motivated to participate (driven by a desire to improve disaster protection, win the mapping competition, or other reasons), and was supervised during the various stages of the process, and the process of data collection and manipulation was well defined. A factor contributing to the project's success was the evaluation of the data by academics and project leaders.

Some limitations of the project involve the quality of the results, which while acceptable overall and in some cases very good, was in some cases very poor (Gadjah Mada University and HOT Team, 2012). There appeared to be many empty or wrong records concerning the structure of buildings. Some minor deficiencies were also noted during the implementation, such as the use of time-consuming technical methods (e.g., use of Excel spreadsheets in data collection or manual methods of data manipulation).

The Indonesian experience suggests several important lessons:

- An ex post response can be focused on appropriate models and parameters and can calculate the damages in case of a physical disaster by using crowd sourced spatial data sets.
- Successful interaction between the VGI community and Indonesian government officials, who evaluated the data used for scenario building as reliable—led to the project's being continued and expanded past the initial phase.
- Risk managers and the local community can combine local wisdom with scientific knowledge to produce realistic scenarios for numerous different physical disasters that may occur at the area of interest.

- The success of the project was due in part to the coordination of volunteers and full use of human resources and technical innovations.
- The mixed quality of the attribute data is an issue of concern.

Imagery to the Crowd. As shown in Haiti, facilitating the access of volunteer communities to high-quality aerial and satellite imagery can have dramatic results. Such imagery is often prohibitively expensive, however, or available only under licenses that would prevent digitization by the public. With this in mind, the U.S. State Department's Humanitarian Information Unit (HIU) launched a new initiative in 2012 called Imagery to the Crowd. This program makes high-resolution imagery, purchased by the U.S. from providers like Digital Globe, accessible to humanitarian organizations and the volunteer communities that support them. Since its inception, Imagery to the Crowd has facilitated the digitization of basic infrastructure data into OSM in eight countries to support humanitarian response or disaster risk reduction.

Following the Typhoon Haiyan disaster in the Philippines in November 2013, Imagery to the Crowd published images for Tacloban, Ormoc, Northern Cebu, and Carles. This imagery supported a massive volunteer effort of over 1,600 mappers from the OSM community, coordinated by HOT, who contributed nearly 5 million changes to the map—changes that provided detailed information on the location and extents of pre-event infrastructure as well as offering a preliminary damage assessment. (See **Error! Reference source not found.** for more information.)

Technical and policy efforts are under way to increase the speed at which imagery can be released and to standardize and improve the process, but this new initiative has already achieved demonstrable results.

Collection of Exposure Data to Underpin Natural Hazard Risk Assessments in Indonesia and the Philippines

Australian Department of Foreign Affairs and Trade (DFAT) / Australia-Indonesia Facility for Disaster Reduction (AIFDR) / Indonesian National Disaster Management Agency (BNPB) / Collective Strengthening of Community Awareness on Natural Disasters (CSCAND) / Geoscience Australia (GA)

Until recently, the scope and usefulness of risk assessments in the Asia and Pacific were limited because the fundamental exposure data required were either missing or incompatible with the level of risk assessment required. But two projects in the region, one in Metro Manila, Philippines, and the other in Indonesia, have each found a way to develop much-needed exposure data.

Philippines. In the Philippines, Geoscience Australia has worked with the Office of Civil Defense and a group of government of Philippines technical agencies, known jointly as Collective Strengthening of Community Awareness for Natural Disasters (CSCAND), to promote the goals of the Greater Metro Manila Area Risk Assessment Project (GMMA RAP). This project represents was one of the first integrated multi-hazard probabilistic risk assessments ever undertaken for a megacity and included estimations of economic loss and potential casualties.

The project was intended to provide a better understanding of exposure databases, including how to prepare them; to make exposure information available for analyzing natural hazard risk and climate change impacts in the Greater Metro Manila Area; to improve assessments of the risk of and impacts from flood (in the Pasig-Marikina River basin) and from tropical cyclone severe wind; and to improve the understanding of earthquake risk in the Greater Manila Metro Area.

To achieve its goals, the project needed to address the challenge of gathering data in a highly complex urban environment. Attempting to acquire, manage, and maintain exposure information for every significant feature was not practical (there are over 1.5 million buildings, for example). In addition, few risk analysis tools can handle extremely large amounts of exposure data. In response to this complexity, a state-of-the-art technological approach was developed to collect exposure data across this immense urban area, an approach that also made use of existing methods and lessons learned in preparing exposure data for an earlier project on earthquake risk in Iloilo City.[8]

The database was populated with a range of data from other projects or already held by government of Philippines agencies, Local Government Units, and other organizations, and these were then enhanced with additional data. To support the process of developing data and offer local expertise and knowledge, a technical working group of specialists was established. Given the difficulties involved in acquiring and managing highly complex data, and given the lack of detailed exposure data available for some areas of the Greater Metro Manila Area, an area-based approach to exposure data development was adopted; this approach allowed data to be included in the database at a suitable level of detail.

Statistical information on population and building type (e.g., from National Statistics Office Census data) was used to describe exposure characteristics for broadly defined areas (in this case, barangays, the smallest administrative division in the Philippines, equivalent to an inner-city neighborhood or suburb). This information was then supplemented with exposure data derived through a novel technological approach developed at Geoscience Australia, in which data from airborne LiDAR, which can be used to measure building footprints and heights very accurately, and high-resolution aerial imagery were incorporated into GIS models.[9]

Several additional data sets were derived from these LiDAR data, including a digital elevation model and a digital surface model. Both these data sets were generated with a 1m horizontal resolution, making them ideal for high-resolution spatial analysis. Where the digital elevation model and digital surface model were spatially coincident, the difference

---

[8] This project was the joint GA/PHIVOLCS (Philippine Institute of Volcanology and Seismology) pilot study of earthquake risk in Iloilo City, in the Western Visayas region of the Philippines (Bautista et al., 2012).

[9] For more information, see Geoscience Australia, “New Building Assessment Tool Supports Better Risk Analyis,” February 12, 2014, http://www.ga.gov.au/about-us/news-media/news-2014/new-building-assessment-tool-supports-better-risk-analysis.html.

between their elevation values was the height of features above the ground. After vegetated areas were isolated from the derived features through analysis of aerial imagery that accompanied the LiDAR data, a model of artificial elevated areas—i.e., buildings—was left.

The extents and heights of buildings determined from the LiDAR data were then used to estimate the floor area of the buildings (which is ultimately used to determine the amount of damage a building will suffer in the event of a hazard event). The vertical distance between floors of buildings, also referred to as the inter-story height, was assumed for each relevant barangay, and this was used in conjunction with the areal extent of the building to calculate the floor area. Sample images are in Figure **4.**

Figure 4. Application of aerial imagery, LiDAR data, and land-use mapping to develop exposure database.
a. High-resolution aerial imagery over Taguig City and its application to derive exposure data. b. Detailed land-use mapping. c. Heights of buildings determined from LiDAR data (red = high; blue = low). d. Number of stories (blue = low rise; green = medium rise; orange = high rise).
Source: Geoscience Australia.

Finally, the collected (census) data and calculated (LiDAR) data were combined into statistical models for individual barangays based on land use. These formed the basis of the Greater Metro Manila Area exposure database and the economic loss calculations determined through the risk analysis.

Crowdsourcing in Indonesia. In Indonesia, where natural disasters are being assessed at a national scale, technological approaches for exposure data acquisition were not feasible because of the cost and because of the collection area's spatial extent. Instead communities and volunteers, crowd sourced necessary data using the OpenStreetMap framework.

The Australia-Indonesia Facility for Disaster Reduction (AIFDR) initiative, which is a key part of Australia's development program in Indonesia,[10] collaborated with the Indonesian National Board for Disaster Management (Badan Nasional Penanggulangan Bencana, or BNPB), the GFDRR, and the World Bank to develop InaSAFE (see Section X for more information). The requirement to provide a spatially independent product that could be applied anywhere across Indonesia meant it was not possible to underpin the risk models with a single exposure database, as was the case in the GMMA RAP. Instead, a partnership was formed to obtain location-specific exposure information that was at the right scale, up-to-date, and complete.

To determine if OSM could be used to map exposure in Indonesia—that is, provide exposure data for impact scenarios—a community mapping pilot was developed through collaboration with the Australian aid–funded Australian Community Development and Civil Society Strengthening Scheme (ACCESS) Phase II and the Humanitarian OpenStreetMap Team (Chapman, 2012). OSM provides communities with tools to quickly, simply, and easily map their environment; when mapping infrastructure, users can tag objects with information (for example, about use, wall type, roof type, capacity, etc.). This participatory mapping approach provides detailed, local-scale exposure information that can be used by governments and communities for developing impact assessments. It minimizes access and usability issues by requiring low-tech approaches that are easy to carry out (for example, it uses paper maps with digital imagery that can later be uploaded into a database); and because it engages communities in mapping their own vulnerability, it has the added benefit of increasing their sense of ownership over resultant impact assessments.

This pilot was the first attempt to use OSM to collect detailed exposure and vulnerability data and then feed it into scientific models to determine how a disaster would affect a specific location. During the first phase of the pilot, workshops were held to train participants and to educate them on building construction and data collection. Mapping was done by editing paper maps using satellite imagery (where available) and GPS tracks. Urban areas, including Padang, Jakarta, Surabaya, Yogyakarta, and Bandung—were mapped by students who took part in a mapping competition. Rural areas were mapped with ACCESS contributors and local people. During this phase, 163,912 buildings were mapped, including 29,230 urban buildings. During the second phase, from July 2012 to March 2013, additional exposure information was gathered.

An evaluation of OSM data showed that for the 163,912 buildings mapped in Indonesia, results were not significantly different from ground-truthed and referenced data (Chapman, 2012). Figure 5 shows the increase in exposure data over time for three locations in Indonesia being mapped by OSM.

[10] For more AIFDR, see its website at http://www.aifdr.org/.

Figure 5. Growth in exposure data through crowd sourced (OSM) mapping of buildings and infrastructure in three locations in Indonesia.
Source: Geoscience Australia.
Note: Top shows Sumbawa in January 2011, January 2012, and December 2012. Middle shows Jakarta in January 2011, January 2012, and December 2012. Bottom shows Padang in January 2011, August 2011, and December 2012.

Since the end of the pilot in March 2012, over 1.3 million buildings have been mapped in Indonesia with OSM, over 900 Indonesians have been trained in the use of the software, and three universities have begun to teach OSM within their GIS program.

This project has since been used as a template for similar endeavors worldwide and as a model for coordinating and structuring a crowdsourcing project. It is also a representative example of prevention and a priori protection of developing countries against natural disasters. The project succeeded because it was supported by the local government with money and time depth; the methodology was adapted to the nature of the mapping area (rural or urban); and it was well designed and defined in terms of technical structure and human resources. Incentives were also offered to encourage volunteers to remain involved and not abandon the effort prematurely. Moreover, everyone working on the project could quickly see how the new data they had collected could be combined with hazard layers to determine potential disaster impact—which showed them the importance of their work.

International Collaboration of Space Agencies to Support Disaster Risk Management Using Satellite Earth Observation[11]

Philippe Bally (European Space Agency), Ivan Petiteville (European Space Agency, CEOS Disasters Working Group Chair), Andrew Eddy (Athena Global), Francesco Gaetani (Group on Earth Observations Secretariat), Chu Ishida (Japan Aerospace Exploration Agency), Steven Hosford (Centre National d'Etudes Spatiales), Stuart Frye (NASA), Kerry Sawyer (CEOS Executive Officer), Guy Seguin (International Space Consultant)

Working together in groups, such as the Committee on Earth Observation Satellites (CEOS), national space agencies are seeking to coordinate their efforts and resources to make large volumes of earth observation (EO) data available for use in risk management and disaster reduction. EO data are currently used operationally in the context of disaster response by the International Charter (see Box 2).

The EO data come in various forms—medium- and high-resolution optical data; medium- and high-resolution microwave radar data (C, L, and X band); interferometric SAR (synthetic aperture radar) data products; infrared and thermal data; and meteorological data sets—and can serve as the basis of regular, detailed updates on the status of hazards globally, regionally, or nationally. Currently, much EO data complements ground data, but where in situ information is limited, EO data may be the only source of information available.

Box 2. International Charter Space and Major Disasters

A good example of the potential of satellite EO can be seen in the International Charter Space and Major Disasters (www.disastercharter.org), an international collaboration among space agencies that uses space technology to aid in response to disasters. When a disaster occurs, the International Charter grants access to satellite data at no cost and in a rapid fashion. The Charter aims to help better organize, direct, and mobilize national disaster management resources during emergencies and the international relief community during situations where humanitarian assistance is required. The only users that can submit requests are Authorized Users, a predefined list of organizations with a mandate related to DRM. The Charter is focused on hazards with rapid onset scenarios, in the immediate response phase, and aims to service operational users, wherever a disaster occurs. Since its inception in 2000 it has delivered services over 400 times in well over 100 countries.

To cite the Charter and its dramatic evolution over the last decade as progress toward risk assessment may be surprising, given the Charter's response-only focus. Yet the Charter remains a striking example of what space agencies working together can achieve. By raising the profile of satellites in disaster response, the Charter has greatly increased the DRM community's interest in EO satellite data and EO-based solutions. Satellite based geo-information can contribute to the entire cycle of risk management, including mitigation, warning, response, and recovery. To date, much of the DRM effort of the EO sector has been focused on disaster response and recovery, which by its nature attracts more attention but also more resources than pre-crisis phases. Stronger ties to end-users and increased collaboration with DRM practitioners would increase the impact of EO-based response activities such as those of the Charter. At the same time, meeting the ongoing need for information by supplying large volumes of data over large areas is very different from meeting the more limited needs arising during the response phase; and within the context of existing systems, supplying EO data for disaster mitigation on a global basis represents a clear operational challenge for satellite agencies.

---

[11] This paper draws in part on Petiteville, Bally, and Seguin (2012).

EO data can be instrumental in risk assessment and disaster reduction. These data can be used for a range of applications, such as mapping hazards, evaluating asset exposure, and modelling vulnerability:

- *Basic mapping.* Nearly all the mapping services provided by satellite EO to DRM and humanitarian aid projects are underpinned by basic mapping. This base-layer information serves as a standardized geographical reference data set that can be used to determine key geographical attributes of a given area.
- *Asset mapping.* Asset mapping provides up-to-date, synoptic, and objective infrastructure information concerning the asset at risk. It can also add to and improve knowledge about the potential impact of natural hazards in areas at risk.
- *Urban mapping.* This service assesses the structure of the built-up areas. In agglomerations where urban expansion is progressing very rapidly and the territorial conditions are extremely constrained, EO data help to create easily updatable baseline maps of urban assets while taking into account location of informal settlements and their high vulnerability to natural hazards such as floods and landslides.
- *Remote assessment of damage*. This service uses processed satellite data from before and after a disaster to provide crisis mapping, situation mapping, and damage assessment for on-the-ground disaster response by governments, first responders, and planners of resilient recovery.
- *Flood risk analysis*. This service provides information to support risk management and water resources management. Depending on input data and methodologies used, different types of information can be extracted, such as the classified distribution of the land cover and socioeconomic units in areas at risk, or hazard damage information based on measurements of water depth and/or flow velocity.
- *Precise terrain deformation mapping.* This service contributes to geohazard risk assessment to support mitigation, prevention, and preparedness. For a wide range of risk assessments, including those concerned with flood, seismic hazard, and climate change, terrain-motion information has direct relevance.
- *Landslide inventories and landslide monitoring*. These services provide hazard mapping information in landslide-prone areas and carry out repeat observations over large areas. (Locally, emergency monitoring of hot spots typically is performed using ground-based radar as the primary source).

CEOS has developed a long-term vision for how it can expand its contributions to all phases of DRM. It anticipates contributions that are global in scope, even as they build on strong partnerships at local, national, or regional levels; that are user driven; that address several hazard types; and that take into account all relevant EO-based capabilities available or under development. As part of this vision, and to demonstrate the benefits of EO data used in complement to more conventional data sources, CEOS is implementing pilots defined with representatives of the user community (scientists, civil protection agencies, local resources management authorities, etc.) for floods, seismic hazards, and volcanoes in 2014–2016.

For the flood pilot, the objectives are as follows:

- Integrate existing near-real-time global flood monitoring and modelling systems.
- Link global systems to regional end-to-end pilots that produce high-resolution flood mitigation, warning, and response products and deliver flood- and flash flood–related services in the Caribbean (with particular focus on Haiti), southern Africa (including Namibia, South Africa, Zambia, Zimbabwe, Mozambique, and Malawi), and Southeast Asia (with particular focus on the lower Mekong basin and Western Java, Indonesia).
- Develop new end products and services to better deliver flood-related information and to validate satellite EO data and products with end-users, including retrospective products working from archived EO flood-extent data.
- Encourage regional in-country capacity building to access EO data and integrate them into operational systems and flood management practices.

For the seismic hazards pilot, the objectives are as follows:

- Support the generation of globally self-consistent strain-rate estimates and the mapping of active faults at the global scale by providing EO InSAR and optical data, and support processing capacities for existing initiatives, such as the Global Strain Rate Model, based on wide extent satellite observations.
- Continue support to the Group on Earth Observations' Geohazard Supersites and Natural Laboratories (GSNL) initiative for seismic hazards and volcanoes.
- Develop and demonstrate advanced science products for rapid earthquake response for events of magnitude greater than 5.8.

For the volcanoes pilot, the objectives are as follows:

- Demonstrate comprehensive monitoring of Holocene volcanoes in the Latin American volcanic arc.
- Develop new protocols and products over active volcanoes where EO data collections are already taking place (Hawaii, Iceland, and Italy through GSNL).
- Demonstrate operational monitoring over a large-scale eruption (e.g., Merapi 2010) during 2014–2016.

The CEOS pilots aim to reach out to the global DRM community and showcase what is possible when large volumes of satellite EO are made available to support full-cycle risk management. A substantial space capability already exists and is growing; it includes radar, optical very high- and high-resolution satellites, and many others. The collective capability offers high-revisit and wide-area synoptic coverage. Innovations in EO (see Box 3) will also bring new capabilities.

Looking at the tremendous resources of new EO missions and the volume of service delivery of current projects in DRM, users could consider how such volumes of data might be better exploited. Existing use for risk assessment and disaster preparedness remains embryonic, despite evident potential. Further investment may be required to support new user communities and emerging partnerships. Looking at efforts to reduce disaster risk, existing services have proved useful and have demonstrated the cost benefit of providing risk assessment based on satellite EO data. For some geo-information needs, additional research and development is required. For other needs the available products are mature, precise, and documented. However, currently it appears that the main obstacle to progress remains lack of awareness of what exists and what can be accomplished.

Box 3. Innovations in Earth Observation over the Coming Decade

The resolution and availability of earth observation satellites are much greater now than they were a decade ago. It is still the case, however, that the use of satellite-based EO in DRM is often constrained by the lack of observations for risk-prone areas.

Space agencies are addressing this issue by putting in place new data policies that will soon provide users with open and free access to agencies' archives of images from the past 10 years, starting with SPOT images. They are also developing complementary plans of observation. Two upcoming satellite missions—Sentinel-1 and Sentinel-2, jointly developed by the European Commission and the European Space Agency and scheduled to launch in spring 2014—will make high-quality SAR and multispectral data freely available to end-users.

The SAR data generated by Sentinel-1 can be used for global, national, and local hazard assessments. The multispectral Sentinel-2 mission—for global land observation at high resolution with high-revisit capability—will provide enhanced continuity of data so far provided by SPOT-5 and Landsat 7 and 8 and will offer data comparable to those provided by the U.S. Landsat system. With a constellation of two operational satellites allowing a five-day geometric revisit time, Sentinel-2 will provide systematic coverage of the overall land surface. Other EO missions that will greatly enhance global observations for DRM applications include the ALOS-2 mission of JAXA (Japan Aerospace Exploration Agency) and the Canadian Radarsat Constellation Mission (RCM). Two new U.S. commercial optical satellites, Skybox and PlanetLab, will become available in the near future and will greatly enhance the accessibility of these high-resolution images.

In complement to the systematic and frequent coverage over wide areas made available by EO missions, detailed and up-to-date observations are being provided through very high-resolution systems operated by commercial players and national space agencies. Relevant missions are the Pléiades mission of CNES (France's National Center for Space Studies) and Astrium Geo-Information Services; Cosmo-Skymed of ASI (Italian Space Agency) and e-geos; TerraSAR/Tandem-X of DLR (German Aerospace Center) and Astrium Geo-Information Services; and Radarsat-2 of CSA (Canadian Space Agency) and MDA Corporation.

Global Earthquake Model

Helen Crowley, Nicole Keller, Sahar Safaie, Kate Stillwell (GEM)

The Global Earthquake Model (http://www.globalquakemodel.org/) is a collaborative effort involving global scientists and public and private stakeholders. Founded in 2009, GEM aimed to build greater public understanding and awareness of seismic risk, and to increase earthquake resilience worldwide, by sharing data, models, and knowledge through the OpenQuake Platform; by applying GEM tools and software to inform decision making for risk mitigation and management; and by expanding the science and understanding of earthquakes.

During the last five years, GEM has focused on four key pillars:

- Trusted and credible science: Assessing earthquake risk holistically requires multidisciplinary knowledge—seismology, geotechnical and structural engineering, economics and social science—combined with the latest technology. GEM has brought this diverse scientific community together in various scientific platforms which aim to achieve a common language, while keeping discussion and debate alive.

- Wide impact and public good: GEM has focused on trying to bridge gaps—both from science to practice, and from knowledge to action.
- Open and transparent: The OpenQuake platform is being designed to allow users to evaluate the impact of any assumption on results, implement alternative data or models, and explicitly account for uncertainty. Source code of the software and tools is publicly accessible.
- Working together: GEM is made up of people with a passion for contributing to the mitigation of seismic risk, so collaborations have been built across sector, geography, and discipline.

Between 2009 and 2013, GEM made a significant contribution toward advancing the science and technology needed for global state-of-the-art seismic hazard and risk modelling, data collection, and risk assessment at the global, regional, national, and local scales. These contributions include the following:

ISC-GEM Global Instrumental Earthquake Catalogue (released January 2013). This risk assessment data set is a homogenous global catalog of nearly 20,000 earthquakes. Archiving and reassessing records from 1900 to 2009, the catalog represents the most state-of-the art record for earthquake locations and magnitudes currently available.

Historical Catalogue and Archive (released June 2013). This project archives almost a thousand earthquakes. Using the most detailed and up-to-date studies in the scientific literature, this archive spans nearly a millennium, from the early Middle Ages (1000 CE) to the advent of instrumental recording at the start of the 20th century (1903 CE). The catalog itself provides detailed parameters on 827 earthquakes of magnitude greater than 7 across the globe; see Figure **6** for a sample image.

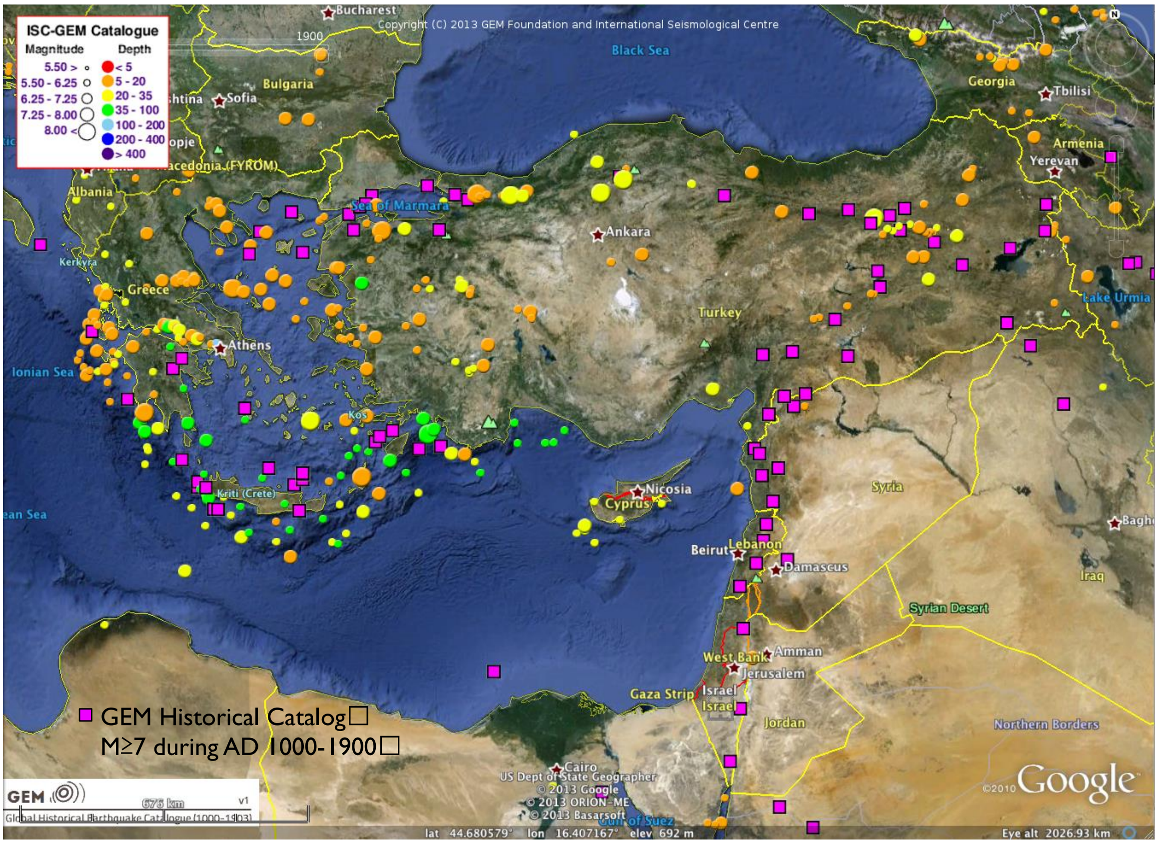


Figure 6. A fuller picture of seismic history is obtained when instrumentally recorded events are combined with events from historical records (in pink).
Source: GEM Historical Catalogue, Global Earthquake Model, http://www.globalquakemodel.org/what/seismic-hazard/historical-catalogue/.

Geodetic Strain Rate Model (released February 2014). This model estimates deformation rates on the Earth's surface based on measurements from the global network of geodetic instruments using the Global Positioning System (GPS). Building upon a data set of more than 18,000 GPS velocity measurements worldwide, the GEM Global Geodetic Strain Rate model represents a fivefold expansion of data from its 2004 predecessor. It features global coverage and high resolution in actively deforming regions.

Active Faults Database and Tools (expected release November 2014). This database assembles available national, regional, and global active-fault databases worldwide within a common repository. A capture tool has been developed to allow local and regional geologists to feed data on local active faults into the common database.

Global Exposure Database (expected release November 2014). The first open database of global buildings and population distribution is being built through the GED4GEM project. GEM's Global Exposure Database will be a multi-scale, multilevel database that will be an integral part of the OpenQuake platform. It has been designed to accommodate data at four levels of resolution, from national to individual-building scales.

Earthquake Consequences Database (expected release November 2014). This database captures a full spectrum of consequences from earthquake-induced ground shaking, landslides, liquefaction, tsunamis, and fire following 66 historical earthquakes between 1923 and 2011.

Physical Vulnerability Database (expected release November 2014). This data set contains more than 7,000 existing and new fragility and vulnerability functions ("damage curves") from around the world, derived from empirical, analytical, and expert-opinion methods, and rated for quality. The functions form the basis for estimating damage and loss in terms of fatalities and building repair costs.

Socio-Economic Vulnerability and Resilience (expected release November 2014). This global database contains indicators measuring social vulnerability, resilience, and economic vulnerability at various scales. The data are structured and sub-structured according to a taxonomy that accounts for eight major categories (population, economics, education, health, governance and institutional capacities, the environment, infrastructure and lifelines, and current indices).

Ground Motion Prediction Equations (released December 2013). This initiative conducted a critical appraisal of ground motion prediction equations (GMPEs) in published scientific literature from around the globe. Defining a clear and reproducible process for the selection of ground motion models across all tectonic settings worldwide, the initiative proposed a set of 10 GMPEs for use in seismic hazard analysis in subduction, active shallow crust, and stable continental regions around the globe.

Building Taxonomy (released December 2013). This taxonomy categorizes buildings uniformly across the globe. It features 13 building attributes, including building occupancy, roof, and wall material. Selected characteristics are those affecting the seismic performance of a building, and also those used to describe exposure. This "common language" will facilitate global collaboration to understand the diversity and seismic vulnerability of buildings.

Physical Vulnerability Guidelines (expected release June 2014). These guidelines apply to the development of empirical, analytical, and expert opinion–based vulnerability functions.

Inventory Data Capture Tools (released January 2014). This set of open source tools captures data on buildings (inventory) both before and after an earthquake. Tools range from those capable of extracting footprints from satellite photos, to tablet or paper forms suitable for field use. After validation, the captured data can contribute to the Global Exposure Database or the Global Earthquake Consequences Database.

Socio-Economic Vulnerability and Resilience (expected release November 2014).This set of tools assesses integrated earthquake risk by combining indices of physical risk with indices of socioeconomic vulnerability and resilience; the latter allows users to incorporate local knowledge.

Modelling Developments

Global Probabilistic Risk Assessment: A Key Input into Analysis for the 2013 and 2015 Global Assessment Reports

Manuela Di Mauro (Risk Knowledge Section, United Nations Office for Disaster Risk Reduction)

The Global Assessment Report on Disaster Risk Reduction (GAR) is the UN flagship publication on global disaster risk and disaster risk management. Building on the UNDP (2004) report on global risk patterns and trends and on the World Bank's 2007 report on natural disaster hot spots throughout the world (Arnold 2005) the GAR has been produced every two years since 2009 by the UN Office for Disaster Risk Reduction (UNISDR). Each report is based on original research and a global assessment of risk from natural hazards. Since 2013, this GAR global risk assessment has been carried out following a fully probabilistic approach applied at global scale (UNISDR, 2013a). The research carried out for the 2013 assessment (UNISDR, 2013b) and for the 2015 assessment involved contributions from world-leading institutions.[12] From this research, original data have been produced, new hazard models have been built, and existing hazard and risk modelling tools have been upgraded, with all outputs peer-reviewed.

Rationale for the probabilistic approach to risk assessment.

The 2009 and 2011 GAR took an historical based approach to risk assessment. Researchers looked at hazardous events and their consequences over the last 30 years and derived exposure and vulnerability parameters (UNISDR, 2009b; UNISDR, 2011). They then used these parameters to estimate losses for any given year from 1970 to 2010. These results were then used to produce a proxy of current risk and past trends by region. The main strength of this model was its capacity to reveal and measure underlying risk factors and drivers. This approach, however, had significant limitations driven by the short historical records which typically did not provide limited temporal and spatial information about the event and lack detailed records of consequences.

A probabilistic approach minimizes these limitations. It uses historical events, expert knowledge, and theory to simulate events that can physically occur but are not represented in the historical record over the past few decades. A probabilistic approach can generate a catalogue of all possible events, the probability of occurrence of each event, and their associated losses. For these reasons, a probabilistic risk assessment approach was used for GAR13, development of which began in late 2011, and it is being further developed for GAR15. This approach delivers a number of key outputs:

[12] Institutions include the Arab Centre for the Studies of Arid Zones and Drylands, Beijing Normal University, Centro Internazionale in Monitoraggio Ambientale (CIMA) Foundation, Geoscience Australia, Global Volcano Model, Joint Research Centre of the European Commission, Kokusai Kogyo, the Norwegian Geotechnical Institute, International Centre for Numerical Methods in Engineering (CIMNE), University of Geneva, Famine Early Warning Systems Network (FEWS-NET), Global Earthquake Model Foundation, the United Nations Environment Programme–Global Resource Information Database (UNEP-GRID), and the World Agency for Planetary Monitoring and Earthquake Risk Reduction (WAPMEER).

- Global stochastic hazard catalogues of earthquakes and tropical cyclones that include their spatial, temporal, and intensity characteristics, and their associated losses
- Regional probabilistic models for riverine flood and agricultural drought
- A global exposure database
- Loss exceedance curves for each hazard at the country level, which provide an estimation of the annual average and the probable maximum loss for a given return period

The flood, earthquake, and tropical cyclone risk assessments were carried out using the CAPRA risk modelling suite (www.ecapra.org).

Applications of the global risk model results. The aim of the GAR global risk assessment is to produce an order of magnitude of the risk at global scale as a basis for advocating for investments in disaster risk reduction. Thus the GAR global risk assessment's results should not be downscaled to a local level and do not render other types of risk assessments unnecessary. Instead, the GAR global risk assessment advocates for national and sub-national risk assessments using consistent approaches and highlighting estimates of hazard, exposure, and risk at national level.

The results from the GAR global risk modelling have a variety of uses:

- They can be used by government officials and ministries as evidence to support the funding of higher resolution risk assessments and can encourage countries to optimize their disaster risk management portfolios.
- For governments engaged in transboundary and regional partnerships implying mutual support and collaboration in case of disasters (e.g., ASEAN), they can be used to provide an overview of the risk levels of the partner countries.
- They can show international organizations (international financing institutions, the UN, NGOs, etc.) how disasters are likely to affect different countries, and can thus form the basis for strategic definition, programmatic prioritization and planning, budgeting, etc.
- They can be used by investors to gain an understanding of the overall level of risk, and thus the potential losses, that a country faces from specific hazards. They can be a means of encouraging investors to perform detailed risk analysis, to budget for DRM as part of their investment planning, and to work with governments to reduce the risk for the country in which they plan to invest.
- For organizations representing small and medium enterprises (the commercial entities that are usually most affected by disasters), results can offer a broad estimation of how major hazards would translate into direct losses. This information can in turn encourage businesses to assess their particular risk and governments to adopt DRM strategies.

The Global Exposure Database. The Global Exposure Database (GED)—with a 5km x 5km cell resolution—was developed for GAR13 by CIMNE and Associates and UNEP-GRID. The GED includes the economic value and number of residents in dwellings, commercial and industrial buildings, and hospitals and schools in urban agglomerations (De Bono, 2013). The physical areas were defined using an urban mask based on MODIS land cover

(Schneider, Friedl, and Potere, 2009) and were divided into rural, minor urban, and major urban areas. Population in urban areas was extracted from LandScan™ (ORNL, 2007). Building classes and percentages for each country were derived from various sources, including the World Housing Encyclopedia, detailed in WAPMERR (2013). The economic value was calculated through analysis of income levels and education levels, with downscaled nationally produced capital based on a gross domestic product proxy. Further details of the exposure analysis are in De Bono (2013); WAPMERR (2013); and CIMNE et al. (2013).

For the 2015 release, the GED will be enhanced to enable inclusion of other initiatives, such as GED4GEM,[13] as well as future population distribution models, a building-type pilot study, and critical facilities, should these become available at a later stage. Additional improvements for 2015 include the following:

- The ability to account for both urban and rural populations and buildings when calculating human and economic losses. This will involve new geospatial layers defining urban areas, such as the global built-up area layer developed by the European Union Joint Research Centre.
- The flexibility to replace the LandScan™ data with gridded population supplied by an alternative source. This makes it possible to avoid any constraints to data distribution linked to proprietary licences.
- Inclusion of socioeconomic parameters, based on income, employment, etc., to the most detailed level possible from subnational data.
- A downscaled 1km x 1km GED in coastal areas for the calculation of tsunami risk and the integration of storm surges in the tropical cyclone risk assessment
- Improvements in the building class distribution at national level and for large countries (e.g., China and United States) to subnational levels (e.g., administrative level 1).
- System performance improvements in functions and algorithms that will support the increased data volume.

Earthquake. For GAR13, the stochastic earthquake event set (location, depth, frequency, and magnitude) was built considering principal seismic sources, tectonic regions and seismic provinces, and historical earthquakes from the U.S. Geological Survey National Earthquake Information Center catalogue. Analysis was undertaken using the CRISIS 2012 earthquake modelling software (Ordaz et al., 2012; CIMNE et al., 2013), which is compatible with the CAPRA modelling suite. The results are expressed in terms of ground shaking (spectral acceleration) in a 5km x 5km grid for each event. The combination of the modelled losses for each building class in each cell of the exposure grid is used to calculate the seismic risk for the cell.

[13] For more on GED4GEM, see "Global Earthquake Model" in part III and **Error! Reference source not found.** ("Global Exposure Data Sets").

For the 2015 GAR global risk assessment, the earthquake model will be improved using the products developed by the GEM foundation, including the new set of Ground Motion Prediction Equations and the new historical seismicity catalogue.[14]

Tropical cyclone. GAR13 assessed tropical cyclone risk using stochastic cyclone tracks generated from historical track information from the IBTrACS database of the National Oceanic and Atmospheric Administration (NOAA). The track information was integrated with data on global topography (derived from NOAA) and terrain roughness (derived by integrating European Space Agency GlobCover and Socioeconomic Data and Applications Center data sets) to estimate surface-level winds over land using the hurricane model of CAPRA (CIMNE et al., 2013).

The tropical cyclone risk model for GAR13 did not consider storm surge, even though this can contribute substantially to the losses caused by this hazard (as Typhoon Haiyan in the Philippines in 2013 made clear). Storm surge will therefore be included in global risk assessment for GAR15. GAR15 will also aim to implement improvements in tropical cyclone modelling highlighted in a peer-review process lead by the World Meteorological Organization.

Riverine flood. A new, fully probabilistic Global Flood Model was developed for GAR15 by the CIMA Foundation and UNEP-GRID.

The GAR13 flood model calculated flood discharges associated with different return periods, in each of the world's major river basins, based on flood discharge statistics from 7,552 gauging stations worldwide. Where time series of flow discharges were too short or incomplete, they were improved with proxy data from stations located in the same "homogeneous region." Homogeneous regions were calculated taking into account information such as climatic zones, hydrological characteristics of the catchments, and statistical parameters of the streamflow data. The calculated probabilistic discharges were introduced to river sections, whose geometries were derived from topographic data, and used with a simplified approach (based on Manning's equation) to model water levels downstream.[15]

Improvements in the 2015 release include the following:

- Updates to the Global Streamflow database, and definition of new approaches to extracting hydrological and climatic information from the database
- Consideration of the influence of dams on the different streamflow conditions, with particular attention to extremes
- Updates to the model's regionalization through a reworking of the concept of homogeneous region with respect to more detailed metrics (e.g., reweighted area on the basis of rainfall volume contribution, seasonality, and time series variance)

[14] For more detail on these products, see "Global Earthquake Model" in part III.
[15] The full technical description of the approach can be found in Herold and Rudari R. (2013).

Tsunami hazard. The global tsunami modelling carried out for GAR13 constituted a significant improvement to the first global-scale tsunami hazard and exposure assessment, carried out for GAR09. In comparison with the previous study, GAR13 provides a more complete coverage of tsunamigenic earthquake sources globally (developed by the Norwegian Geotechnical Institute and Geoscience Australia).

The GAR13 model uses two methods, one based on scenario analysis and one based on a probabilistic method known as Probabilistic Tsunami Hazard Assessment (PTHA) (Burbidge et al., 2009). The first method now uses better input data and is applied for more sources than in the GAR09 model. The second method has been applied for the Indian Ocean and the southwest Pacific using research and analysis undertaken by Geoscience Australia (Cummins, 2009; Thomas and Burbidge, 2009). It calculates a set of synthetic earthquakes to obtain a distribution of possible run-up heights rather than using one scenario per location, and it allows for a robust determination of the return period.

For GAR13, the tsunami hazard was calculated based on earthquakes with a 500-year return period—those earthquakes that are expected to contribute most significantly to tsunami risk.

For GAR15, a fully probabilistic model will be developed through application of the PTHA method globally, in partnership with Geoscience Australia and the Norwegian Geotechnical Institute.

Volcanic hazard. The Global Volcano Model is working on an initial global assessment of probabilistic volcanic ash hazard, using an updated version of the model developed at the University of Bristol. The model employs stochastic simulation techniques, producing a large number of potential scenarios and their relative ash dispersal patterns (Jenkins et al., 2012a, 2012b). In addition, a regional-scale probabilistic volcanic ash hazard assessment is being undertaken using an innovative approach developed by Geoscience Australia. Building upon existing modelling methodologies (Bear-Crozier et al., 2012), this approach emulates hazard for ash-producing volcanoes in the Asia-Pacific.[16] A risk calculation using the CAPRA platform will also be piloted; this approach combines the probabilistic volcanic hazard results and vulnerability models developed by Geoscience Australia with exposure data from the GAR Global Exposure Database.

Vulnerability functions. The vulnerability functions used for the GAR13 global risk assessment are based on those developed for the U.S. Federal Emergency Management Agency's Hazus-MH, also taking into account different resistant construction qualities and the level of countries' development (which affects, for example, the completeness of and adherence to building codes).

The next advance will be to improve the set of vulnerability functions that capture regional variations in construction practices. For GAR15, regional vulnerability curves will be adopted

[16] Two publications are planned under this effort: Probabilistic Volcanic Ash Hazard Analysis (PVAHA) I: Adapting a Seismologically Based Technique for Regional Scale Volcanic Ash Hazard Assessment, by A. N. Bear-Crozier and colleagues; and Probabilistic Volcanic Ash Hazard Assessment (PVAHA) II: Asia-Pacific Modelling Results, by Victoria Miller and colleagues.

for East Asia, Oceania, and the Pacific Islands, through consultation with local experts lead by Geoscience Australia under its existing international development programs (Sengara et al., 2010, 2013; Bautista et al., 2012; Pacheco et al., 2013).

Risk assessment for earthquake, flood, and tropical cyclone. For each building class associated with a gridpoint, the risk is calculated using CAPRA by assessing the damage caused by each of the modelled hazard events.

Because the model considers different events, each gridpoint can be associated with a probability distribution of hazard intensity for certain return periods. As each point of the vulnerability curve is itself a probability distribution, a different probabilistic distribution of damages is calculated in each gridpoint for each event and for each building class. A distribution of losses is therefore calculated for each gridpoint, for each modelled event, and for each building class.

This analysis produces an annual average loss metric, which estimates the loss likely every year due to a specific hazard. As the GAR global risk assessment is performed at global scale, the AAL assessed should be read as an order of magnitude estimate for the potential recurrent extent of losses in a country. The assessment also produces a probable maximum loss metric, which estimates the loss expected for long return periods—for example, 100, 200, or 500 years (depending on the hazard and the needs of the stakeholder). For GAR13, the return period of 250 years was used to assess the PML. This corresponds not to a loss that will happen once every 250 years, but to an event that has 0.4 percent of chance of occurring in any year.

It should be recognized that all results are uncertain. The uncertainty arises from assumptions and data sets used in the assessment of the exposed value, the simplifications necessary to model the hazards at global scale, and the use of vulnerability curves that are not country-specific. However, for the purposes of global-scale analysis and country-to-country comparisons, the level of uncertainty is considered acceptable. These results should thus be considered an initial step toward understanding the extent of disaster losses that a country might face and toward determining further actions, such as detailed country and subnational risk assessments.

Landslide hazard and risk. Analysis in GAR09 showed that 55 percent of global mortality risk from landslides is concentrated in the Comoros, Dominica, Nepal, Guatemala, Papua New Guinea, the Solomon Islands, São Tomé and Príncipe, Indonesia, Ethiopia, and the Philippines. These countries also account for 80 percent of the exposure at risk of landslide (Peduzzi et al., 2009). The landslide susceptibility is a result of terrain slope, soil and geology type, soil moisture content (resulting from rainfall), and seismicity. Given the localized nature of this hazard, a probabilistic approach at a global scale is problematic; however, a number of case studies of countries highly prone to landslide were undertaken by the Norwegian Geotechnical Institute (NGI, 2013).

Landslide risk in Indonesia and El Salvador was assessed in 2011 and 2013, respectively. The El Salvador model produced a detailed susceptibility analysis, which was overlaid by population distribution, to highlight high-risk areas. For 2015, the landslide hazard and risk will be calculated for high-risk countries such as Italy and the Philippines, and systematic improvements will be made in the analysis.

Agricultural drought hazard and risk. The GAR has used both deterministic and probabilistic approaches to analyse the complex phenomenon of agricultural drought.

The deterministic approach developed for GAR13 analyzed the Normalized Difference Vegetation Index, which is derived from 10 years of satellite imagery. This data set, which combines data on land use and agricultural information, provided a regional assessment of drought frequency. This methodology is useful in that it draws on easily available data and it gives a general overview (Erian et al., 2012). Kenya and Somalia will feature as case studies in 2015.

An alternative approach undertakes probabilistic analysis of the relationship between crop losses and precipitation, temperature, and soil conditions. The technique is based on modelling the water content needed by the soil to sustain vegetation, which is done by representing the relationship between water requirement, evapotranspiration, rainfall (satellite derived), soil water-holding capacity, etc. The deficit in water content at critical times of the year (i.e., when germination occurs) and for prolonged periods of time translates into crop losses, which are also determined stochastically by relating known water deficits with data on crop losses. Once these relationships are established, it is possible to produce a synthetic time series of crop losses.

This stochastic water content event set was used to determine annual average crop losses and the probable maximum crop losses for different return periods (Jayanthi and Husak, 2012). This probabilistic approach will be applied to other countries, possibly including different regions in Africa, and will be improved based on peer reviewers' comments. Future work will also include climate change scenarios based on changes in seawater temperatures.

To improve the transparency and the dissemination of the results, the GAR global risk assessment follows an open data policy. The results and data produced within the GAR global assessment reports are available for viewing and downloading (from www.preventionweb.net/gar).

Regional Flood Risk Model for Risk Analyses and Management

Daniela Falter, Dung-Viet Nguyen, Sergiy Vorogushyn, Kai Schröter, Yeshewatesfa Hundecha, Heidi Kreibich, Heiko Apel, Falko Theisselmann, Bruno Merz (GFZ German Research Centre for Geosciences, Potsdam)

During the last decades, damage from floods has increased dramatically. Flood risk is expected to continue rising in response to global changes in climate and vulnerability. The need for regional risk-orientated flood management approaches is widely accepted; indeed, it is required by the European Union flood directive. Large-scale risk assessments are needed for a number of purposes, including development of national risk policy, large-scale disaster management planning, and risk management by the insurance and reinsurance industries. However, large-scale risk assessment methods for areas that are 10,000km^2 or more are still in the early stages.

The most common approach to large-scale flood hazard assessment is the reach-wise calculation of T-year discharges for the entire river network assuming a spatially uniform return period. This method estimates inundation extent and depths using derived flow peaks and their associated synthetic hydrographs, which show variations in discharges over time. The estimation of discharges for different return periods is typically based on extreme value statistics of gauging station data. An example is the Rheinatlas (http://www.rheinatlas.de/), which gives data on inundation extent and associated damage along the Rhine for several return periods. Merz, Blöschl, and Humer (2008) similarly estimate 30-, 100-, and 200-year return period flood discharges for 26,000 river km in Austria.

The assumption of spatially uniform return periods is very valuable for deriving the local hazard, but it is of limited use when large-scale patterns are important. The assumption of a T-year flood for the entire river network gives an unrealistic picture and tends to overestimate flood risk on large scales. The probability of a single flood reaching the extent of a flood with a 100-year return period in the entire large-scale river network is much smaller than the annual probability of such a flood at a single site (1/100 per year). This difference arises because events that occur upstream, such as dikes overflowing or breaching, tend to diminish flooding downstream—a tendency that most spatially homogeneous return-period approaches do not account for.

The disadvantage of spatially homogeneous return-period scenarios can be overcome by another group of event-based approaches, which generate a set of spatially consistent synthetic flood events with heterogeneous local return periods (e.g., Rodda, 2005; Lamb et al., 2010; Keef, Tawn, and Lamb, 2013). However, depending on the complexity of the methodology, event-based approaches may suffer from their focus on only a few scenarios, their generation of unrealistic hydrograph shapes, or their provision of only peak flows. Floods are generated and influenced by a multitude of catchment and river processes that might not be captured adequately by event-based statistical-stochastic methods.

An alternative approach is the continuous simulation of rainfall-runoff with hydrological models, driven by continuous synthetic or observed climate data or climate model scenarios. This approach has the advantage that all hydrological processes that influence the runoff are implicitly considered in a consistent way, and the complete flood event, including antecedent processes, is modelled throughout the entire catchment. This approach is complemented by including the hydrodynamic simulation of water levels and inundation processes within the continuous simulation. In that way, physical processes like storage effects, flood attenuation, or channel-floodplain interactions can also be accounted for. However, large-scale, continuous hydrodynamic simulation requires excessive computational time and brings additional sources of uncertainty into hazard and risk assessment.

Despite the methodological strengths of continuous simulation approaches, until now there have not been attempts to combine hydrological and one-dimensional/two-dimensional (1D/2D) hydrodynamic and damage assessment models within a continuous simulation framework for large-scale flood risk assessments; the computational challenges and data requirements of 2D hydrodynamic flood inundation models have been an impediment. We describe below a first attempt to apply a full deterministic flood risk assessment chain for large-scale basins based on a continuous simulation approach. The framework for this Regional Flood Model (RFM) includes rainfall-runoff, 1D river network, 2D hinterland inundation, and damage estimation models. The approach combines different elements of the flood risk chain, from flood-triggering precipitation to damage, in a continuous simulation mode that enables a spatially consistent flood hazard and risk assessment.

Regional Flood Model. The proposed RFM consists of four model parts: the rainfall-runoff model (called SWIM, for Soil and Water Integrated Model), a 1D channel routing model, a 2D hinterland inundation model, and the flood loss estimation model for residential buildings (FLEMOps+r) (Figure **7**).

The SWIM hydrological model (Krysanova, Müller-Wohlfeil, and Becker, 1998) computes the routing of the daily rainfall-runoff through the river catchment. When the water fills the river to the tops of the banks and starts to overflow in the floodplain, the 1D hydrodynamic model routes the flow exceeding this bankfull discharge downstream along the river network. The routing along the river network is based on simplified cross-sections describing the overbank river geometry and elevation of flood protection dikes. Whenever the water level reaches the dike crest height, the overtopping flow into the hinterland is calculated with a 2D hydrodynamic hinterland inundation model. For each flood event during a continuous simulation, maps of maximum water depths are generated and used as input to the FLEMOps+r damage model (Elmer et al., 2010). Further, the recurrence intervals of the flood peaks for each hydrological sub-basin are estimated. Using the information about inundation depth, recurrence intervals, exposure, and characteristics of the residential building stock, the multifactorial flood damage model FLEMOps+r provides an estimate for flood losses (Elmer et al., 2012).

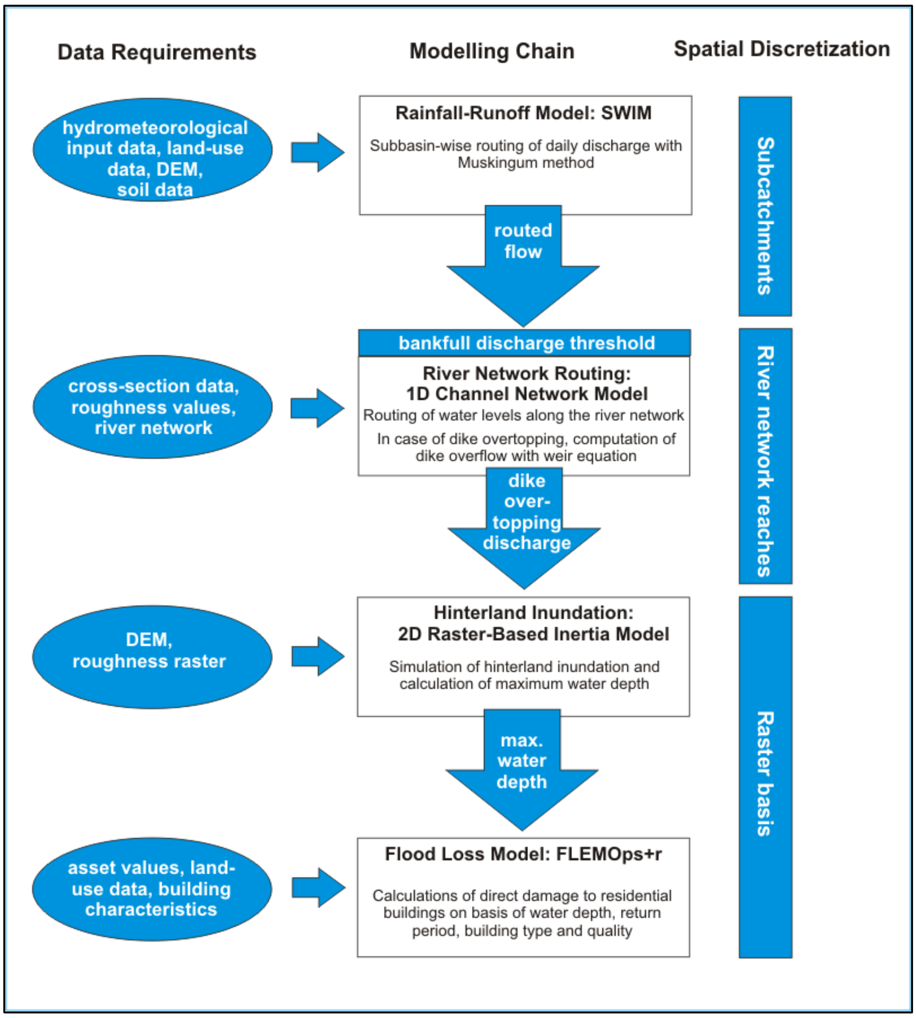


Figure 7. Components and data requirements of the Regional Flood Model.
Source: Falter et al., forthcoming.
Note: DEM = digital elevation model.

Regional Flood Model: Proof-of-concept. Falter et al. (forthcoming) performed a proof-of-concept exercise for large-scale flood risk assessments with RFM, including a careful discussion of the proposed methodology's limitations. The model chain was applied to one of the largest catchments in Germany, the Elbe. Hydrodynamic simulations included a catchment size of around 66,000km^2 with a relatively high resolution of 100m and a river network of around 2,700km. The simulation period comprised 14 years (1990–2003).

Results and conclusion. Each module of the model chain introduces uncertainties; therefore simulation results were validated against observed data where possible. In general, discharge was found to be simulated adequately with SWIM compared to observed data, although simulations were not reliable for tributaries under heavy human intervention. The quality of water level simulation varied depending on the representation of overbank cross-sections and on the definition of bankfull flow thresholds. Better data on cross-sections and better definition of threshold values would very likely improve current simulation results. Hinterland inundation extents are difficult to validate. To our knowledge, there occurred three floods during the simulated period causing hinterland inundation and flood loss: April 1994, August 2002, and January 2003. Inundation extents are documented only for the disastrous flood event in August 2002, however. The simulated and observed flood extents were not expected to match, given that the inundation areas of 2002 mainly depended on the location, timing, and characteristics of the numerous cases of dike overtopping and dike breaching. A qualitative comparison indicated an underestimation of inundation extents. This can be attributed to missing dike breach representation within the RFM framework. Flood loss estimates were available only for two out of three documented flood events. Whereas calculated flood loss estimates for the flood in April 1994 are of the same order of magnitude as the available estimates, the damage of August 2002 is underestimated in accordance with the underestimation of inundation extent (Table 1).

Table 1. Comparison of Flood Loss Model Results with Other Damage Estimates for April 1994 and August 2002 Floods (€ millions)

Event	Area	FLEMOps+r	Other damage estimates		
		Residential building damage (€ millions)	Total damage (€ millions)	Residential building damage (€ millions)	Source
Apr. 94	Germany	-	161	48[a]	EM-DAT 2012
		-	153	46[a]	Munich Re
	Elbe catchment in Germany	42	-	-	
Aug. 2002	Germany	-	8,923	2,677[a]	EM-DAT 2012
		-	11,800	3,540[a]	Munich Re
	Elbe catchment in Germany	237	8,900	2,670[a]	IKSE 2004
	Saxony	-	6,196	1,706	State Chancellery of Saxony 2003

Source: Falter et al. forthcoming; based on EM-DAT: The OFDA/CRED International Disaster Database, Université Catholique de Louvain, Brussels, Belgium (accessed June 18, 2012), www.emdat.be; Munich Re, NatCatSERVICE, Munich, Germany (accessed June 18, 2012), www.munichre.com.

a. Amounts are estimated as 30 percent of total damage, based on State Chancellery of Saxony (2003).

The run time of the 2D hydrodynamic hinterland inundation model was optimized by implementation for highly parallelized graphics processing units. For a simulation period of 14 years, the 1D and 2D hydrodynamic models needed around 20 hours of run time. This run time enabled the application of 1D and 2D hydrodynamic models for long-term simulations of several decades and longer. Errors are significant in the current application of RFM, partly due to neglect of dike breach processes, but mainly due to low data quality. Better information on dike location and height as well as on overbank cross-sections will significantly improve the hydrodynamic simulation results and the damage estimation.

We conclude that the concept of RFM is applicable to large-scale deterministic flood risk assessment. When long-term observed or generated climate data or climate change scenarios are used, results and run time are adequate for the purpose of continuous simulation at the large-catchment scale. The model is unique in incorporating continuous and coupled simulation of rainfall-runoff processes, 1D hydrodynamic river network simulation that includes representation of the dike system, 2D hydrodynamic simulation of hinterland inundation, and flood loss estimation at relatively high spatial resolution at the large-catchment scale. In contrast to large-scale applications that use a reach-wise approach and assume a spatially uniform return period for the entire river network, the holistic approach used in RFM can potentially provide a realistic large-scale picture of deterministic flood risk. Because of the continuous simulation approach, there is no limitation on event sets, as proposed by some other studies. Nor is there a need to create hydrographs that might be unrealistic in their shapes. The relatively high resolution of 100m has the potential to provide adequate inundation depths and extents for detailed flood loss estimations.

First applied to the Elbe catchment, Regional Flood Model can be transferred to other large basins in Germany and elsewhere, and has the potential to provide deterministic flood risk statements for national planning, reinsurance, and other areas where spatially consistent, large-scale assessments are required.

Global Water-related Disaster Risk Indicators Assessing Real Phenomena of Flood Disasters: Think Locally, Act Globally[17]

Toshio Okazumi, Sangeun Lee, Youngjoo Kwak, Gusyev Maksym, Daisuke Kuribayashi, Nario Yasuda (International Centre for Water Hazard and Risk Management)

Water-related disasters, including both flood and drought, continue to pose threats globally. Although preventive strategies have been devised to address this risk, especially in the years since the Hyogo Framework for Action (HFA), important steps still need to be taken to guide DRM.

Water-related risk assessments do exist, but none is without limitations.[18] Credible water-related disaster risk indicators need to meet five particular challenges (ICHARM, 2013):

[17] The International Centre for Water Hazard and Risk Management (ICHARM) operates under the auspices of UNESCO and the Public Works Research Institute, Japan. The authors would like to express their sincere appreciation to the following for their valuable inputs: Dr. Satoru Nishikawa (special representative of the Secretary-General for DRR on the Post-2015 Framework for DRR and the Global Platform); Mr. Yusuke Amano (Water and Disaster Management Bureau, Japan); and Dr. Yuki Matsuoka (UNISDR Hyogo Office). We are also indebted to the Philippine Atmospheric, Geophysical and Astronomical Services Administration and the Asian Disaster Preparedness Center for providing their data and comments.

[18] For the sake of brevity, the discussion here will focus on the risk of fatality-causing floods.

1. *They must represent the real phenomena.* Categorizing data and proxies on an ordinal scale[19] creates indicators that lack transparency and physical meaning.

2. *They must evaluate flood hazard in terms of the frequency and intensity of the physical phenomenon.* Hazard assessments that examine the frequency of occurrence of flood events often do not highlight the potential intensity and therefore potential impact of the event.

3. *They must take into account the effectiveness of water infrastructure.* Global-scale hydrological models generally ignore the effectiveness of dams, reservoirs, levees, etc. This practice produces inaccurate indicators and fails to emphasize governments' efforts to protect people from floods.

4. *They must use meaningful proxies for vulnerability.* Using poverty-related proxies such as GDP per capita or a national wealth index to represent vulnerability assumes a clear relationship between poverty and flood risk, though one has not been established. Nor does this approach provide guidance on how to protect people from flood disasters (Wisner, et al., 2004).

5. *They must clearly identify risk hot spots*. Identifying large target areas is insufficient because affected people and fatalities may be concentrated in risk hot spots that are small fractions of the target area.

This discussion below focuses on the third issue, concerning the inclusion of water infrastructure in regional or national flood risk assessments, using three case studies. All three river basins are heavily populated, located in or near capital cities, and suffer frequent floods from tropical cyclones and typhoons. Table 2 summarizes the overall characteristics of the three river basins.

Table 2. Basic Characteristics of the Three River Basins

	Pampanga	Chao Phraya	Tone
River length (km)	265	1,100	322
Basin area (km^2)	10,540	163,000	16,840
Population	5.8 million	23 million	12 million
Percentage of national population (%)	6.8	40	10
River bed gradient in the midstream area	1/1,000 to 1/2,500	1/11,000 to 1/12,000	1/4,000 to 1/6,000

[19] Such a conceptual approach uses hazard, exposure, and vulnerability indices to assign data to various categories. For each category, a score is derived by arithmetic computations, such as by using the weighted rank sum method. A conceptual risk index is finally presented on a 0 to 1 scale by summing the scores.

Average annual temperature at key gauging stations	27.5 °C, CLSU Munoz station	28 °C, Nakhon Sawan station	15 °C, Maebashi station
Average precipitation (mm/year)	2,100	1,487	1,300
Peak discharge at key gauging stations during the recent largest flood	About 1,880 m^3/s, Arayat station, 2004	About 6,900 m^3/s, Nakhon Sawan, station, 2011	About 9,200 m^3/s, Yattajima station, 1998

Sources: JICA (2011) for Pampanga; JICA (2013) for Chao Phraya; MLIT (2006) for Tone.

In the delta area of the Pampanga River, the flow capacity is so small that even low river discharges, such as those of floods with a five-year return period, can cause flooding. Over the whole river basin, floods happen almost every year.

In the Chao Phraya River basin, four tropical cyclones and Typhoon Nesat in 2011 caused floods that broke levees at 20 locations. For the period from July to November 2011, flooding damaged industrial parks and affected residents' livelihoods over large areas inside and outside Bangkok.

The Tone River basin experienced tremendous damage from Typhoon Kathleen in 1947. After this event, the Japanese government strived to improve levees and construct dams and retarding basins. Although middle-sized discharges are common, they have not been a serious threat to the mainstream river, but the tributaries often experience floods. Nevertheless, large floods (those with a 100-year or greater return period) are anticipated to pose a significant threat to the social and economic systems, given the area's high population density and many links with domestic and overseas industries. Impacts of these historical floods in the three river basins are summarized in Table 3.

Table 3. Historical Flood Disasters in the Three River Basins

	Pampanga	Chao Phraya	Tone
Date of disastrous flood	August 2004	July 2011	September 1947
Inundation area (km^2)	1,151	28,000	440
Affected people (persons)	757,000	13,500,000	600,000
Damaged houses (numbers)	120 totally damaged	2,300 totally damaged	23,700 totally damaged
	1,200 partly damaged	97,000 partly damaged	31,400 partly damaged
Affected agricultural area (ha)	71,772	1,800,000	177,000
Fatalities (persons)	14	660	1,100

Sources: JICA (2011) for Pampanga; JICA (2013), data from Philippine Bureau of Agricultural Statistics (2013) for Chao Phraya; MLIT (2006) for Tone.

Hazard assessment. To assess the flood hazard, we utilized a simplified modelling technology to produce flood inundation depth (Kwak, et al., 2012) based on flood river discharge simulated with the distributed hydrologic Block-wise TOP (BTOP) model (Takeuchi, Ao, Ishidaira, 1999). Using global data sets, this enabled us to apply a standard hazard assessment methodology to various river basins in different countries for inundations associated. This approach had a number of advantages:

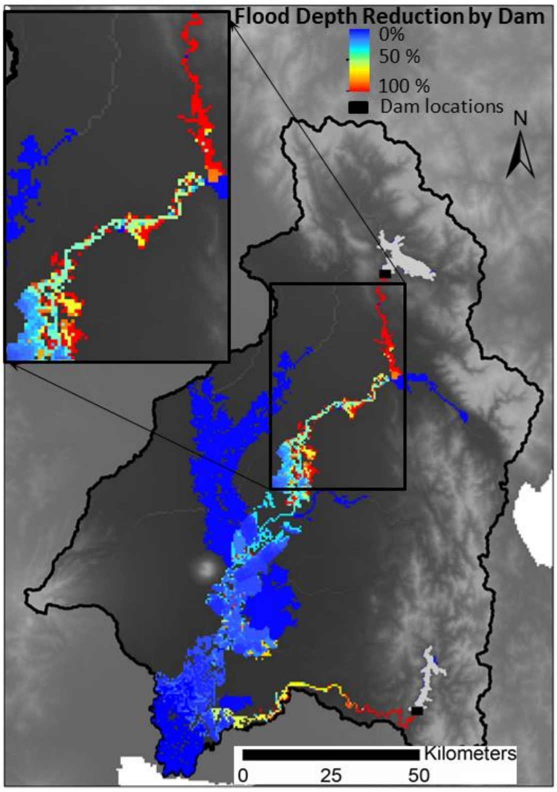
- Data sets used (for precipitation, temperature, topography, soils, land use, etc.) were globally available.
- Visual comparisons were undertaken between 1 in 50 year flood events and historical flood inundation maps.
- Consideration of dam effectiveness made it possible to account for individual dams' flood control capacity, which in turn made it possible to reduce the 50-year flood discharge.
- It was possible to consider levee effectiveness when calculating overflow water level (the overflow water level is calculated as the difference between the flood water level of the 50-year flood discharge and the bankfull water level) and inundation depth for each grid globally.[20]

This hazard assessment calculated changes in inundation with and without water infrastructure such as dams and levees (Figure 8). The inundation changes due to dams with flood control capacity are shown in panel a for the Pampanga River basin and panel b for the Chao Phraya River basin; inundation changes due to levees are shown in panel c for the Tone River basin.

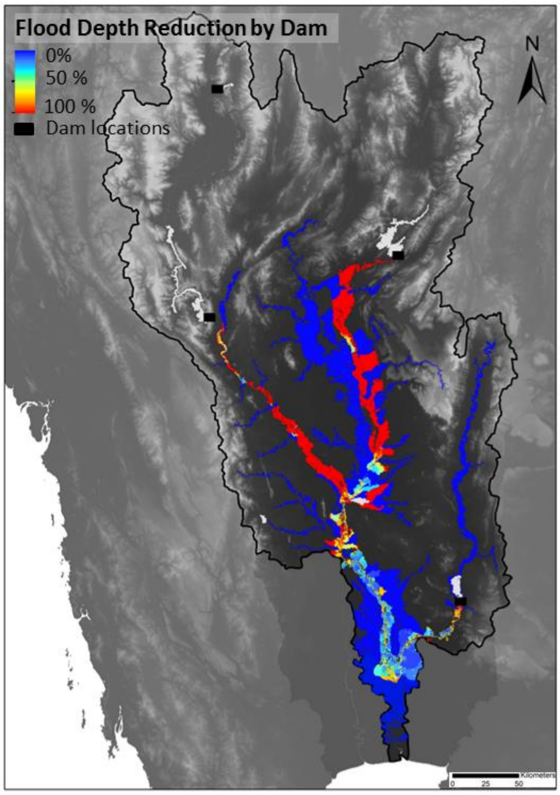
In the Pampanga River basin (panel a), the Pantabangan Dam makes a large change to inundation in its downstream area (see the enlarged area in panel a). In the Chao Phraya River basin (panel b), three dams have very large flood control capacities and reduce the inundation. In the Tone River basin (panel c), the water infrastructure does not affect the headwaters but creates drastic changes in the downstream area. This dramatic inundation change can be explained by the comprehensiveness of the water infrastructure, including super-levees designed to protect the highly populated Tokyo Metropolitan area.

Table 4 presents the respective values of flood inundation area change in the three river basins considering water infrastructure. The projected flood inundation area due to a 50-year discharge decreases in response to both types of infrastructure (dam and levee). Above all, the Tone River basin case is noticeable, in that the reduction is as high as 86 percent owing to the effect of levees.

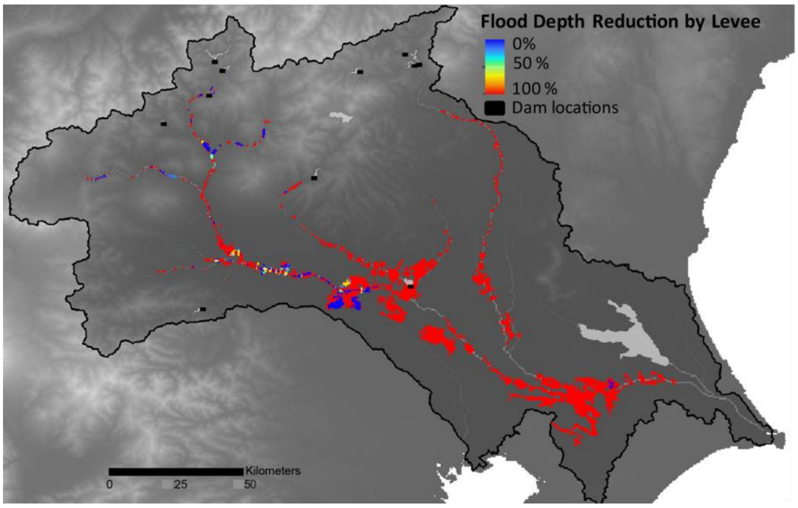
[20] Only the effectiveness of the levee with respect to overflow is considered. Breaching of levees is not considered in this analysis. This may underestimate the calculated inundation extend and the water depths of the flood when levees are included in the calculation.



a. Pampanga River basin



b. Chao Phraya River basin



c. Tone River basin

Figure 8. Effects of Water Infrastructure in Reducing Flood Inundation Depths for 50-Year Floods.

Table 4. Potential Flood Inundation Areas in the Three River Basins (considering or omitting dams and flood protection)

	Pampanga	Chao Phraya	Tone

Infrastructure	Dam	Without dam	Dam	Without dam	Levee	Without levee
Potentially inundated area (km^2)	1,320	1,360	14,310	18,060	130	890
Percent change	3.2		21		86	

To assess flood exposure, we assumed a critical inundation depth of 0.1m in view of the minimum resolution of topographical data and models. We used the Global Population Database of LandScan™ as a digital population map in order to estimate potentially affected people, i.e., population at grid cells where 50-year floods are likely to cause inundations beyond the critical level.

Table 5 shows the respective values of flood exposure change considering water infrastructure. The number of affected people decreases in response to both dams and levees. The dams' flood control capacity in the Pampanga River basin resulted in a small decrease in flood inundation depths and areas, implying a 6 percent decrease in the number of affected people. The decrease in affected people was much more noticeable in the zone managed by the Pantabangan Dam (see the enlarged areas in panel a of Figure 8). The number of affected people was reduced by about 30 percent. Dams in the Chao Phraya River basin could moderately decrease flood inundation depths and areas, implying a 48 percent decrease in the number of affected people. In the Tone River basin, levee infrastructure has the potential to significantly decrease inundation depths, implying a sharp decrease—88 percent—in the number of affected people.

Table 5. People Potentially Affected by Flood Inundation (considering or omitting dams and flood protection)

	Pampanga		Chao Phraya		Tone	
Infrastructure	Dam	Without dam	Dam	Without dam	Levee	Without levee
Potentially affected persons	935,000	993,000	4,342,000	8,301,000	59,000	487,000
Percent change	6		48		88	

This analysis has clearly shown the importance of including water infrastructure in a flood risk assessment. Global and regional flood analysis that fail to consider water infrastructure should be treated with caution, as this type of analysis will inevitably result in an overestimation of both the flood extent and impact to communities.

Risk Assessment Case Studies

Government-to-government Risk Assessment Capacity Building in Australasia[21]

DFAT/AIFDR/BNPB/Badan Geologi/CSCAND/Geoscience Australia

During the last five years, the Australian aid program has supported a series of successful capacity-building activities for natural disaster risk assessment within neighboring Southeast Asian countries. Although the modality of engagement between the agencies has varied in

[21] The authors gratefully acknowledge Guy Janssen, whose independent review of the Indonesian Earthquake Hazard Project identified and articulated many of the factors for success discussed in this paper. XXX publish with the permission of the CEO, Geoscience Australia.

each country context, the successes have been uniformly underpinned by strong, long-term bilateral government-to-government (G2G) relationships between Geoscience Australia and partner technical agencies.

In Indonesia, the Jakarta-based Australia-Indonesia Facility for Disaster Reduction provides a forum for ongoing interactions between risk assessment practitioners from government of Indonesia, technical agencies and Australian risk and vulnerability experts posted in Indonesia. Earthquake, tsunami, and volcanic hazard modelling activities have increased government capacity to understand the country's natural hazard risk profile, and these gains have in turn informed significant policy directives at the national level (e.g., the 2012 Indonesian Presidential Master Plan for Tsunami Disaster Risk Reduction).

In the Philippines, capacity-buildings activities have been facilitated through remote bilateral relationships between the government of Philippines Collective Strengthening of Community Awareness on Natural Disasters (CSCAND) agencies and Geoscience Australia staff based in Canberra. As a result of these activities, the Greater Metro Manila Risk Assessment Project (GMMA RAP) has produced one of the world's first non-commercial multi-hazard risk assessments for a megacity on this scale. See Section X for more information about this project.

Background. The Australian government has invested in a variety of DRM activities, including efforts to strengthen the capacity of partner government technical agencies to map risks from natural hazards. The Australian aid program draws on the technical expertise of Australian government departments to help developing country partners build their capacity to reduce disaster risk.

Geoscience Australia, the Australian government's national geoscience agency, provides geoscientific advice and information to support governmental priorities. Geoscience Australia has had a long engagement in disaster mitigation and preparedness, primarily through the quantitative modelling of the potential risks posed by natural hazards in Australia. Geoscience Australia has accumulated important research, tools, and experience over the past 15 years as part of efforts to mitigate and prepare for the risks to Australian communities from earthquakes, tsunami, severe wind, flood, and volcanoes. This work has included the development of open source software that can be used in quantitative modelling of these hazards and risks. Examples include the EQRM for earthquake hazard and risk modelling (http://code.google.com/p/eqrm/; Robinson, Dhu, and Schneider, 2006) and the ANUGA for flood and tsunami inundation modelling (https://anuga.anu.edu.au/). For the past six years, as part of the Australian aid program, Geoscience Australia has been actively applying these risk modelling tools and experience to capacity building activities with partner technical agencies in the Asia-Pacific region.

Two of Geoscience Australia's official development assistance programs, with the governments of Indonesia and the Philippines, have strengthened the capacity of partner technical agencies to undertake natural hazard and risk modelling. Though the two programs faced different challenges and were delivered through different modalities of engagement, both have been considered successful. This paper outlines Geoscience

Australia's engagement with technical partners in Indonesia and the Philippines and explores the common factors that have led to significant gains in capacity in the region.

Indonesia. The AIFDR, in operation since 2009, represents the Australian government's largest bilateral commitment to reducing the impact of disasters and is a key part of Australia's development program in Indonesia.[22] The program aims to strengthen national and local capacity in disaster management in Indonesia and promote a more disaster-resilient region. A key component involves facilitating partnerships between Australian and Indonesian scientists to develop and demonstrate risk assessment methods, tools, and information for a range of natural hazards, in which Geoscience Australia played a key leadership role.

Two activities undertaken between 2009 and 2013 illustrate this style of partnership: the Indonesian earthquake hazard project, and a volcanic ash modelling project.

The earthquake project aimed to build the capacity of the Indonesian government to understand and quantify Indonesia's earthquake hazard, including earthquakes' likely location, size, and frequency. Achievements include: a revised national earthquake hazard map for Indonesia, designed for use within Indonesia's building codes as well as for more general risk assessment; the capacity to maintain and update this hazard map in the future; and the production of over 160 real-time ShakeMaps and impact forecasts to inform emergency earthquake response.

The project was implemented by a partnership of Indonesian and Australian government science agencies and academic institutions with additional technical and management support from AIFDR staff. The major deliverables were produced collaboratively with five key Indonesian agencies[23] and the interagency memorandum of understanding developed among these agencies represented the first formal agreement on roles and responsibilities for understanding and managing earthquake hazard analysis in Indonesia.

---

[22] For more information, see http://aid.dfat.gov.au/countries/eastasia/indonesia/ and http://www.aifdr.org/. The AIFDR is managed by Australian and Indonesian co-directors, and AIFDR work programs and funding decisions are jointly developed by the Australian Department of Foreign Affairs and Trade (DFAT) and Badan Nasional Penanggulangan Bencana (BNPB; Indonesian National Agency for Disaster Management)

[23] The agencies are the BNPB; Badan Geologi (Geological Agency of Indonesia); Badan Meteorologi, Klimatologi, dan Geofisika (Indonesian Agency for Meteorology, Climatology, and Geophysics); Lembaga Ilmu Pengetahuan Indonesia (Indonesian Institute of Sciences); and Institut Teknologi Bandung (Bandung Institute of Technology).

Figure 9. Extract from a probabilistic seismic hazard map of Gorontalo Province developed collaboratively by Badan Geologi and Geoscience Australia.

In addition, significant improvements were made in earthquake education and research; notably, the program for Graduate Research in Earthquakes and Active Tectonics was established at the Bandung Institute of Technology. This program has become a crucial resource for government of Indonesia, providing it with opportunities for earthquake-related education and collaborative research as well as independent scientific expertise.

A mixture of modalities was used in this program. The primary form of technical assistance was direct training and mentoring of Indonesian scientists by Australian scientists who were based in Jakarta. These were supplemented with additional technical support from Canberra-based scientists through short-term (one- to three-week) missions. Funding was also provided to allow Indonesian students to study in Australia, and to facilitate Indonesian students and academics to undertake research in Indonesia.

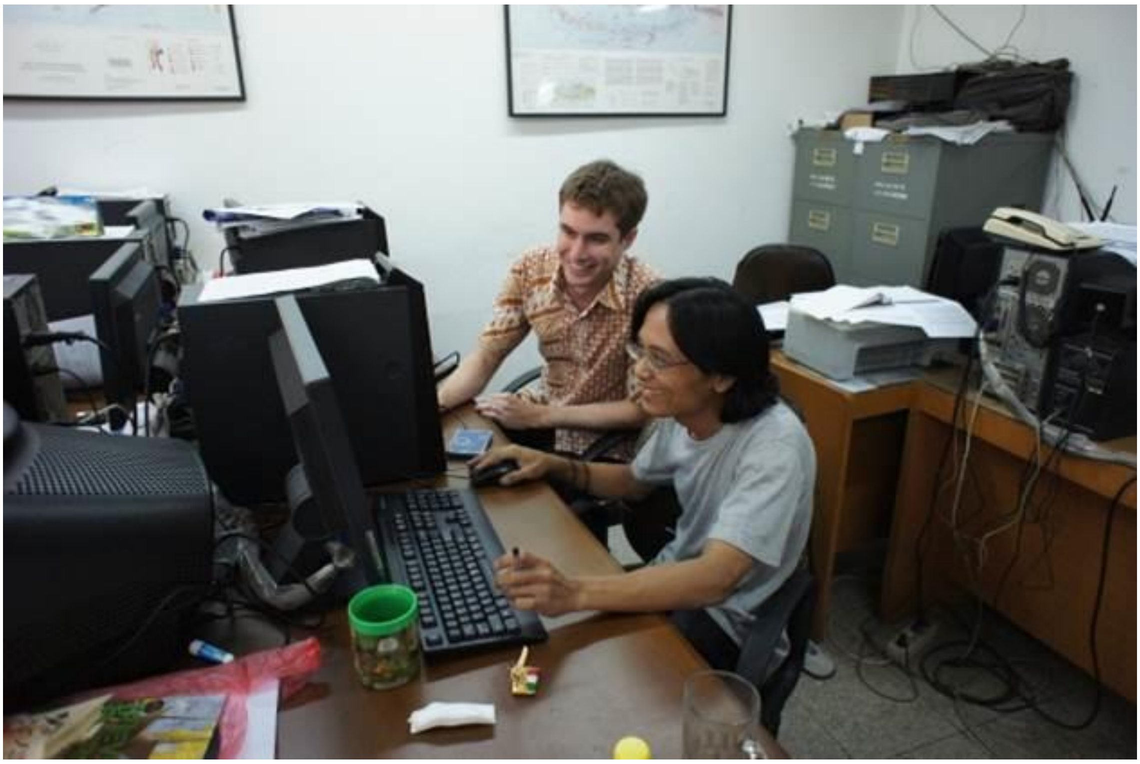


Figure 10. Badan Geologi and Geoscience Australia staff working collaboratively on probabilistic seismic hazard maps for Indonesia.

The second activity designed to build the risk modelling capacity of Indonesian technical agencies focused on volcanic ash modelling. The activity's specific goal was to develop the capacity of Badan Geologi to undertake probabilistic volcanic ash modelling using open source modeling tools. This capacity allows the government of Indonesia to rapidly assess the potential volcanic ash risk from Indonesian volcanoes.

The first phase of the activity focused on testing and assessing existing volcanic ash dispersal models and identifying the most suitable model for adaptation and use in Indonesia. The second phase involved validating the chosen model against historical eruptions in Indonesia in order to assess the accuracy and uncertainty in the simulations, and implementing the model as part of a case study of four volcanoes located in West Java. (Field work is shown in Figure 11.) The final phase of the activity primarily focused on building the capability to undertake near-real-time volcanic ash forecasting using the existing model.

Figure 11. Badan Geologi and Geoscience staff collect volcanic ash samples from a roadside agricultural plot of land approximately 10km from the summit of Ciremai volcano, West Java, in 2010.
Source: A. Bear-Crozier, Geoscience Australia.

All phases of this activity were successfully completed, with the following results:

- Badan Geologi has the capacity to use volcanic ash modelling tools in Indonesia.
- The GoI has probabilistic volcanic ash hazard information available for four West Javan volcanoes and near-real-time forecasting information available for two North Sulawesi volcanoes.
- Badan Geologi has the capacity to apply the volcanic ash dispersion model using standard computers. To undertake more computationally intensive probabilistic and near-real-time forecasted volcanic ash modelling into the future, the government of Indonesia has invested in high-performance computing equipment.
- Badan Geologi has determined that further engagement with Geoscience Australia and the AIFDR in volcanic ash modelling would be highly beneficial. This work would likely focus on building Badan Geologi 's capacity to produce regional and national scale map products from volcanic ash modelling.

The success of this program was demonstrated in early 2013, when Gunung Guntur erupted in West Java. After increased seismicity was detected, Indonesian volcanologists at the Volcanology and Geological Disaster Mitigation Centre assumed responsibility for using the volcanic ash dispersal models to gain some insight into how wind conditions over the coming days could affect ash dispersal. Figure **12** shows the center's ash dispersal model for the last historical eruption of Guntur, in 1840.

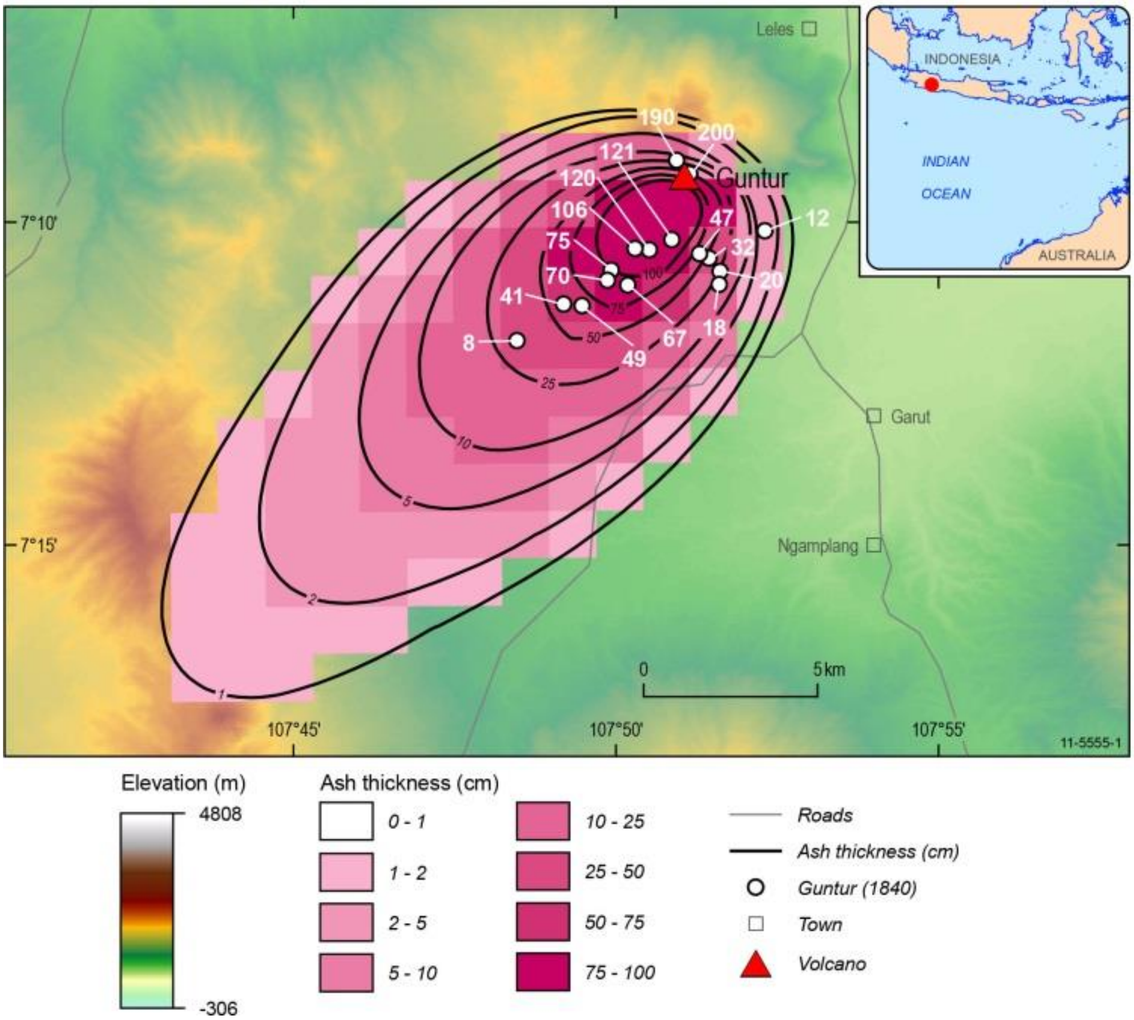


Figure 12. The dispersal of volcanic ash from the last historical eruption of Guntur in 1840, which was modelled as a proxy for what could happen in a future eruption.
Source: Volcanology and Geological Disaster Mitigation Centre.
Note: A combination of field data and volcanic ash dispersion modelling was used to calibrate the dispersion model for forecasting possible future eruptions.

The volcanic ash modelling activity was implemented almost entirely through short-term missions, conducted as a series of workshops hosted by both Badan Geologi and Geoscience Australia. These workshops provided an important capacity-building environment for knowledge transfer and intensive skill building. In the months between workshops, Geoscience Australia staff provided ongoing remote technical support to Badan Geologi via email, telephone, social media, and videoconference.

Philippines. In 2008, a partnership between Australia and the Philippines was formed with the aim of reducing disaster risk. During the initial years of this engagement, Geoscience Australia worked with government of Philippines technical agencies, known jointly as the CSCAND agencies, on a project to strengthen natural hazard risk assessment capacity in the Philippines.

In 2010, the BRACE (Building the Resilience and Awareness of Metro Manila Communities to Natural Disaster and Climate Change Impacts) program was developed, which aimed to reduce the vulnerability and enhance the resilience of Metro Manila and selected neighboring areas to the impacts of natural disasters and climate change. As part of this larger program, Geoscience Australia worked with CSCAND agencies on the Greater Metro Manila Area Risk Assessment Project;[24] see also section X. This collaboration contributed to the overall aims of the program by increasing the capacity of Philippine Government technical experts to understand how the potential risks and impacts of natural hazards in the Philippines can be assessed.

In contrast to the Indonesia initiative, the work in the Philippines involved a multi-hazard probabilistic risk assessment for a single megacity (Manila) that included estimations of economic loss and potential casualties. Significant coordination from the Philippines Office of Civil Defense and associated agencies was needed to bring together the disparate agencies working on different hazards for the same area.

The key outcomes of the project are these:

- Manila and national government authorities have base data sets (such as high-resolution digital elevation models, captured through LiDAR) available for analyzing natural hazard risk and climate change impacts.
- Government of Philippines technical specialists better understand, and are better able to produce, exposure databases and exposure information is now available in the Greater Metro Manila Area for analyzing natural hazard risk and climate change impacts.
- Scientists within government technical agencies are better able to assess the risk and impacts from flood (Figure **13**), cyclone and earthquake, and better understand these risks in the Greater Metro Manila Area.

[24] GMMA RAP is also known as the Enhancing Risk Analysis Capacities for Flood, Tropical Cyclone Severe Wind, and Earthquake for Greater Metro Manila Area program.

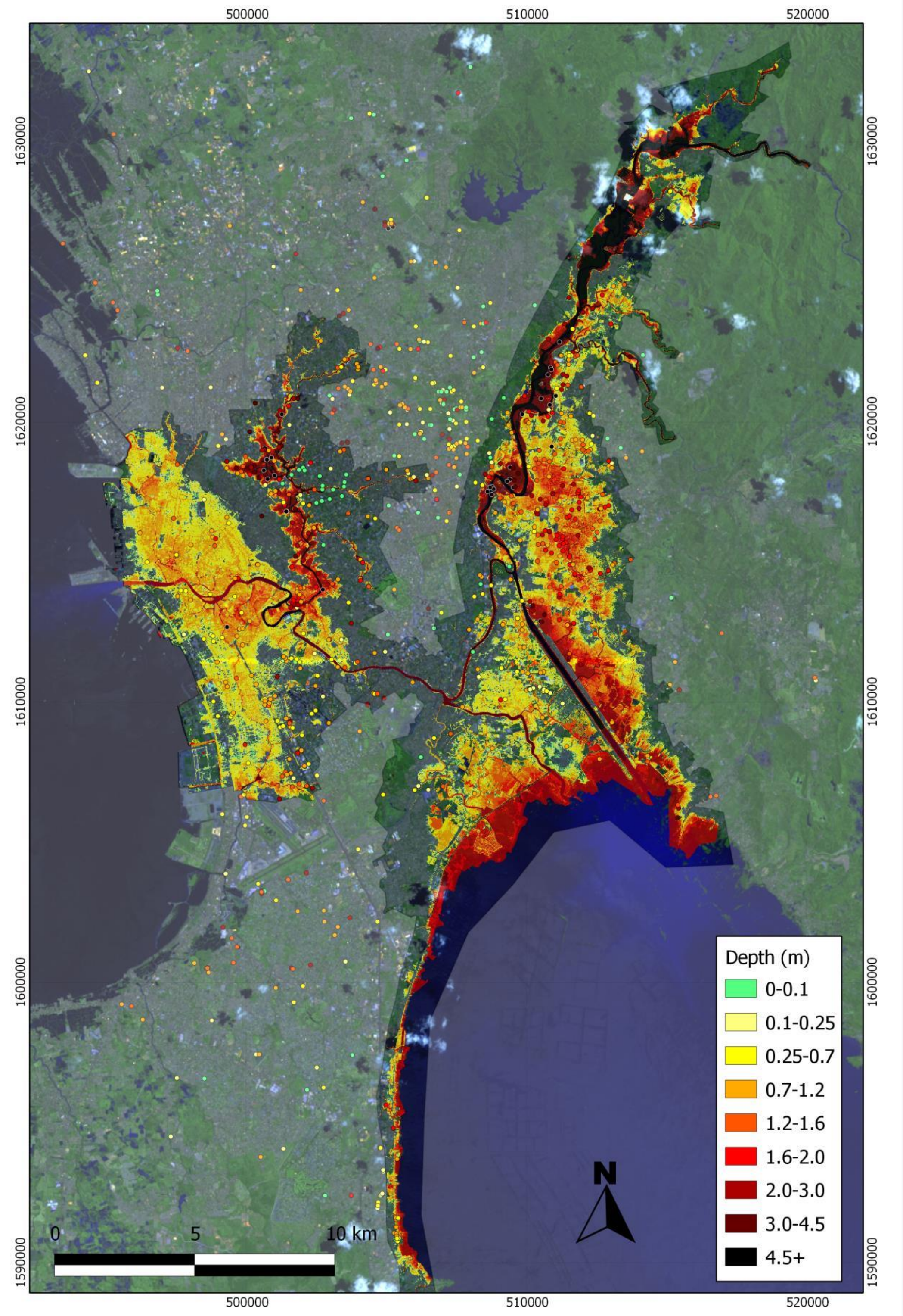


Figure 13. Modelled depths for a flood equivalent to that experienced in Manila during Typhoon Ketsana in 2009. *Note:* The colored points are measured depths for comparison. Areas outside the model region are shaded semi-transparently.

The risk maps and models developed collaboratively by the government of Philippines agencies (the CSCAND agencies) and Geoscience Australia were delivered to the mayors and planning officials of the Greater Metro Manila Area and selected neighboring areas to inform their decisions about planning and mitigation for natural hazards.[25]

Like the Indonesia volcanic ash modelling activity, the GMMA RAP was implemented almost entirely through short-term missions comprising workshops hosted by staff from both Geoscience Australia in Canberra and CSCAND. Evaluation of these programs has identified key success factors in the capacity building element (Box 4).

Box 4. Factors Leading to Successful Technical Capacity Building

The success of the collaborative programs between Geoscience Australia and the governments of Indonesia and the Philippines demonstrates that government-to-government cooperation is an effective mechanism for technical capacity building. This observation is supported by recent research that indicates G2G capacity building is more effective and sustainable than postgraduate training, learning by doing, and centers of excellence.[a] Two broad factors led to successful capacity building in the G2G partnerships between Australia and Indonesia/Philippines: the presence of *trust* and use of a *catalytic approach*.

The G2G projects showed repeatedly the importance of trust as a foundation for working relationships between technical experts. These projects suggest that trust develops for a variety of reasons:

- *Experts' knowledge and skill make them credible.* Technical experts' ability to communicate with and speak the same technical language – the language of science and engineering— as recipient partners is a critical first step in building credibility, which in turn is the basis for developing relationships of trust.
- *Government scientists have shared experience.* Their common understanding of government operations and the science-to-policy cycle can solidify foundations of trust built through scientific expertise.
- *G2G relationships are institutional and national.* As such, they can be an effective basis for long-term cooperation, diplomacy, and trust between partner countries.
- *Personal agendas are absent.* Officials solely delivering to a government mandate (like those in Geoscience Australia) are less likely to push a personal or academic agenda. Experience has shown that in many cases, the need to produce academic publications under authorship other than that of the host nation can interfere with trust. However, the metric of success of this program was relationships and capacity development, so the drive to produce authored publications was absent.

The catalytic approach exemplified in the G2G projects described above focuses not on replacing or displacing capacity, but on building or strengthening capacity. It does so specifically by showing the technical capacity the project delivers; by demonstrating the added value of science; and by serving ad hoc needs of counterparts. The catalytic approach fosters improvement in processes and cooperation between partners through ongoing successful activities of mutual benefit.

A critical first step in using the catalytic approach is for the agencies within which capacity is being developed to identify their own capacity gaps (Simpson and Dhu, 2009). Once these gaps are known, it becomes possible to showcase the potential impact of science in addressing them—without taking

[25] Geoscience Australia, "International Work Helps Build Safer Communities in the Philippines," http://www.ga.gov.au/about-us/news-media/news-2014/international-work-helps-build-safer-communities-in-the-philippines.html.

on a structural role or starting work that in the long run should be done by the recipient agency. The initial steps should always involve gaining an understanding of how the existing system works or should work, so that capacity-building efforts can focus on realizing or strengthening this system.

Capacity-building interventions require a long-term, consistent, and predictable investment that facilitates repeated application of improvements, reinforcing changes until they are sustainable. Strengthening public sector systems is complex and involves individual, institutional, and sectoral capacity. Unavoidably, unforeseen complications emerge when systems are strengthened or changed. These complications can be discovered only by working in line with anticipated systems, and resolving challenges in line. The system is sustainable when it has been operating long enough for each step in the process to become standard and routine.

The focus for each of the activities outlined above is on realizing systems that produce ever-improving DRM outcomes in some of the world's most hazard-prone nations. Capacity building is a long-term effort in this context, but a catalytic approach ensures that local capacity is enhanced and not replaced or displaced.

a. Scholarships are more effective at the individual level and centers of excellence are more effective at the national level, but G2G has proven to be most effective overall. See Lansang and Dennis (2004).

Conclusions. GA's long-standing engagement in official development assistance programs with the governments of Indonesia and the Philippines has strengthened the capacity of partner technical agencies to undertake natural hazard and risk modelling. In both countries, common factors—the presence of trust and use of a catalytic approach—led to significant capacity-building gains. However, neither of these factors is achievable without the right experts: building technical capacity through a G2G relationship requires individuals with the right combination of specific technical and social skills. These projects have relied upon credible, capable, and committed staff members who do not have a personal agenda, whose interest in their work goes beyond the purely technical issues to be resolved, who understand the partner country's systems and cultures, including its language, and who have exceptional interpersonal skills. To ensure the long-term success of technical capacity–building activities, partners should make this necessary staff profile more explicit and recruit new staff based on their inclination toward teamwork and client focus as well as technical expertise.

Informing Disaster Risk Management Plans in Aqaba, Jordan, through Urban Seismic Risk Mapping

Kamal Kishore (United Nations Development Programme)

Seismological and archaeological studies indicate that Aqaba, Jordan's only coastal city, is at significant risk of intensive earthquakes. As many as 50 major events have occurred in the last 2,500 years, including one as recent as November 1995.[26] At that time, DRM considerations were not included in city plans.

In 2001, Aqaba was declared a special economic zone, which opened the door for investment, especially in tourism- and trade-related services. The anticipated urban growth associated with Aqaba's new status was expected to increase its seismic risk. To minimize

[26] The event occurred 95km south of Aqaba.

the potential human and financial losses from seismic hazards, the Aqaba Special Economic Zone Authority (ASEZA), the United Nations Development Programme (UNDP), and the Swiss Agency for Development and Cooperation launched a project to integrate seismic risk reduction considerations into Aqaba's economic development in 2009.

Assessing risks and using risk information. Under this partnership, the Jordanian Royal Scientific Society conducted a seismic hazard assessment. In addition to producing tools for quantifying the level of seismic risk affecting the city (useable by both scientists and legislators), the project supplied the evidence for an earthquake risk management master plan and served as the basis for an operational framework for earthquake risk reduction.

The seismic hazard analysis focused on two potential sources of earthquake threat to Aqaba, the first from the fault system that runs from Wadi Araba fault, through the Aqaba fault to the Gulf of Aqaba fault and the second from an earthquake on the Dead Sea fault system.

A deterministic (impact) scenario from a maximum magnitude earthquake of 7.5 on the Aqaba fault section was produced showing the impact on people, buildings, and the economy, with key results presented in Table 6. This analysis built on data on building distribution provided by the Aqaba Department of Statistics, Population and Housing Census.

Table 6. Seismic Risk Scenario for Aqaba (maximum magnitude 7.5 earthquake)

Effect on buildings

Building damage state	Number of buildings	Share of the total (%)
None	2,500	20
Slight	3,600	30
Moderate	2,300	20
Severe	2,500	20
Complete collapse	1,200	10
Total (in 2010)	12,100	100

Effect on people

Human casualty class	Number of people
Minor injury	2,500
Medium injury	1,300
Severe injury	600
Dead	600
Total casualties	5,000
Total affected population (in 2010)	106,000

Source: Based on analysis of data from Aqaba Department of Statistics, Population and Housing Census.

Analysis also pointed to temporal elevated changes in the risk associated with the tourist peak season, weekend, and/or Ramadan. Moreover, the hospital capacity at the time of the analysis was 206 beds among three hospitals—a figure that clearly highlights challenges that would be encountered in the aftermath of an earthquake event, given that the scenario predicted more than 1,900 people requiring treatment. The study also made estimates of the restoration times for critical infrastructure and transport systems, and determined that main and secondary roads would likely be disrupted for more than 40 days, and wastewater systems disrupted for almost a month.

Economic analysis undertaken at Hashemite University (Al Waked 2011) provided a comprehensive view of the direct, indirect, and secondary effects of this earthquake scenario. Findings are summarized in Table 7.

Table 7. Economic and Financial Impacts of Earthquake Scenario (magnitude 7.5 earthquake)

Impact indicators	Loss (million US$)	Share of 2010 GDP (%)
Direct losses (wealth, compensation for death and disability)	856	2.8
Indirect losses (impact on output, emergency assistance)	694	2.5
Secondary effects (account balance, fiscal impact)	715	2.6
Total	2,265	7.9

Source: Al Waked, 2011.

A key finding was the potential impact of the earthquake on Jordan's only seaport, through which most imports and exports pass. For example, disruption of port activities for three months due to damage or due to a focus on humanitarian activities could amount to ~JD 299 million (US$ 422 million). This loss would be nearly equaled by the predicted loss associated with a reduction in tourism, which was estimated at ~JD 212 million (US$300 million).

This earthquake scenario made clear that unless DRM considerations were better accounted for in city planning, the potential impacts of an earthquake would be serious indeed. In response, ASEZA took steps to strengthen DRM in the city Aqaba. Among the improvements that were made are the following:

- A new DRM master plan was prepared for the city.
- A DRM Unit and multi-stakeholder coordination committee were established within the ASEZA to ensure that all development work takes risk reduction into account.
- Through this city assessment, the Jordanian Royal Scientific Society strengthened its risk assessment capacity and is now able to carry out seismic risk assessments for other parts of the country, including the Irbid Governorate.

- Using the plausible seismic risk scenarios, ASEZA has also established and trained community-level emergency response teams, including search and rescue teams, to save lives in the event of a disaster.
- The Aqaba Development Company, a partner of the ASEZA, is now using the findings of the seismic risk assessment to make decisions about construction projects and about allocation of land to new businesses.

The DRM Unit is now a focal point for coordinating stakeholders and integrating DRM into all policies and development planning. In partnership with UNDP, the DRM Unit has trained more than 200 officials to improve its capacity to plan, coordinate, and implement DRM responses more efficiently. The DRM Unit has also implemented a school awareness campaign to educate students about personal safety in earthquakes. These initiatives are being replicated in other Jordanian cities to improve capacities of local authorities to protect trade, tourism, and culture.

Because of these achievements and its overall progress in reducing disaster risk, the city of Aqaba was recognized by UNISDR as a role model city at the First Arab Conference on Disaster Risk Reduction, held in Jordan in March 2013.

Lessons learned through this process to understand seismic risk in Aqaba. Five factors were observed to contribute to the success of this project:

1. A focus on decision making in risk assessment

2. Use of evidence-based risk assessments

3. Use of local expertise to ensure the sustainability and ownership of risk assessment activities

4. Communication of the risk findings over the course of the project implementation

5. Extensive stakeholder engagement, and specifically the use of stakeholder workshops to disseminate knowledge and raise awareness of seismic risk in Aqaba

Several challenges yet remain, including the following: managing and collecting data about natural hazards; applying micro-zonation maps to urban land-use planning; and continuing to build institutional capacity to analyze, assess, and manage disaster risks.

Tsunami Risk Reduction: Are We Better Prepared Today Than in 2004?

Finn Løvholt, Carl B. Harbitz, Farrokh Nadim (Norwegian Geotechnical Institute); Joern Birkmann, Neysa J. Setiadi, Claudia Bach (UNU-EHS); Nishara Fernando (University of Colombo)

The Indian Ocean tsunami of December 26, 2004, which was responsible for over 220,000 deaths, remains one of the deadliest disasters triggered by a natural hazard event (Munich Re, 2013a). It demonstrated the need for more research, improved planning activities, awareness raising, and early warning systems (UNISDR 2005). It also provided important lessons for developing the HFA and sharpened the commitment for its implementation (UNISDR, 2009b).

In hindsight, the 2004 Indian Ocean tsunami should not have come as a surprise (Satake and Atwater, 2007). Events occurring two centuries ago provided a warning sign that was remarked by scientists a short time before the disaster hit (Cummins and Leonard, 2004). Recent paleotsunami deposits provide evidence for past events in prehistorical times (Jankaew et al., 2008). The 2004 Indian Ocean tsunami did introduce a paradigm change in the sense that previous models for constraining earthquake magnitudes along fault zones are now refuted (Stein and Okal, 2007). As a consequence, mega-thrust earthquakes emerging from any of the large subduction zones in the world could no longer be ruled out.

The tsunamis that hit the Mentawai Islands in 2010 and Japan in 2011 also revealed weaknesses in the way society deals with tsunami hazard. The 2011 Tohoku tsunami was stronger than the design standards of the tsunami barriers (Cyranowski, 2011). The event also revealed inadequacies in the Japanese hazard maps, which were largely based on historical earthquake records limiting the earthquake moment magnitude to about 8, one order of magnitude lower than the 2011 event (Geller, 2011). Recent analyses have shown that a tsunami of this size may have a return period of about 500 years and should not have been a surprise (Kagan and Jackson, 2013).

Today, from a scientific point of view, many of the tools for tsunami risk assessment are available, but it remains unclear whether they are actually used in national and regional DRM efforts. This case study reviews the application of DRM methodologies for tsunami risk, with a focus on southeast Asia, and in particular Indonesia and Sri Lanka, which were severely affected by the 2004 Indian Ocean tsunami.

Progress in tsunami hazard assessment. Before the Indian Ocean tsunami occurred, and for a few years afterward, tsunami hazard assessment was mainly based on worst-case scenario analysis. As tsunamis having long return periods are believed to dominate the risk (Nadim and Glade, 2006), the worst-case-scenario approaches may sometimes be appropriate, given the large uncertainty linked to events having return periods of hundreds or even thousands of years. Furthermore, such scenarios are often useful in areas that have a complex tectonic or geological setting, and that lack the information needed to conduct a proper probabilistic analysis (Løvholt et al., 2012a).

The common metric associated with tsunami hazard is usually the run-up height of the tsunami along a coastline. However, other metrics should be considered. The Tsunami Pilot Study Working Group (2006) lists the following tsunami impact metrics (intensity measures) that may be entered as parameters in tsunami models for assessment of mortality, building damage, and forces on structures: tsunami flow depth; wave current speed; wave current acceleration; wave current inertia component (product of acceleration and flow depth); and momentum flux (product of squared wave current speed and flow depth and in many circumstances the best damage indicator).

For hazard assessments, tsunami hazard modellers take different approaches – even if all consider a worst case scenario – and moreover assessments typically rely on different data sources for topography, bathymetry, and/or seismicity. This can result in users being provided with multiple different tsunami hazard maps by different entities, as is described in Box 5. There is also a growing recognition of the limitations of tsunami hazard mapping in areas with coarse resolution digital elevation and bathymetry data sets; see **Error! Reference source not found.** for discussion of this challenge.

Box 5. The Challenge of Multiple Tsunami Hazard Maps in Padang, Indonesia

The city of Padang, Indonesia, is a hazard-prone area, where the potential for a major earthquake and tsunami is well established. As part of the tsunami risk reduction efforts in the city, international scientific groups as well as local institutions developed tsunami hazard maps as a basis for mitigation and evacuation planning. The maps' information on hazard zones, however, differed significantly due to the different approaches and data used by the mappers. As of August 2008, at least eight different hazard maps had been created.[a]

To help stakeholders reach agreement on the most acceptable hazard scenario and mapping approach for the city, the so-called Padang consensus meetings were convened. The scientists and local decision makers who attended the meetings reached agreement on the following major issues: earthquake source scenario (e.g., most plausible worst case, multi-scenario probability approach), basis data (topographical, bathymetry), and modelling parameters (e.g., consideration of roughness coefficient, consideration of buildings that modify the tsunami wave energy, and potentially inundated areas). Although some issues have yet to be resolved, the process has provided an opportunity to reconcile various state-of-the-art scientific findings and to showcase a science-policy platform for advancing tsunami hazard information.

a. The figure is based on personal communication with GTZ, 2008.

Over the last decade, probabilistic methods for estimating tsunami hazard have become increasingly available. One important approach is the Probabilistic Tsunami Hazard Assessment (PTHA) method, which is largely based on the well-documented approach to probabilistic seismic hazard analysis originally proposed by Cornell (1968). In recent years, PTHA has been used to quantify tsunami risk in a number of areas, including Japan, Australia, the West Coast of the United States, and the Mediterranean (Annaka et al., 2007; Burbidge et al., 2008; Parsons and Geist, 2009; Gonzalez et al., 2009; Thio, Somerville, and Polet, 2010; Sørensen et al., 2012).

A crucial element in PTHA is the estimation of the frequency of occurrence and maximum magnitudes of large tsunami-generating earthquakes in each source region. As the historical record for mega-thrusts and other large earthquakes is very short relative to their long recurrence times, it is not possible to constrain the occurrence and maximum magnitudes of intense tsunamigenic earthquakes directly using observed seismicity. Recent events such as the large 2004 Indian Ocean tsunami and the 2011 Tohoku tsunami demonstrate the reality of tsunami risk. Past mega-thrust events along other faults zones (such as those in 1960 in Chile and 1964 in Alaska) provide additional reminders of the need for precautionary actions.

Progress in understanding exposure to tsunamis. Mapping exposure in various hazard zones exploits remote sensing data, geo-information systems, and existing data for population, buildings, critical facilities, etc. Population data are typically obtained from available statistical data (population census) at the lowest administrative level, while data at the building level is normally obtained through remote sensing analysis (e.g., Taubenböck et al. 2008). See Part 2, for a more detailed description of exposure collection.

In Padang the exposure also considered population groups with different evacuation (physical) capabilities. The data included an activity diary that was part of household surveys, as well as local statistics and building data from remote sensing (Setiadi et al., 2010). The analysis emphasized differentiated exposure related to the spatial distribution of the city functions (building uses) and characteristics of the population, and included factors such as work activities, gender, and income groups (Setiadi, 2014).

Progress in understanding and assessing vulnerability to tsunamis. Vulnerability is a multifaceted concept that has different definitions depending on the context and discipline. In natural sciences and engineering, vulnerability often refers to the physical vulnerability of the exposed population or elements at risk. Few reliable models of physical vulnerability to tsunamis currently exist, though substantial progress toward such models is being made.

In social sciences, the term vulnerability refers to societal vulnerability, which is related to a society's exposure, susceptibility, and fragility, as well its capacity to react to a hazardous event. A fair amount of progress has been made in recent years in understanding the factors that influence societal vulnerability and in developing relevant assessment methodologies. For example, important vulnerability factors were revealed by the Indian Ocean tsunami in 2004, which devastated Indonesia's Aceh Province and many coastal districts of Sri Lanka. The especially high number of victims was due to the near absence of preparedness measures appropriate for such an extreme event.

Populations need to be educated about tsunamis and to be aware of hazard zones if evacuations are to be safe and effective. There was little knowledge of tsunamis in the affected areas in Indonesia and Sri Lanka prior to the 2004 tsunami. An Asian Disaster Reduction Center survey (ADRC, 2006) conducted in October–December 2005 showed that most of the Aceh population (88.50 percent) had never heard of tsunamis before the 2004 event. The others (11.50 percent) said that they had heard of a big sea wave coming to land (recounted in Islamic storytelling) from family, friends, books, school, or television. In Sri Lanka, less than 10 percent of respondents reported having had any tsunami knowledge before 2004 (Jayasinghem and Birkmann, 2007). This lack of knowledge led to what was identified as a main reason for the high number of fatalities: a lack of preparedness for such an extreme event (Amarasinghe, 2007). In addition, many people ran to the beach to watch the setback of the sea (Amarasinghe, 2007).

Gaps and recommendations. In the actual planning of tsunami risk reduction activities, limited use of hazard information (hazard maps) for buffer zones and evacuation maps was identified. More advanced methodologies encompassing vulnerability factors have not been fully integrated into risk management activities. Continuous monitoring of vulnerability to tsunamis is hampered by the lack of a centralized database, absence of information sharing among different agencies and local and regional institutions, and lack of standardized common guidelines on tsunami vulnerability assessment. Furthermore, tsunami risk reduction planning tends to focus on hard measures—for example, physical construction of evacuation shelters—but seldom considers soft measure, such as evacuation behaviour and utilization of facilities. Second-order vulnerabilities (in the case of relocation) also call for a detailed analysis and careful implementation of DRM, taking into account factors like the lack of land title and information about resettlement decisions.

While from a methodological perspective, important progress has been made in the last decade, the new methodologies are not widely applied in practice. Hazard maps, for example, are too often used only for establishing buffer zones; when they could also aid in planning of construction and development and in determining evacuation routes. More work is needed to develop indicators and criteria that determine the use of vulnerability information in DRM, as well as to assess of the effectiveness of key strategies and tools (like people-centered early warning systems). These indicators and criteria will ensure the application of the most recent findings on disaster risk and assist in choosing the appropriate risk reduction strategies.

World Bank Probabilistic Risk Assessment (CAPRA) Program for Latin America and the Caribbean: Experiences and Lessons Learned

Fernando Ramírez-Cortés, Oscar A. Ishizawa, Juan Carlos Lam, Niels B. Holm-Nielsen (World Bank, Latin America and Caribbean Regional Disaster Risk Management and Urban Unit)

Urbanization in Latin America and the Caribbean has been dramatic; between 1950 and 2010, the population living in urban areas increased by approximately 600 percent. This increase is more than twice the population growth experienced in the entire region (UN-HABITAT, 2010). Urbanization has resulted in a greater concentration of people and assets in areas exposed to several natural hazards, and to place low-income groups disproportionately at risk (Lall and Deichmann, 2009). By 2050, 150 million people in Latin America and the Caribbean region are expected to live in urban areas exposed to earthquakes.

Decision makers, considering the combined effects of climate change, disaster risks and rapid urbanization, are increasingly citing a lack of required information and awareness as a barrier to managing risk and fostering sustainable development. Indeed, among decision makers recently surveyed, 30 percent cited financial considerations as a barrier to working on climate change adaptation in their cities; 20 percent cited lack of awareness; and 20 percent cited a lack of reliable information and knowledge (Fraser and Lima, 2012).

Unfortunately, national and local governments continue to face significant challenges in generating trusted, accurate, and targeted disaster risk information that can be readily understood and integrated into sustainable development and urban planning. To address these challenges, the Probabilistic Risk Assessment (CAPRA) Program was developed by the World Bank (initially as the Central America Probabilistic Risk Assessment Initiative) in partnership with the Inter-American Development Bank, the UNISDR, and CEPREDENAC (Central America Coordination Center for Natural Disaster Prevention). This paper describes the experiences and lessons learned during the implementation of Technical Assistance Projects carried out under the World Bank CAPRA Program from 2010 to 2013.

During the first phase of CAPRA, which began in 2008, the activities mainly focused on developing the CAPRA software platform, a free and modular risk modelling platform, through integrating existing software and developing new modules under a unified methodological approach (see Yamin et al., 2013). As part of the development and testing of the CAPRA platform, more than 20 risk assessment exercises were undertaken in Belize, Costa Rica, El Salvador, Guatemala, Honduras, and Nicaragua.[27] The original objective of the CAPRA Program was to transfer ownership of hazard and risk information generated by consulting firms to country governments for use in DRM policy and program design. It quickly became apparent, however, that risk information would be integrated into decision making only if government institutions were engaged more deeply and led the whole risk assessment process.

Thus in the second phase, which began in 2010, the focus of the program shifted to supporting government agencies in building their own institutional capacity to generate, manage, and use disaster risk information. This level of engagement was accomplished through the implementation of Technical Assistance Projects (TAPs). Through a partnership between government institutions and the World Bank, and with the financing of donors through the GFDRR and the Spanish Fund for Latin America and the Caribbean, technical agencies leading the development of a TAP were trained in risk modelling and analysis using the CAPRA platform, and also received technical advisory services for generating, managing, and using hazard and risk information. The scope for each TAP was defined by the needs and priorities of each of the institutions involved in the project. Under this approach, a lead government agency establishes an interdisciplinary and cross-agency team for undertaking the risk assessment and discussing the results before using the generated information to inform specific DRM policies and/or programs.

TAPs foster a hands-on approach to generating, understanding, managing, and using risk information, and thus promote ownership of the process and the results of the assessment. Between 2010 and 2013, eight TAPs were implemented in Chile, Colombia, Costa Rica, El Salvador, Panama, and Peru, each focused on answering a different risk-related question. Key features of three TAPs are described below.

Understanding volcanic risk at Galeras Volcano (Colombia). Colombia has a distinguished reputation for leading efforts to reduce the impacts of disasters, with significant progress made in the last 25 years. Despite these efforts, however, many Colombian municipalities are struggling to analyze the risks from hazards such as earthquake, flood, and volcanic eruption, and as a result have difficulty investing and implementing DRM plans and policies.

Volcanic risk—often overlooked because eruptions are relatively infrequent, though the risk is significant for exposed populations—was prioritized by the Colombia National Planning Department for a TAP in partnership with the World Bank. Galeras Volcano, one of Colombia's 25 active volcanoes and the focus of the TAP, poses a significant risk to neighboring towns. Three hazard zones around the volcano cover a total of 888km^2. In the

[27] The software development and the risk assessment exercises were undertaken by ERN-AL consortium.

high-hazard zone, there is more than 20 percent probability that pyroclastic flows would completely destroy all property and kill any residents who did not evacuate. In the middle- and low-hazard zones, the probabilities are 10 percent to 20 percent and 10 percent, respectively.

A recent cycle of volcanic activity in Galeras took place between 1987 and 2010, with eruptions in 2010 forcing the evacuation of 8,000 people. Despite this exposure, a number of municipal settlements stretch into the high-hazard zone. The Colombian government is attempting to reduce this risk through resettlement of populations living in areas at highest risk, but the success of this effort will depend on effective communication of trusted risk information.

Starting in March 2011, the TAP aimed to complement the deterministic volcanic hazard analysis on Galeras, undertaken by the Colombia Geologic Service (Servicio Geológico Colombiano), with additional vulnerability and risk evaluation. Pyroclastic flows and volcanic ash were the focus of the modelling activity. Modelling was based on a compilation of data on historical events, a newly developed exposure database, and vulnerability functions. The exposure database included information on population, essential buildings, public services, and housing, among others, all of which was compiled into a GIS database.

The program also delivered a series of technical workshops designed to introduce specialists to the CAPRA platform and to provide hands-on training in developing and carrying out comparative analysis of the deterministic and probabilistic pyroclastic flows and volcanic ash risk assessment results. Experts in charge of monitoring the Nevado del Huila and Machín volcanoes, both of which remain active, also participated in the training activities.

Consolidating the national seismic hazard model and understanding the risk of earthquake to schools and hospitals in Lima (Peru). Peru has a long history of seismic activity, with historical records telling of an earthquake in 1582 that destroyed most of the city of Arequipa. An earthquake and associated tsunami in 1746 destroyed the city of Callao and resulted in more than 5,000 fatalities. A number of subsequent events have underscored the seismic risk in the country, with the most recent events—in 2007—causing significant damage and disrupting transportation, electrical, and communication networks.

In Peru, two TAPs since 2010 have addressed different needs. The first TAP developed a seismic hazard model at the national level and was completed in 2012. Under the second TAP, the seismic risk assessment focused on essential services and in particular on a probabilistic seismic risk assessment for schools and hospitals in the Lima Metropolitan Area.

The national seismic hazard model was developed by a team of researchers and engineers from the National Seismological Service of the Peruvian Geophysical Institute (Instituto Geofísico del Perú). Team members collected, generated, and analyzed historical seismicity data and tectonic data, and also tested different attenuation models. These results are currently considered as key inputs into the updates of the national building codes and standards led by Peru's National Committee for Building Codes and Norms.

All hazard information produced under this TAP is being integrated into the National Public Investment System (Sistema Nacional de Inversión Pública) database. This critical step facilitates the sharing of findings with the scientific community, government authorities, and the general public. This information will be essential in general urban development planning and specifically in the design and construction of infrastructure, schools, and hospitals, as well as in mining. Moreover, local engineers and researchers trained in the use of CAPRA's seismic and tsunami hazard module[28] will be able to use and update the hazard model and incorporate their finding in future analysis.

Under the second TAP, a seismic probabilistic risk assessment was carried out for 1,540 schools and 42 hospitals in Lima and Callao. Currently, the results of this study are being used by the Ministry of Education to complement the countrywide infrastructure census and to design the National School Infrastructure Plan. Under this process, the World Bank is providing technical assistance to (a) extend the seismic risk assessment to other cities; (b) design a structural retrofitting program; (c) conduct a cost-benefit analysis of existing structural retrofitting alternatives; and (d) define short- and medium-term investment for the infrastructure rehabilitation.

The outcomes of the TAPs in Peru confirmed the importance of institutional engagement throughout the whole modelling process: they showed that the greater the level of engagement, the more likely it was that targeted and strategic risk information informed DRM decision making.

Understanding and managing the risk to water and sanitation systems (Costa Rica). Decision makers in Costa Rica have prioritized the analysis of natural disaster impacts on infrastructure systems—that is, their focus is identifying the most vulnerable parts of a system, realistically assessing the expected damage at different locations and the impact on populations, and setting investment priorities with limited financial resources. The Costa Rican Water and Sanitation Institute (Instituto Costarricense de Acueductos y Alcantarillados) has been working in partnership with the World Bank to preserve and protect the water supply and to establish a system that restores water and sanitation as soon as possible after an earthquake. Not only does reducing interruption to water and sanitation reduce costs after an event, it can also reduce the prevalence of waterborne diseases.

This TAP focuses on seismic risks to water and sanitation systems in the San José Metropolitan Area, the San Isidro area, and the Higuito area. Because these three systems differ in their demand levels and complexity the project team had to consider a flexible approach that could work anywhere in Costa Rica. For example, the San José Metropolitan Area includes 1.2 million residents; draws water from riverine, spring, and artesian well sources; and has primary and secondary pipework of 570km and 2,610km, respectively, as well as numerous water treatment plants, storage tanks, and pumping stations. The San José wastewater system covers 85 km of piping, pumping stations and treatment plants. In contrast, the Higuito area is serviced by two streams, a small treatment plant, eight storage tanks, and no wastewater facilities.

[28] This module, called CRISIS, was developed at the Engineering Institute of the National University of Mexico by M. Ordaz, A. Aguilar, and J. Arboleda.

The TAP began by collecting the input data sets required to understand seismic hazard, inventorying and categorizing water and wastewater systems and components, and defining appropriate vulnerability functions. The next step was to analyze scenario earthquake events; this made it possible to understand what could happen to the system, highlight the most vulnerable sections or components, and provide estimations of the maximum probable physical and economic losses.

These results provided a baseline for the formulation of a risk reduction program that articulated short-, medium- , and long-term investments for protecting access to water and sanitation after an earthquake. They also provide an evidence base to guide design and siting of new infrastructure. Moreover, under Presidential Decree No. 36721-MP-PLAN, CAPRA has been established as the standard tool for DRM purposes and provides for an active government-sponsored risk management approach.

Lessons learned from the CAPRA Program experience about effectively developing, communicating, and using risk information. The CAPRA Program has continually evolved and developed to incorporate lessons learnt about the effective development, communication, and use of risk information. Specifically, it takes into account the need for risk information to be targeted, strategic, interdisciplinary, dynamic, accessible, and formal. These characteristics are explained below.

Risk information is **targeted** and **strategic** when the scope and specific objectives of the risk assessment are consistent with the institutional needs and the surrounding context (e.g., existing programs and policies). The use of the resulting information from risk assessment will define the level of detail of the model and the resolution to be used.

Entailing as it does the involvement of many different institutions, disaster risk assessment is a complex technical and institutional process that requires an **interdisciplinary** and cross-institutional framework.

Risk information should be **dynamic:** it should take advantage of new available data from hazard models and should include changes in exposure from the urban environment and sectoral infrastructure. Risk information must remain **accessible** to support decision making processes in each institution leading a risk assessment, even as institutional needs evolve. Moreover, good practice requires that the owners of the risk information clearly communicate with information users. They need to explain their understanding of the main hypothesis, limitations, and uncertainties associated with the assessment, and they need to highlight input data and information gaps and limitations in resolution (so that the assessment may be improved upon).

Information is **formal** when it is generated under an established institutional and legal framework. This is a critical condition for the effective use of risk information in the design of public policies and risk reduction programs. Where information is formal and has an official and legal status, decision makers are more likely to promote its use and application for specific purposes. Experience proves the following:

- When created under an official legal and institutional framework, risk information is considered legitimate for use in policy design and decision making in DRM.

- When institutions participate in and lead risk assessment processes, they are more likely to take ownership of the information and to be aware of the information's characteristics and limitations.
- The formal/official dimension of risk information encourages institutional endorsement, which in turn supports links between risk management policies and policies that address the risk's financial, social, and institutional impacts.

The CAPRA Program has found that well-targeted programs can help individual institutions strengthen their own capacity to use risk information and take decisions around it. However, from a broader perspective, the lack of technical capacities for generating, understanding, and integrating risk information poses a complex problem. Experience in Latin America and the Caribbean reveals that government agencies and institutions need considerably more technical support in order to undertake risk assessments and produce needed risk information.

Detailed Island Risk Assessment in Maldives to Inform Disaster Risk Reduction and Climate Change Adaptation

Kamal Kishore (United Nations Development Programme)

With sea levels expected to rise and extreme weather events expected to increase in intensity, Maldives, located in the central Indian Ocean, is considered one of the world's most vulnerable countries. Eighty percent of the small atoll islands that make up Maldives are less than 1m above sea level and are prone to flooding and coastal erosion. More than 44 percent of settlements—home to 42 percent of the population—and more than 70 percent of all critical infrastructure is located within 100m of the shoreline. As coastal erosion and pressure on scarce land resources increase, the physical vulnerability of island populations, infrastructure, and livelihood assets will increase as well.

The most significant driver of increasing vulnerability to natural hazards and climate change in Maldives is the absence of systematic adaptation planning and practice. Climatic risks and long-term resilience are not adequately integrated into island land-use planning or into coastal development and protection policies and practice.

Safe Island Programme. In order to reduce the environmental, economic, and social vulnerability of the widely dispersed population, in 2002 the government of Maldives initiated a program to encourage voluntary migration to larger islands. The program's long-term objective was to reduce the number of inhabited islands and consolidate the population in fewer settlements across an identified number of islands.

The 2004 Indian Ocean tsunami underlined the urgency of providing safe zones for isolated communities living on distant islands. This event caused severe damage to physical infrastructure of many islands and set back development. The total damages were estimated at US$470 million, amounting to 62 percent of the gross domestic product. Of these, direct losses totaled US$298 million, which is 80 percent of the replacement cost of the national capital stock.[29] Most of the islands that were destroyed in the tsunami were highly exposed, with little or no coastal protection. The tsunami led Maldives officials to seek financially sustainable and ecologically safe settlement planning and socioeconomic development of atolls, and to integrate safety considerations into planning and development.

Toward this end, the Safe Island Programme was established in 2006. Its goals were to protect the islands from natural and other hazards; to rebuild and improve existing infrastructure and economic facilities; and to build community resilience to disasters through improved planning and implementation of risk reduction investments. The program emphasized that it was a multi-sectoral effort and that it was to be seen as integral to all development and planning (that is, not optional). It held that decision making should be based on widespread consultation and participation, and that human activities that damage the natural environment should be minimized and existing damage rectified.

A key step in achieving the goals of the Safe Island Programme involved producing a short list of potential safe islands through consultation, using both subjective and objective criteria. Once the short list of potential safe islands was agreed to, detailed island-level assessments were planned and carried out. These assessments aimed at filling gaps in knowledge and engaging with island officials and the general public.

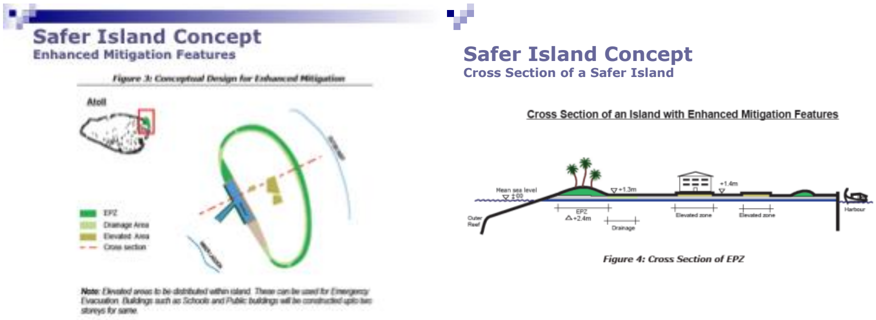


Figure 14. Enhanced mitigation features of safe islands.
Source: SAARC Disaster Management Centre, 2008.

The vision was that Safe islands developed under the program would have appropriate coastal protection; improved communication and transportation facilities; improved housing, infrastructure, and social services; and adequate capacity/preparedness to manage emergencies and disasters. For example, safe islands developed under the program would have access to all basic services in an emergency, particularly those related to health, communication, and transport, and would have a buffer stock of basic food and safe drinking water. Some of the enhanced mitigation features of safe islands are shown in Figure **14.**

Identifying Safe Islands. Detailed risk assessments were undertaken for 10 islands short-listed for development as safe islands (see

[29] World Bank, Asian Development Bank, UN System, "Tsunami: Impact and Recovery, Joint Needs Assessment," 2005.

Figure 15). The assessments, carried out with technical and financial assistance from UNDP, aimed to produce risk information that would be used to recommend specific mitigation options. Key outcomes of the risk assessment included the following:

- Design and development of a risk information process that would generate critical inputs for the Safe Island Programme
- Mapping of the selected islands' overall hazard context, including hazard event scenarios, their probability of occurrence, and their geospatial extent, based on geological and historical disaster data and simulated hazard data
- Assessment of the islands' full range of vulnerabilities (environmental, physical, economic, social), with reference to multiple hazard events and relocation
- Creation of comprehensive risk information for coastal ecological systems, building stocks, infrastructures, and the most important economic sectors (mainly tourism and fisheries)

The project was carried out in three phases, starting in January 2007:

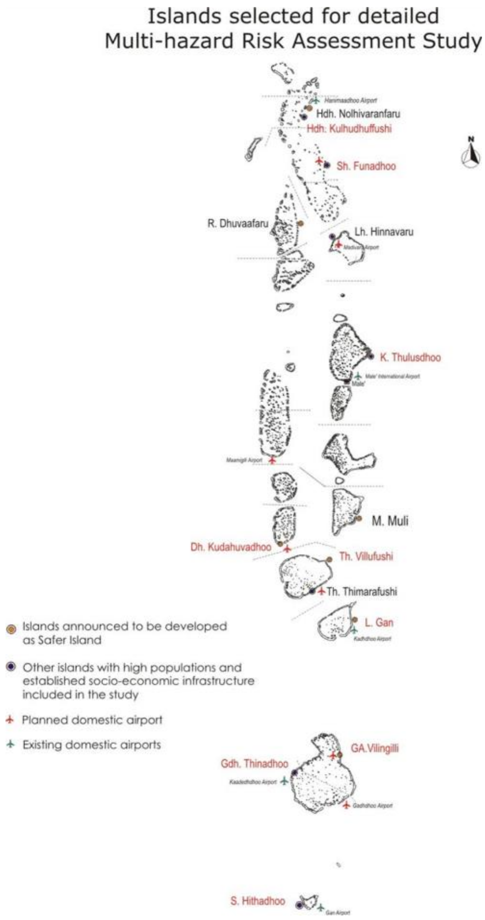


Figure 15. The islands selected for detailed multi-hazard risk assessment (marked in red).
Source: SAARC Disaster Management Centre, 2008.

Phase 1 involved a hazard assessment of tsunamis, swells or high tides, wind storms, heavy rainfall, storm surges, droughts, and earthquakes. These were conducted for return periods of 25, 50, and 100 years for 10 islands (UNDP and RMSI, 2006).

An environmental vulnerability assessment was undertaken at the same time. It examined the effects of coastal erosion and compiled available data on coastal erosion and hazards as well as related parameters. The assessment also included mapping of coastal vegetation.

The exposure of buildings and infrastructure to different hazards was calculated and "safe" buildings on each island identified. This effort included determining the capacity of safe buildings to serve as shelters, and identifying where public infrastructure required retrofitting.[30]

In the second phase, hazard data from phase 1 were used to determine the vulnerability of fishery, tourism, agriculture, small business, and home-based industry sectors. This effort also included a comparative analysis of livelihood opportunities and relocation costs. A social vulnerability assessment was undertaken that (among other things) considered communities'

[30] The outputs of this phase included a synthesis report, a report on methodologies, 10 detailed island reports, and a technical specification report on databases. All are accessible at the Maldives Department of National Planning website, http://planning.gov.mv/en/content/view/306/93/.

feelings about integrating outsiders (since development of safe islands requires relocating people).[31]

The third phase integrated all the information and made recommendations for island-specific disaster risk mitigation measures based on a cost-benefit analysis.[32]

Using risk information. The 2011 Strategic National Action Plan, which has been fully endorsed by the government of Maldives, built on the recommendations of the risk information and cost-benefit analysis. Moreover, the risk information has provided key inputs into the development of risk-sensitive national building codes. Finally, the risk outputs were used to design and develop a national training program and used to promote a national public awareness campaign for disaster risk reduction, early warnings, and response actions. Launched in 2009 by the National Disaster Management Centre and Maldives Meteorological Service in partnership with the UNDP, the "Rakkaavethibiyya—Dhivehiraajje" ("Be aware—Be prepared") campaign was the country's first public awareness campaign addressing disaster risk.

There are still challenges to integrating risk information into the Safe Islands Programme, which has hindered progress towards the original vision. Specifically:

- The cost-benefit analysis showed that mitigation investments must be approached with caution because there is significant uncertainty in the analysis and because the benefit-to-cost ratios are not consistently positive or indeed very high. Therefore any change in the underlying assumptions could result in a net loss on investment.
- Perceptions that there needs to be a greater shift toward softer protection measures (e.g., planting or maintaining mangroves on shorelines) and other options to increase resilience.

There were also challenges encountered during the implementation of the risk assessment activities:

- *Insufficient time was planned for project implementation.* The duration of four months for project implementation was not sufficient, given the complexity of the analysis.
- *Identifying local technical specialists was difficult.* The project struggled to recruit a local structural engineer, resulting in significant reallocation of responsibilities, including the diversion of staff from other UNDP programs.
- *The islands were far apart from one another.* Arranging the field survey across 10 dispersed islands posed challenges for physical access as well as information sharing.
- *Data acquisition was not straightforward.* Like risk assessments undertaken in other developing countries, the assessment in Maldives found data collection problematic. Maldives lacked certain necessary data, including base maps, long-term climatologic

[31] This phase produced social and economic vulnerability assessment reports as follows: a synthesis report, a methodological description, and 10 detailed island reports. All are accessible at the Maldives Department of National Planning website, http://planning.gov.mv/en/content/view/306/93/.

[32] The cost-benefit report is accessible at http://www.preventionweb.net/english/professional/publications/v.php?id=14437.

data, and historical event data; some necessary data were available but had to be purchased. For acquisition of exposure data, field surveys were the only option.
- *Capacity and institutionalization were limited.* The Government of Maldives has limited staff with the requisite skills and/or qualifications. Moreover, there is no institution or organization specifically responsible for risk information and no unified data management mechanism in place.

Lessons learned. The work in Maldives on risk suggested the following lessons:

- Evidence-based hazard risk profiles are critical for carrying out cost-benefit studies of disaster risk mitigation measures and for communicating risks to national stakeholders.
- Risk information can be an effective means of engaging national stakeholders and decision makers, and maintaining engagement from the start to finish will increase the buy-in of the results.
- It is important to systematically document data collected and produced over the course of the project, including the implementation plans, methodological framework, data and databases, etc. This documentation provides critical inputs to the institutionalization of the National Disaster Management Centre and lays down a solid foundation for the establishment of a national risk information system in the future.

Malawi: How Risk Information Guides an Integrated Flood Management Action Plan

Francis Nkoka, Pieter Waalewijn (World Bank)

Natural and man-made hazards cumulatively affected 25 million people in Malawi between 1974 and 2003, with weather-related disasters occurring on average once a year over the last 40 years (Government of Malawi, 2010). Disaster risk in Malawi arises from a combination of tectonic activity, erratic rainfall, environmental factors, and socioeconomic vulnerability driven by widespread dependence on rain-fed agriculture, a narrow economic base, and extensive rural poverty (Government of Malawi, 2011). With climate change, population growth, urbanization, and environmental degradation, the trend is toward more frequent and more intense disasters.

The government of Malawi recognizes that improved management of the natural hazard risk can lead to intensified, yet sustainable, agricultural production, better transport links, and more secure homes and livelihoods. With this vision of the country's potential, the government of Malawi partnered with the World Bank and GFDRR to undertake a national risk assessment (RMSI 2011). This proactive, evidence-based analysis sought to determine, quantify, and map Malawi's flood and drought hazard potential both historically and probabilistically, using annual average and probable maximum direct and indirect loss as metrics. It was recognized that improved flood management in the Shire River Valley, in particular, could significantly reduce entrenched poverty and potentially could make the Shire Valley a national economic hub. With this in mind, the government of Malawi also commissioned a detailed flood analysis of the Shire basin (Atkins 2012). This staged approach to understanding risk in Malawi— national to local level—highlights the need for understanding of risk at many levels and for many purposes.

National assessment of drought and flood risk. Following the Standard Precipitation Index methodology (McKee, Doesken, and Kleist, 1993), the drought risk assessment measured daily rainfall from 45 meteorological stations in Malawi to determine the precipitation time series. This historical series was used to generate a 500-year stochastic weather event set, which was in turn embedded in an agro-meteorological model to ascertain long-term drought frequency. The crops considered most exposed to drought included three types of maize and one type of tobacco. Economic crop production (and losses) leveraged data collected and shared by the Malawi Ministry of Economic Planning and Development.

The analysis, completed in January 2011, revealed that the central region of Malawi had the greatest potential for losses, and that losses associated with LMZ (local) maize were the highest for any crop; the 50-year return period loss of LMZ maize in central Malawi was US$34 million. Across the entire country, the loss for this maize at this return period was as high as US$62 million, and the annual average loss for this maize was US$6 million. Composite maize was found to be the most drought-resistant. Losses associated with tobacco were considerably lower, with an annual average loss of US$1 million.

Flood hazard analysis used daily flow discharges from 13 Malawi river stations over different two-year time periods, with ~90m resolution digital elevation model, a digital river network, and HEC-RAS flood modelling software. The Dartmouth Flood Observatory satellite images of the January 2003 flood event were used to calibrate the flood extent. Flood extent maps were produced to show return periods of 2, 5, 10, 20, 50, 100, 200, and 500 years. Exposure data consisting of population and dwellings (households),[33] roads, railway, and agriculture (maize and tobacco) were then overlaid on the flood extent maps. Results reveal that, on average, about 26,000 people and 6,000 dwellings are inundated each year at a cost of US$6.5 million, with the district of Chikwawa most affected.[34] The annual average loss to roads, railways, and agriculture was found to be US$38,000, US$61,000, and US$19 million, respectively.

Economic analysis reveals that Malawi loses about 1 percent of GDP per year as a result of drought, though during a 1-in-25-year drought, GDP can contract as much as 10 percent. A 1-in-25-year drought can also significantly exacerbate income poverty—that is, can cause an almost 17 percent increase in poverty, which is equivalent to an additional 2.1 million people falling below the poverty line. Malawi loses 0.7 percent of GDP per year as a result of flooding in the south—the part of the country where flooding is most severe. Since farmers in other parts of the country and export farmers typically benefit from higher prices during

---

[33] These data were from the National Statistics Office 2008 population and housing census.

[34] Note that for the purposes of analysis flood defenses were assumed to be not effective due to insufficient maintenance.

southern flood events, the 0.7 percent contraction in national GDP really does not reveal the significant localized impacts from flood.

Lower Shire River basin study.[35] Following the national-level study and other analysis (DNRDM, 2008), a decision was made to undertake a comprehensive flood analysis of the Shire River basin. Approximately half a million people live in the Lower Shire valley and are regularly affected by flooding and water pollution. The highest-risk areas in the Shire Basin are Chikwawa and Nsanje districts, which are located in the lower section of the basin, and Mangochi district, just downstream of the outflow from Lake Malawi in the upper section of the basin, where flooding is caused when lake levels are high.

Flooding in the Lower Shire River often occurs without warning, and some flood protection works currently in place have been found to be unsafe or unsustainable due to poor engineering practices. The Lower Shire River is the site of flood disasters nearly every year, and these cause damage to infrastructure that is never successfully repaired. These disasters require significant flood aid and other relief support to a region that is the poorest in the country, and that already struggles with inadequate sanitation and limited access to clean water.

The Shire River is economically and environmentally very important. It is the site of hydroelectric schemes that generate 98 percent of Malawi's electricity; it contains extensive fisheries and wildlife conservation areas; and it provides freshwater for irrigated agriculture and for industrial and domestic uses. A better understanding of flood risk, and the mitigation of risk through targeted measures based on the findings of the assessment, would help to improve agricultural production and generally aid the population that lives in the area.

The integrated flood risk analysis aimed to achieve the following:

- Construction and calibration of a hydrodynamic model of the catchment capable of accurately predicting inundation of the floodplain for extreme fluvial flooding. This model was developed so that it can be updated in the future to improve accuracy and reliability as better data become available and can assess the effectiveness of potential interventions to mitigate flood impact.
- Simulation of floodplain inundation for 5-, 10-, 20-, 50-, 75-, 100-, and 500-year return period flood events, and for 100-year return period inundation considering change in rainfall patterns with climate change.
- Production of flood maps of the catchment for each of these design modelling scenarios.
- Development of a framework for flood forecasting and an early warning system in the basin.
- Development of guidelines for flood mitigation measures.
- Building capacity of stakeholders involved in flood management and development of an institutional development plan.

[35] Material in this section is based on the World Bank–commissioned *Shire Integrated Flood Risk Management Program Final Report: Volume 1*, and completed in 2012 by Atkins.

The objectives were achieved by developing a Soil Conservation Service rainfall-runoff model (SCS 1986) using time varying rainfall data for different return periods (derived from depth-frequency statistical analysis of daily rainfall), with input and flow data, where available, used to calibrate the model. A sample flood map is in Figure **16.**

Physical data sets on topography, land use, geology, and soil type, as well as time series data, were used in the flood analysis. A variety of improvements is being made to these data for future analysis:

- For topography, SRTM data were used, but these have inadequate vertical accuracy and spatial resolution to serve as the basis for detailed flood modelling and mapping. Higher resolution digital elevation is being developed for the catchment, and the integration of these data will result in substantial improvements in model accuracy.
- For flow and level data, sub-daily rainfall and flow data are now being used to improve hydrological modelling.
- Observed water level on the Shire and its tributaries should be used to provide calibration data. Once limitations in the location of gauges within the basin are addressed, better calibration of the model will be possible.

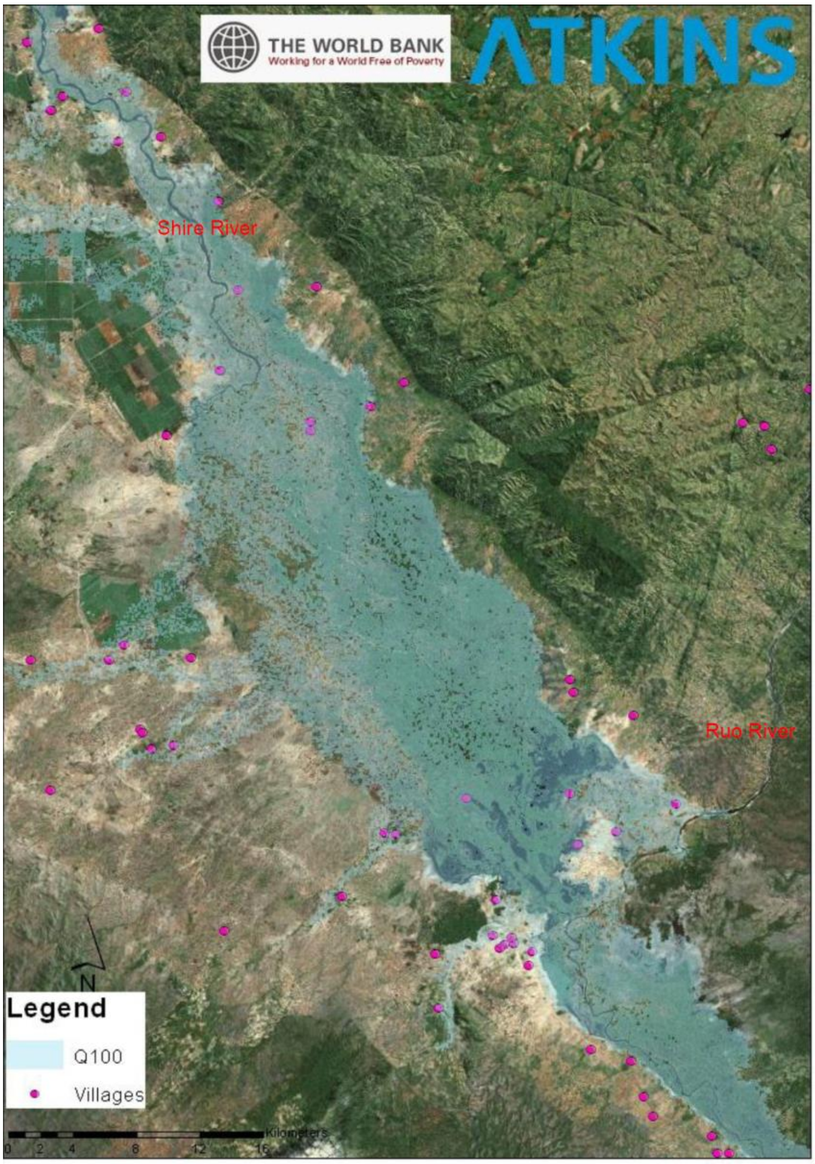


Figure 16. 1-in-100-year flood extent (in pale blue) around the Elephant Marshes of the Lower Shire Valley, Malawi. *Source:* Atkins, 2012.

An assessment of the baseline flood risk to high-risk villages was used in conjunction with the economic assessment of flood damage to assess the likely benefits of implementing flood protection measures such as defenses, catchment improvement through reforestation, and flood storage. Key findings from this analysis include the following:

- Increase in forest cover to reduce flood depth in catchments should be applied on a case-by-case basis, since the measure is not effective in every catchment.
- Flood storage options were found to be impractical and ineffective for events larger than those having a 10-year return period. These options appeared to reduce flooding in more-frequent events, but the analysis was not conclusive and would benefit from analysis of higher-resolution LiDAR data.
- Predicted changes associated with climate—such as a 12 percent increase in river flow—did not result in a significant change in flood inundation along the river. However, changes may be more apparent with a higher-resolution digital elevation model.

Based on the flood hazard and inundation maps, flood zones (Figure **17**) were defined with the following zoning categories for the Shire River basin:

- Low flood hazard zone: land inundated in a 500-year flood event
- Moderate flood hazard zone: land inundated in 100- to 500-year flood events
- The floodplain: land inundated in 100-year flood events
- High flood hazard zone: land inundated in 20- to 100-year flood events[36]
- Functional floodplain: land between the river at normal flow levels and the 20-year flood event

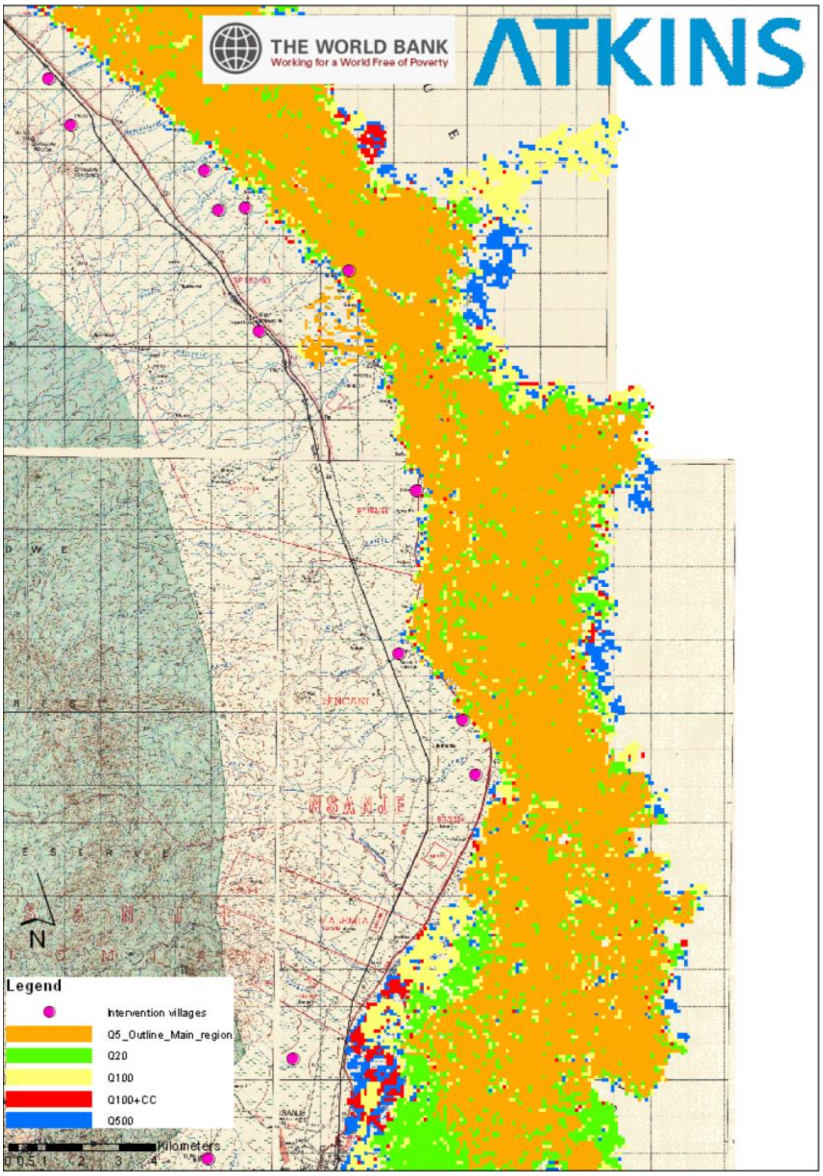


Figure 17. Flood zoning in the area of the Elephant Marshes based on different return period flood events.
Source: Atkins, 2012.
Note: The map shows flood events with various return periods, including 5 years (gold), 20 years (green), and 100 years (yellow), and 500 years (blue).

[36] For this determination, the 1-in-100-year scenario with climate change was used.

After defining flood zones, the assessment then provided guidelines for risk-sensitive development within the different zones: for example, emergency and other essential services should be located in low flood hazard zones, water-compatible or less vulnerable development should be in high hazard zones, and a minimum of development should occur within the functional flood plain. However, agriculture could be promoted within the highly productive flood plain area that was found to be dry during five-year flood events.

Additional analysis and consultation based on this analysis led to development of the Shire Integrated Flood Risk Management Action Plan. The plan is guided by three principles:

1. *Flooding is a natural process and a development issue.* The action plan will work toward a more detailed and robust understanding of flooding through improvements in input data. It will also identify where human development and activities intersect with high flood risk areas and implement measures (both structural and nonstructural) that protect populations from flooding and ensure effective response to flooding.
2. *Flood management requires a whole-of-government/country approach* and entails partnerships between government agencies, donors, communities, land owners, and private sector players. The action plan creates an improved institutional structure and aims to equip all stakeholders with the skills needed to contribute to a holistic approach to flood risk management.
3. *A pragmatic and integrated approach to flooding includes flood management, risk reduction, preparedness, response, and recovery*.

The action plan has identified approximately 100 intervention measures under four main themes. Several sample interventions are highlighted here.

1. *Improving the hydrodynamic modelling framework that was produced in the first phase of analysis*, in recognition of the limitations and uncertainties of this risk assessment. Key activities include channel topographic surveys to extend the model to tributaries and improve the accuracy of the model, improvement of data-sharing procedures and protocols, and additional modelling of factors contributing to flood such as sedimentation.

2. *Investing in structural interventions*. These focus on flood protection for villages found to be most at risk, catchment improvements through reforestation, maintenance of culverts and bridges to improve flow capacity, considerations of flood storage options, and a feasibility analysis of a plan to flood-proof existing buildings to act as flood shelters.

3. *Supporting improvements to flood forecasting and early warning systems* through review of past programs and interventions, improvements to monitoring systems, assessment of the monitoring system overall, and consideration of improvements in light of flood risk assessment.

4. *Building institutional capacity* through a comprehensive training package on collecting hydrometeorological data, running the hydrodynamic model, and building institutions.

As a step toward implementing the action plan, and specifically with the goal of improving data sharing across government agencies, in November 2012 the Malawi government launched the Malawi Spatial Data Portal (MASDAP http://www.masdap.mw/about/). This GeoNode already hosts 123 spatial layers,[37] including infrastructure, OSM layers, flood outlines from a 2012 Atkins study, elevation and other data, and data sets on soil type. It is part of the Malawi government's effort to open data, support community mapping activities, and develop decision support tools that leverage open data for contingency and land-use planning activities.

Reducing Seismic Risk to Public Buildings in Turkey

Elif Ayhan and Joaquin Toro (World Bank)

Seismic risk in Turkey is substantial. Estimates suggest that in the 76 earthquakes that have occurred since 1900, 90,000 lives have been lost, 7 million people have been affected, and US$25 billion in direct damages have been incurred (Erdik, 2013). The 1999 Izmit-Kocaeli and Duzce earthquakes were vivid reminders of this risk. They prompted scientific analysis that emphasized the increased risk to Istanbul arising from the nature of the North Anatolian fault zone (Parsons et al., 2000). Indeed, this analysis suggested that Istanbul's 1 million buildings have a 2–4 percent chance of heavy damage and a 20–34 percent chance of moderate damage from a scenario earthquake event.

In response to the heightened concern, the Istanbul Metropolitan Municipality, in cooperation with the Japan International Cooperation Agency (JICA), prepared a micro-zonation study with various seismic scenarios (Pacific Consultants International et al., 2002). This analysis involved developing fundamental data sets on the seismology and ground conditions that could amplify earthquake shaking.[38] It also involved deriving exposure data—including data on public and private buildings, land use, hazardous facilities, lifelines, and road networks—from a variety of sources such as census and cadastral records, and then compiling them into a GIS database. Impact analyses were undertaken for four scenario earthquakes, ranging in magnitude from 6.9 to 7.7, which were selected in partnership with researchers from the Turkish scientific committee. The results suggested that 7–8 percent of buildings would have heavy damage, as many as 87,000 people would be killed, and 135,000 would be severely injured—significantly greater damage than was found by the previous analysis. The newer analysis also highlighted the vulnerability of Istanbul's schools,

---

[37] The figure is as of March 1, 2014.

[38] This involved data from 1,076 existing boreholes and 48 new drillings undertaken under the project.

hospitals, and other public buildings to earthquake shaking, and found they had a high potential for collapse.

This risk assessment made the following high-priority recommendations:

- 635 hospitals should be urgently prioritized for detailed assessment and retrofitting.
- Almost 2,000 schools should be urgently reviewed and retrofitted to prevent "pancake-like" collapse during an earthquake.
- 24 bridges with a high probability of collapse and two viaduct bridges should be urgently reviewed and retrofitted to prevent collapse during an earthquake.
- To reduce the risks of secondary fires and explosions, systems that would automatically shut down the gas distribution network after an earthquake should be considered.
- A disaster management center should be established, and a campaign to raise awareness of disaster prevention should be conducted.

The Istanbul Metropolitan Municipality took these recommendations into consideration in developing the Istanbul Earthquake Master Plan.[39] This plan was ultimately funded under a government of Turkey and World Bank risk reduction program known as Istanbul Seismic Risk Mitigation and Emergency Preparedness Project (ISMEP).[40]

Implementation of this program has improved emergency preparedness, reduced risk to existing public facilities, and resulted in some improvement to building code enforcement across Istanbul—achievements that have collectively increased Instanbul's seismic resilience. Highlights of progress achieved under ISMEP by 2012 include the following:[41]

- Seismic risk evaluation was carried out for 1,515 public buildings associated with 749 schools, 31 hospitals, 57 health centers, and 51 other public facilities.
- Work was done to retrofit or restore 658 buildings associated with 451 schools, 8 hospitals, 10 health centers, and 31 other public facilities.
- Reconstruction was performed for 95 schools deemed not suitable for retrofitting (where estimates gave a total retrofit cost ratio higher than 40 percent of the value of the building).
- Inventories were made of 176 historical buildings in 26 complexes, and seismic evaluations were carried out for classical and outbuildings of the Archeological Museum, Hagia Irene Museum, and Mecidiye Kiosk, including development of recommendations about structural reinforcement.

This series of risk assessment studies, development of risk reduction plans, and implementation of investments to reduce seismic risk in Turkey constitute a remarkable example of how risk information can influence and trigger actual on-the-ground risk reduction. Turkey's achievements came about because of (a) strong relationships between

[39] See Pektas and Gulkan (2004).

[40] ISMEP is a €1.5 billion project running from 2006 to 2018. It is funded by the World Bank, European Investment Bank, European Council Development Bank, and Islamic Development Bank.

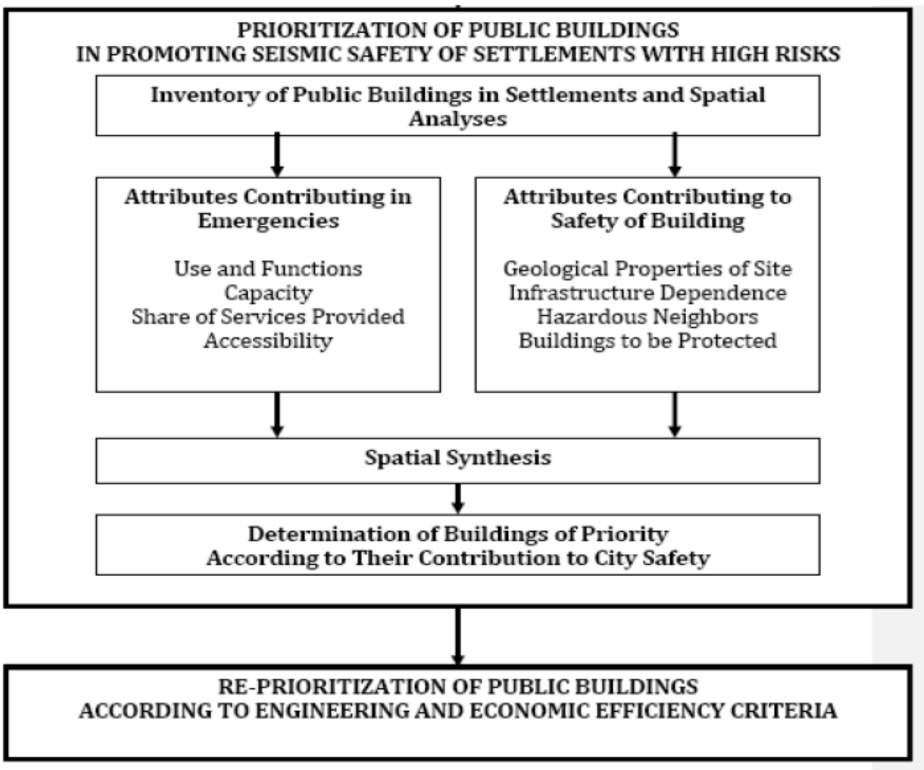
[41] ISMEP Magazine, May 2012, http://issuu.com/guvenliyasam/docs/ismep_dergi_en5/9?e=0/6534273.

those developing the risk information and the decision makers who using the information; (b) clear actionable recommendations from risk assessment; (c) strong political will to invest in risk reduction (driven by the devastation associated with the 1999 earthquakes); and (d) the prioritization of financial resources to invest in risk reduction.

These achievements notwithstanding, seismic risk in Istanbul continues to increase—mainly because of population growth, urbanization, overcrowding, and challenges associated with enforcement of land-use plans and construction policies. Moreover, other cities in Turkey have made less progress than Istanbul in reducing seismic risk.

In light of the remaining seismic risk across the country, the government of Turkey is seeking to build on the success of the ISMEP project and extend it nationwide, focusing on public buildings (schools, hospitals, administrative buildings, emergency response centers, and other public buildings with important life-safety or emergency response functions). Given the immense scale of this task, however, robust and objective prioritization of buildings for retrofitting or reconstruction is required.

Turkey's Disaster and Emergency Management Presidency, with support from the World Bank and GFDRR, has developed a preliminary methodology for prioritization (World Bank, 2012b).[42] This approach involves the development of an inventory of public buildings, an evaluation of the relevant importance of different buildings, and an assessment of the elements of the building construction that make them more or less likely to be damaged in an earthquake. This broad assessment methodology is described in Figure **18.**



:

[42] World Bank. 2012. Consultancy for Prioritization of High Seismic Risk Provinces and Public Buildings in Turkey by Proto Engineering.

Figure 18. Prioritization methodology for high seismic risk public buildings.
Source: World Bank, 2012b.

This methodology is used to distinguish building significance levels which ranged from low, moderate, significant, to high importance. Some of the attributes used to classify buildings' importance are described in Table 8.

Table 8. Building Classifications Used in Prioritization Methodology

Attribute	Weight	Classification details
Current and emergency use	20%	5: vital buildings such as hospitals 4: schools, major public buildings, etc. 3, 2, and 1: less important buildings
Service role (who and what relies on this building)	20%	5: a single facility that serves the entire region or city 1: facility for which there is reasonable redundancy
Urban context	20%	5: a building that, if damaged, will cause physical damage to surrounding buildings, fires, infrastructure problems, or other problems in its vicinity
Accessibility	15%	5: an accessible building reachable by many roads or methods 1: a building likely to be inaccessible in a disaster
Geologic properties of site	10%	5: a building on poor soils 1: a building on better soils
Infrastructure dependence	10%	5: a building totally dependent on local infrastructure 1: a building that can operate independently for at least two weeks without external services
Historical and cultural value	5%	5: an historically important building 1: not historically important

Source: World Bank, 2012b.
Note: For brevity, only levels 5 and 1 are described, although each attribute can earn a score of 1 to 5. For certain attributes, there are multiple proposed methods for assigning values, such as based on the number of students in a school.

The estimation of the earthquake performance of buildings by experienced earthquake engineers was based on building geometry and number of stories; construction quality and material properties; and geotechnical and geological maps. This information is used to determine the structural vulnerability class of low, medium, or high collapse potential.[43]

Based on a synthesis of both these criteria, buildings for reconstruction/rebuilding were prioritized using the priorities defined in Table 9. Under this methodology, all buildings that have a high collapse potential, irrespective of the building's significance level as defined by its class, were allocated a priority 1 (P1). Buildings with low structural vulnerability were assigned the lowest priority, P5, except for class IV buildings, which were assigned a priority of P3.

Table 9. Prioritization for Reconstruction and Rebuilding

	Structural vulnerability classes

[43] This assumed the same level of seismicity across the country.

Building significance levels	Low	Medium	High
Class I	P5	P4	P1
Class II	P5	P4	P1
Class III	P5	P3	P1
Class IV	P3	P2	P1

Source: World Bank, 2012b.

A pilot application of this method was completed in Tokat Province of Turkey in 2013. The selection of Tokat was based on its proximity to the highly active North Anatolia fault and building stock largely characteristic of the country. Among a sample of 12 buildings, two buildings were found to be priority 1 and therefore require urgent retrofitting and/or reconstruction, one building was a priority 2, seven were priority 3 buildings, and two were priority 4 buildings. This methodology is now forming the basis for ongoing dialogue between the government of Turkey—specifically the National Disaster and Emergency Management Presidency—and the World Bank on the design of future disaster risk reduction investments.

Morocco Comprehensive Risk Assessment Study[44]

In recognition of the accelerating series of global shocks—financial crises, commodity volatility, and natural disasters—officials in the government of Morocco proactively developed and adopted a national strategy for integrated risk management (IRM). Working in partnership with the World Bank, Morocco is using this strategy to reduce the potential impacts of future crises, to increase its resilience and responsiveness if/when crises occur, and to support decision making on resource allocation and prioritization. This effort followed initial investment in preliminary risk profiles, as described in Box 6.

This integrated risk approach was viewed as critical because not all risks are equal across the public sector; thus any risk management strategy must be appropriately targeted. The IRM avoids the tendency of risk management to be undertaken in "silos" and is a rare example of enterprise risk management—that is, the process of quantifying risks, comparing them with one another, and managing them in a coordinated manner—applied in the public sector.

[44] This section is drawn from the World Bank report entitled *Building Morocco's Risk Resilience: Inputs into an Integrated Risk Management Strategy* (Washington, DC: World Bank, 2013), which summarizes technical assistance work performed in the period 2008–2013. The project's original task team leader was Pierre Rondot; the current task team leader is Axel E. N. Baeumler. The government of Morocco counterpart is M. Benchakroune. Professors A. Dahman, E. Michel-Kerjan, and C. Scawthorn served as advisors to the project. The MnhPRA technical contractor was RMSI Pvt. Ltd.

The IRM initiative was launched in 2008 with financial support from the GFDRR and the Swiss Agency for Cooperation and Development. It has focused on three key risk areas: (a) natural disasters, specifically earthquake, tsunami, flood, and drought events; (b) commodity (energy) price volatility; and (c) agricultural risks, comprised of drought, pests and diseases, and market price volatility. Of these, natural disaster risk has been the most extensively assessed, and the results of these assessments are discussed here in greatest detail.

The historical record of disasters in Morocco is relatively short and incomplete. However, it is clear that hydrometeorological risk has affected the most people and created the most economic loss, whereas earthquakes have resulted in the most fatalities (12,000 people were killed by the 1960 magnitude 5.7 Agadir earthquake) and have also been a major source of economic loss.[45] Given that Morocco's urban population is expected to increase 15 percent by 2025, seismic and flood risk will likewise increase unless well managed. In addition, the country already experiences more intense and frequent droughts and floods resulting from climate change, and increasingly scarce freshwater availability.[46]

Probabilistic disaster risk assessment. As part of the IRM project, a probabilistic open source GIS analysis tool, MnhPRA (Morocco natural hazards Probabilistic Risk Assessment), was developed and used to assess current earthquake, flood, tsunami, drought, and landslide risk in Morocco (World Bank, 2013). This software package enables users to inventory Morocco's assets at risk, determine the hazard characteristics and assign vulnerability functions, and estimate the impacts of these hazards on the assets in a robust and quantitative manner. The impacts can be determined as estimates of the fatalities, injuries, and direct economic consequences of all possible hazard occurrences—ranging from rare and potentially catastrophic events to frequent, lower-impact events. Loss estimates are provided in detailed tables at the commune level; in summary tables at the province, region, and national levels; and as maps. Risk can be assessed under current conditions and for future points in time considering growth and urbanization as well as alternative public policies.

MnhPRA used input-output and computable general equilibrium modelling to measure the indirect economic costs of disasters (how the economy adjusts to the shock, including the effects of and household income and consumption). These models, which were developed in conjunction with the government's High Commission for Planning, capture the interdependencies between all sectors of the economy as well as the ex ante and ex post macroeconomic decisions of the government.

The project built a comprehensive exposure model for Morocco covering residential, commercial, industrial, and public infrastructure and agricultural assets. The exposure model

[45] EM-DAT: The OFDA/CRED International Disaster Database, www.emdat.be, Université Catholique de Louvain, Brussels (Belgium).

[46] Abdelhamid Ben Abdelfadel and Fatima Driouech, "Climate Change and Its Impacts on Water Resources in the Maghreb Region," http://www.arabwatercouncil.org/administrator/Modules/Events/IWRA%20Morocco%20Paper.pdf.

was compiled through a combination of existing data sets (collected from government institutions), satellite imagery, site visits, and statistical modelling. The project found that the total value of the built environment in Morocco—that is, the replacement value of houses, businesses, factories, roads, bridges, ports, vehicles, electrical networks, and other assets—is DH 2.7 trillion (US$ 330 billion), or around DH 90,000 (US$11,000) per capita.

Earthquake risk was found to be concentrated in the north of the country and in the seismically active area between Fez, Marrakech, and Agadir—essentially the mountainous belts formed by the collision of the African and Eurasian plates. Five provinces (Nador, Al-Hoceima, Berkane, Taza, Tetouan) were found to account for 34 percent of the estimated annual average loss from earthquake despite having only 8 percent of the national building exposure. These findings highlight the government's opportunity to significantly reduce seismic risk in these provinces through focused investments that increase earthquake resiliency.

Floods are a chronic disaster management challenge for Morocco. Analyses showed that a significant fraction of Morocco's total exposure is at risk from flood, but that four provinces contribute 60 percent of the total flood loss with respect to annual average loss. These findings provide a clear target for future flood mitigation investments; they also indicate which areas should give greater consideration to flood risk in future urban and land-use planning. The analyses also highlighted the effects of flood on the economy—evident, for example, in the vulnerability of the main railway line in the Gharb plains, which when damaged significantly reduces the flow of goods across Morocco.

Tsunami events were found to represent a rare but potentially devastating risk to Morocco's Atlantic and Mediterranean coastlines, with waves as high as 10m possible in Casablanca, Morocco's largest port. Not much attention is paid to tsunami risk, particularly in the Atlantic basin. But tsunami caused significant loss of life in Morocco after the 1755 earthquake (better known for its catastrophic effects in Lisbon).

Drought is an insidious and significant risk to the agricultural sector in Morocco, which currently employs about 40 percent of the nation's work force. Especially at risk are the lowlands where cereal crops are grown, which are subject to considerable variation in annual precipitation. Indeed, on average, drought occurs every third year in Morocco, creating volatility in agricultural production that is the main constraint to expansion in the sector.

Cost-benefit analysis provided a key tool in communicating the costs and benefits of different risk reduction and mitigation actions. While benefits can be derived by increasing mitigation efforts, these efforts come with an increasing cost. Hence it is critical to determine, through cost-benefit analysis, the optimal level of mitigation—that is, the point where decreasing loss equals the increasing cost of mitigation.

For Morocco, the comprehensive probabilistic risk assessment allowed benefit-cost ratio (BCR) analyses to rank the effectiveness of 51 potential mitigation options. The BCR for these scenarios ranged from 54.0 to 1.1 (the higher the BCR, the more benefits for the money spent), with some specific ratios as follows:

- Flood warning systems for the Ouregha subbasin: BCR = 54.0
- Culverts on railway lines in the Gharb plains: BCR = 34.6
- Strengthening of hospital buildings in Nador Province: BCR = 5.8
- Risk assessment for proposed new schools in the country: BCR = 5.7
- Seismic strengthening of schools in Nador Province: BCR = 3.6

These BCR analyses provide a quantitative measure that promotes efficient resource allocation.

A risk assessment also provides a higher-level perspective on the cost of various portfolio investment choices. For example, the cost to strengthen the seismic resilience of all schools and hospitals in high-risk provinces was estimated at DH 1.7 billion (US$207 milion) and DH 700 million (US$85 million), respectively. For flood, early warning systems in three regions would involve a capital outlay of about DH 400 million (US$49 million), with annual operating costs of DH 40 million (US$ 4.9 million). Overall, total losses associated with a disaster event were typically found to be 25 to 30 percent higher than the direct losses calculated through physical loss modelling (Government of Morocco, 2012).

Conclusions of IRM study. The probabilistic risk assessment revealed that natural disasters will cost Morocco DH 5.0 billion (US$611 million) annually on average, of which flood contributes the greatest loss. However, the average annual loss does not fully characterize Morocco's risk. An extreme event, such as an earthquake striking a major population center, could have direct costs on the order of DH 100 billion (US$12 billion), equivalent to 5 percent of GDP, or 23 percent of the national budget. This amount is substantially higher if indirect socioeconomic costs are considered, such as the ripple effects on other sectors of the economy. While the government would not bear the full cost of the damage to residential assets, there is an implicit liability attached to this sector, and it is likely that government aid for asset reconstruction and livelihood support would be significant.

The loss from disasters, however, is not the sole risk for Morocco. In 2011, oil volatility in Morocco resulted in a DH 30 billion (US$ 3.6 billion) negative impact on the national budget, a result of the country's existing fuel subsidy system. In 2008, the country's agricultural risks cost an estimated DH 75 billion (US$9 billion), and projections suggest that these costs could rise as high as DH 185 billion (US$22.6 billion) by 2020.

Quantifying these risks will help Morocco to move toward the next phase of managing the risks, mainly through dedicated investment programs targeting both physical and fiscal risks. Using risk analysis, the government of Morocco has begun to prioritize key actions into short-term (one to two years), medium-term (two to five years), and long-term (more than five years) actions across all three risk categories (natural disaster, commodity price volatility, and agricultural risks). For natural disasters, short-term priorities include establishing early warning systems for flood, tsunami, and earthquake events; carrying out additional hazard and risk analyses; enhancing building code compliance; mounting an education campaign around the need for seismic retrofits in the most seismically at risk areas of Morocco; and establishing a national catastrophic insurance program for private assets. Lastly, MnhPRA has been installed in government ministries, with the aim that it will become an ongoing tool for monitoring and managing exposure and risk at both the national and local level.

Box 6. Risk Assessments as an Advocacy Tool for DRM in Middle East and North Africa

In 2008, GFDRR provided seed funding to help scale up DRM engagements in the Middle East and North Africa (MNA). Djibouti, Morocco, and Yemen received US$70,000, US$100,000, and US$150,000, respectively, to fund rapid risk profiling and assessment. These projects enabled each country to better understand and more effectively communicate risk, and they sparked new cooperation across ministries in risk management. With additional funding for risk mitigation in the housing, infrastructure, energy, and education sectors, government leaders partnered with the UN and European Union to carry out post-disaster needs assessments in Djibouti (for the 2011 drought, with funding of $60 million) and Yemen (for flooding in 2008, with funding of $30 million).

In all three countries, risk assessments were used as an advocacy tool. That is, the assessment results showing the potential average annual losses arising from a disaster were used to sensitize finance ministers to the need for DRM. With finance ministers aware of the cost of inaction, technical assistance was expanded to multi-sectoral programmatic risk management; early warning systems, risk management laboratories, and knowledge centers were established, and risk reduction information was integrated into development plans and strategies. Following the success of this approach, risk assessments were initiated by government authorities in Algeria and Saudi Arabia with the aim of sensitizing relevant ministries to the importance of DRM, influencing vulnerability reduction strategies and financial disaster risk transfer instruments, and leveraging best practices. Partly as a result of getting finance ministries to recognize the importance of DRM, most MNA countries have progressed in DRM in recent years. Especially notable is the shift in these countries away from reactive response to disaster to more proactive DRM—a shift that signals increased commitment to HFA objectives and priorities.

Source: Andrea Zanon (World Bank)

Risk Assessment for Financial Resilience: The Approach of the World Bank

World Bank/GFDRR Disaster Risk Financing and Insurance Program

Risk assessment is the first step in managing disaster risk. Understanding and quantifying the risk allows policy makers to estimate the potential direct physical and human losses from adverse natural events. This information can in turn help governments, communities, and individuals make informed decisions to strategically manage their risks. Like other efforts to manage risk, financial protection strategies through disaster risk financing and insurance (DRFI) rely on risk information. Financial risk assessment and financial diagnostics build on this information to help decision makers understand financial and fiscal exposure to disaster risk.

Experience has demonstrated that different DRFI questions require different types and resolutions of disaster risk information. For example, a national disaster risk profile undertaken at a coarse resolution could be the starting point for a policy dialogue on DRM within a country, and could be used to raise public awareness of disaster risks. It could also provide momentum for the more resource-intensive and detailed risk assessments needed to guide specific financial decisions about risk reduction investments.

An analysis of historical loss information can inform initial thinking on DRFI. The next step in developing a robust financial and fiscal protection strategy should be a quantitative risk assessment with detailed probabilistic modelling. Historical loss data and simulated loss data from catastrophe risk models can be used as the basis of financial decision making (see Figure 19). Financial risk analytics helps translate technical risk information into financial analysis that is useful to nontechnical decision makers. With these data as a foundation, governments can develop effective strategies that build financial resilience across society, increase the financial response capacity of the state, and protect long-term fiscal balances.

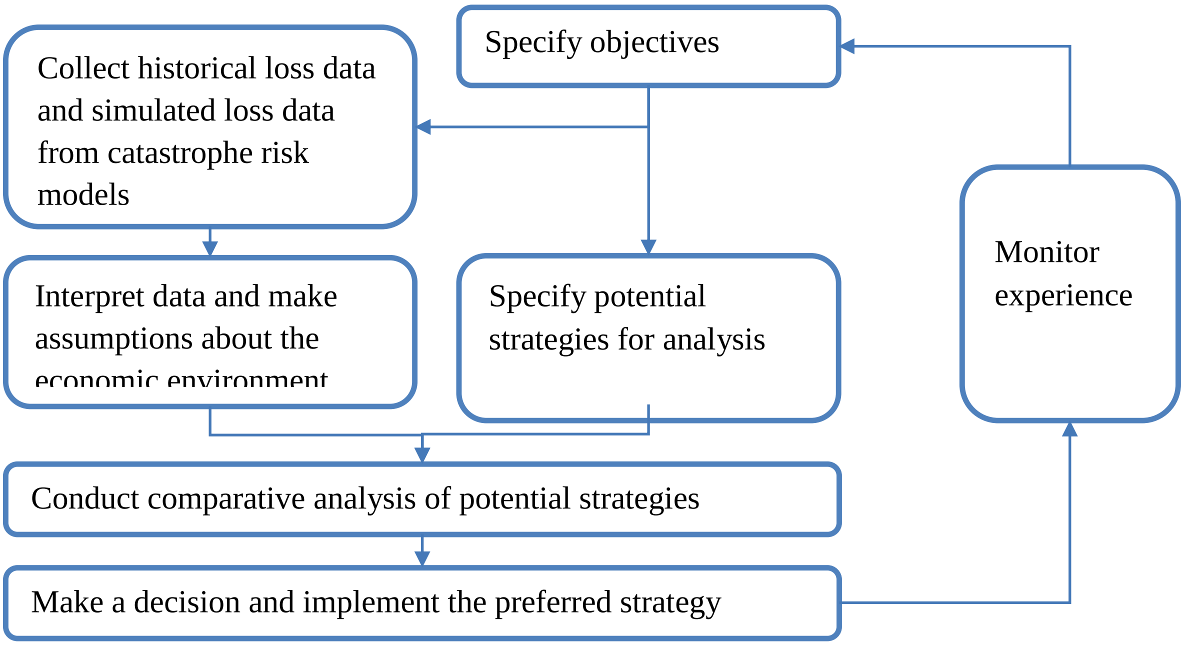


Figure 19. Flowchart for financial decision making.

The level of application and detail of the catastrophe risk model will depend on the decision to be made and the availability of data. Risk models for use in financial risk-transfer applications require high-resolution and high-quality data sets that can withstand scrutiny by international finance and insurance institutions. They also require robust reporting as well as methodologies that effectively convey the nature and uncertainty surrounding risk.

What DRFI decision making requires from catastrophe risk models. The financial analysis enabled through simulated catastrophe risk data empowers policy makers to take more informed financial decisions in the public financial management of natural disasters. While sophisticated financial decision making requires highly detailed and granular outputs, risk modelling provides many useful applications even in the absence of such detailed data. For example, comparatively coarse and incomplete data can still be sufficient for showing governments the relative importance of different risk layers.

But to provide the necessary level of granularity of outputs for the most complex financial decision making, catastrophe risk models risk require high-quality, high-resolution inputs of their own. Specifically, they require the following:

- *A database of assets at risk (exposure module).* A high-resolution exposure database comprised of the assets at risk to natural hazards is essential in informing DRFI decision making. At a minimum, individual risks should be identified in terms of their georeferenced location, value (economic replacement cost), usage (school, office, hospital, etc.), and construction type.
- *A probabilistic hazard module comprising synthetic representations of all possible hazard types.* The hazard module of a CAT risk model comprises a stochastic event catalog, which contains simulated hypothetical events of different magnitudes. Events are modelled with a geographic footprint of hazard values represented at high resolution, and take into account local site conditions such as soil type, surface roughness, or elevation. It is important that the event catalog is well calibrated to historical records, but also allows for extreme yet physically plausible events (even if these have a very low likelihood of occurrence).
- A database of asset fragility curves (vulnerability module) that make the translation from hazard and exposure to damage and loss. A high-resolution vulnerability database is crucial for linking the physical characteristics of the assets at risk with the local intensity of the hazards to determine damage and loss estimates. Fragility curves are described as mean damage ratios and will vary by building use, construction, height, and age. The vulnerability component of a CAT risk model must reflect the impact of these key asset components, as well as geographical changes across a country, such as those due to variations in regional construction codes and practices.

Commercial (vendor-built) catastrophe risk models that are used in the private insurance industry also generate estimates of the possible broader sectoral impacts of disasters. Some models can apply adjustments to loss calculations—either based on projections of inflation in labor costs and building materials during the post disaster reconstruction phase, due to increased demand, or based on increases in the cost of food affecting government's contingent liability to food security response. Particularly sophisticated catastrophe risk analyses also attempt to include potential inflation mitigation effects, such as the flow of labor and materials from unaffected regions (increased supply) and the use of public work forces.

The outputs generated by such catastrophe risk models feed into the DRFI decision-making process. Typically these probabilistic models produce 10,000 or more years of simulated event losses and are the basis for metrics such as average annual losses (AALs)—an estimate of the average annual losses that a portfolio of risks would be expected to incur from the hazards modelled—and probable maximum losses (PMLs)—the maximum probable losses that could be expected given the model inputs. PMLs are often described in terms of either a return period of occurrence (e.g., a loss expected to occur, on average, once every 100 years) or an annual probability of occurrence (e.g., a loss expected to occur, on average, with an annual probability of 1 percent).

Deterministic (also known as "scenario" or "what if?") catastrophe model outputs are also useful to governments because it allows analysis to focus on the financial impact of single, defined events. This is particularly beneficial if the country in question has a history of severe natural disasters (one or more of which may still be fresh in residents' memory) or has neighbors that have recently experienced a catastrophic event.

How this information is used. Countries starting a DRFI engagement require a robust process to understand the financial risks they face and to assess and evaluate potential DRFI strategies. This process includes the statistical analysis of historical losses, case studies, and simulated risk data. Probabilistic catastrophe risk models play an important role: they allow analysts to identify the potential economic impacts of natural disasters over different time frames so that analysis can test potential approaches to risk retention and risk transfer before a severe event occurs.

Technical information generated by detailed risk models enables decision makers to carry out a range of important tasks:

- Model and evaluate the cost-benefit ratio of complex financial instruments, such as (re)insurance contracts and catastrophe risk (CAT) bonds when applied as the basis of financial analytics tools
- Understand potential losses due to extreme events
- Quantify AALs and PMLs
- Model different sovereign DRFI strategies, which blend risk-retention, risk-transfer, and budgetary mechanisms, to compare the protection offered and associated cost
- Understand how key economic assumptions in the models (such as inflation and interest rates) affect the losses

AAL and PML metrics are particularly useful for feeding into financial analytical tools, to both inform and test prototype DRFI strategies. Financial risk analysis allows decision makers to take the raw risk information and model complete financial protection strategies, and in this way to understand government's average cost as well as probable maximum retained cost.

AAL and PML metrics enable complementary aspects of financial risk analytics to inform decisions. The AAL metric, calculated from all possible hazards affecting a country, places the focus on the likely annual financial cost of natural disasters. Once this number (or range) is identified, it can be used to inform decisions, such as what the size of a national disaster reserve fund, and the potential annual budgetary allocations to it, should be. Graphical representations of the contributions of factors such as hazard type, geography, and affected asset classes to the AAL across a territory can help decision makers understand which factors cause most of the expected loss.

PML metrics at different return periods help to identify potential financial requirements for catastrophic events with a low annual probability of occurrence. Five-to-ten year PMLs can inform decisions about the size of potential short- to mid-term financing instruments, such as contingent lines of credit. Similarly, low annual probability PMLs (e.g., 100-year or 250-year return periods) can inform the size of financial protection instrumentation for the purpose of transferring sovereign risk to the international capital and (re)insurance markets.

An important component in DRFI is clarifying contingent liabilities of the state. Disaster risks create implicit and explicit contingent liabilities to the government budget, though these are generally not well defined in law, making fiscal risk assessment complex. Beyond explicit contingent liabilities and associated spending needs, such as the reconstruction of public assets and infrastructure, governments may in cases of disaster have moral and social responsibilities (implicit contingent liability) to assist their populations with emergency assistance (such as food, shelter, and medication) and to finance recovery/reconstruction activities (e.g., through stimulus grants for rebuilding low-income housing stock).

Suitable granularity of catastrophe risk modelling output is crucial for determining the elements driving the state's liability—that is, the key asset classes, the location of vulnerable populations, and responsibility for food security. This granularity, which depends on the clear identification of asset classes in the underlying exposure databases, ensures that only risks that the government considers to represent contingent liabilities are used in the financial analysis and evaluation of potential DRFI strategies. For example, a recent preliminary exposure database developed in Colombia for the cities of Bogota, Medellin, and Cali identified the following asset divisions: residential (low, medium, and high socioeconomic classes), commercial, industrial, health (public and private), education (public and private), and institutional (public and private). Information like this allows governments to identify the contingent liabilities that should inform DRFI decision making.

The risk information generated by financial risk assessment and modelling is not only valuable for developing comprehensive sovereign DRFI strategies. Given their high level of detail, the data sets can in some cases be adapted, often quickly and at low cost, to inform local-level planning. The Pacific Catastrophe Risk and Financing Initiative (see X), for example, has adapted data sets in this way.

Limitations and challenges in risk modelling for DRFI. The use of risk assessments' quantitative outputs for DRFI purposes is constrained by a number of challenges. First, low- and middle-income countries tend to lack the technical understanding needed to perceive the importance of ex ante DRFI initiatives and the potential gains arising from ex ante DRFI programs. Countries often lack the capacity, resources, and experience to properly use existing products. Globally, countries and international donors invest significant resources in data collection and risk modelling. But the resulting technical risk information (simulated losses, average annual losses, probable maximum losses, etc.) is difficult to understand for policy makers and often unsuitable for use in financial analysis.

Second, appropriate risk modelling tools are still lacking in countries that need them the most. The sophisticated risk modelling tools required for DRFI analysis are generally unavailable for low-income countries and even for middle-income countries. The science required for modelling some important contingent liabilities, such as those from food insecurity, is still immature; even for better-understood risks, such as earthquakes, existing risk modelling tools are often inadequate for the needs of DRFI and require substantial improvements and additions if they are to be used for DRFI purposes. Exposure data, for example, may rely heavily on official census data and disregard unofficial settlements (such as shanty towns or squatter towns) that regularly suffer the most damage in a disaster.

Catastrophe risk models used in low- and medium-income countries are usually not tailored to provide the type of information that is essential for DRFI (total ground-up losses suffered by the entire built inventory, number of collapsed buildings, fatalities, homeless population, impact on crops, impact on food security, etc.). Retuning existing commercial models can be an expensive endeavor. It is also important to keep in mind that the exposure data underlying risk modelling tools become obsolete quickly; some are even born obsolete or inaccurate. Using old census data to collect information on exposure in fast-growing developing countries is a risky and potentially inaccurate business, even if data are trended. Ownership from countries is needed to maintain these tools, update databases, and essentially keep them alive. This ownership is hard to establish, and significant efforts in capacity building are often needed even where it exists.

Third, underlying disaster risk information is often lacking in developing countries. DRFI solutions are only as reliable as the risk assessment models that support them, and the latter are only as good as the data used to develop them. Data on exposure may be scattered among different governmental ministries and other organizations, and may be kept in precarious conditions (see section X for additional discussion of these challenges). Use of satellite imagery is often the only way to gather up-to-date exposure data, but the cost of acquiring such images can be prohibitive for developing countries, unless organizations provide information already in their possession free of charge for development purposes (see section X on State Department's Imagery to the Crowd Initiative)

Despite best efforts, challenges and imperfections will remain in every exposure database and need to be taken into account when modelling loss estimates. Inflated, detrended historical loss figures provide useful statistical information about the risk faced and can be used to adjust outputs from the risk model. The collection of actual loss data should complement efforts in collecting exposure data.

The way forward. Developing countries are increasingly requesting advisory services to proactively manage the fiscal costs of natural disasters. New financial instruments and strategies are required to address this demand, help governments increase post-disaster financial response capacity, and build domestic catastrophe insurance markets. Probabilistic risk assessment and catastrophe risk modelling are important tools that empower policy makers to take better-informed decisions in DRFI. A prime example of this approach is Mexico's National Fund for Natural Disasters (Fondo Nacional de Desastres Naturales, FONDEN), created in 1996, and its use of R-FONDEN (Box 7). A comparatively new example of this approach is the Southeast Europe and Caucasus Catastrophe Risk Insurance Facility, or SEEC CRIF (Box 8). Technical support helps countries collect the underlying data and build the required models. More work is also needed to establish the link from technical outputs to financial analysis so that nontechnical decision makers can make use of catastrophe risk data. Through simplifying complex technical data and providing key financial figures, DRFI analytics helps strengthen the connection of policy makers and technical experts and ensures that policy makers have the information they need to make the best decisions about financing disaster risk.

Box 7. R-FONDEN: The Financial Catastrophe Risk Model of the Ministry of Finance and Public Credit in Mexico

Mexico has developed a comprehensive financial protection strategy relying on risk retention and transfer mechanisms, including reserve funds, indemnity-based reinsurance, parametric insurance, and catastrophe bonds. An in-depth understanding of the risks has allowed the Mexican government to successfully access international reinsurance and capital markets to transfer specific risks.

A fundamental feature of the strategy is the R-FONDEN, a probabilistic catastrophe risk assessment platform developed to estimate the government's financial exposure. R-FONDEN offers scenario-based as well as probabilistic analysis at national, state, and sub-state levels of four major perils (earthquake, floods, tropical cyclones, and storm surge) for infrastructure in key sectors (education, health, roads, and low-income housing).

R-FONDEN takes as input a detailed exposure database (with information on buildings, roads, and other public assets) and produces as outputs risk metrics such as annual expected loss (AEL) and probable maximum loss (PML). This model is currently used by the Ministry of Finance, in combination with actuarial analysis of historical loss data, to monitor the disaster risk exposure on FONDEN's portfolio and to design risk transfer strategies.

Source: Text is from "Disaster Risk Assessment and Risk Financing: A G20/OECD Methodological Framework," http://www.oecd.org/gov/risk/G20disasterriskmanagement.pdf.

Box 8. Southeast Europe and Caucasus Catastrophe Risk Insurance Facility

The Southeast Europe and Caucasus Catastrophe Risk Insurance Facility (SEEC CRIF) project was created to respond to a growing demand from Southeast European countries for assistance in reducing their fiscal vulnerability to natural disasters and for greater access to high-quality and affordable catastrophe insurance products for homeowners and small to medium enterprises.[a] In support of these efforts, the World Bank provided financial and technical assistance to Albania, the former Yugoslav Republic of Macedonia, and Serbia to establish the Europa Reinsurance Facility (Europa Re).

The main objective of Europa Re is to increase access to affordable catastrophe insurance products for homeowners and to facilitate the development of the catastrophe insurance market in member countries. Specifically, Europa Re aims to increase the level of catastrophe insurance coverage from the current 1–2 percent to 10–25 percent over the next 5 to 10 years. The design of Europa Re follows that of similar successful catastrophe insurance programs in Turkey and Romania. The Turkish catastrophe insurance pool, for example, currently provides coverage for over 6 million households, while the Romanian catastrophe insurance program insures over 5 million.

Increased access to insurance products will occur through investment in key areas. These include educating homeowners and business owners about the exposure of their properties and businesses to natural hazards; improving and standardizing catastrophe insurance products' credit quality; providing support to enable insurance companies to sell complex weather and catastrophe risk insurance products; and helping governments and insurance regulators enact regulatory and policy reforms that promote the development of catastrophe and weather risk markets.

A critical factor underpinning the success of the SEEC CRIF is access to high-quality and high-resolution catastrophe risk models, which have been developed for FYR Macedonia, Serbia, and Albania by AIR Worldwide. For example, earthquake loss estimates are now available for these countries; they give a 1 percent exceedance probability for losses of €1.15 billion, €611 million, and €955 million for Albania, Macedonia, and Serbia, respectively. A sample seismic hazard map produced in this analysis is shown in Figure **20**.

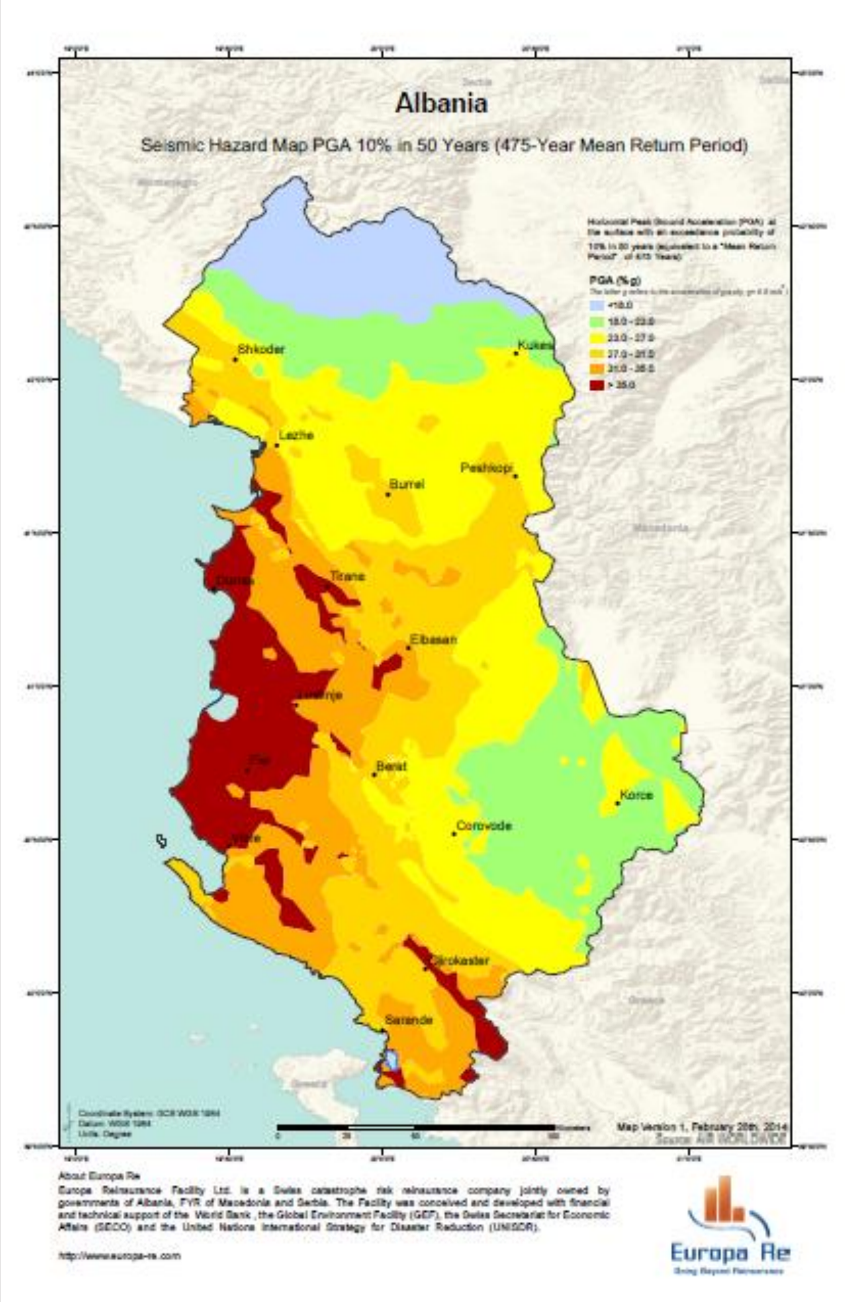


Figure 20. Seismic hazard map for Albania.
Source: Europa Re.

a. The program is strongly endorsed by, and has received financial support from multiple donors, including European Union, UNISDR, Swiss State Secretariat for Economic Affairs, and Global Environment Facility.

The Pacific Catastrophe Risk Assessment Initiative[47]

Olivier Mahul, Iain Shuker, Michael Bonte (World Bank)

---

[47] This account of PCRAFI is based on World Bank project documents, including World Bank, "Pacific Catastrophic Risk Assessment and Financing Initiative: Better Risk Information for Smarter Investments—Catastrophic Risk Assessment Methodology," Washington, DC, 2013, https://www.gfdrr.org/sites/gfdrr.org/files/publication/PCRAFI_Catastrophe_Risk_Assessment_Methodology.pdf.

The Pacific Islands are extremely exposed to natural hazards, including volcanic eruptions, floods, droughts, earthquakes, tsunamis, and tropical cyclones. With rising populations, increasing urbanization, and changes in climate, the impacts from these hazards are growing. Indeed, some Pacific Island countries (PICs) face losses that could well exceed their annual gross domestic product. The September 2009 tsunami that hit Samoa, American Samoa, and Tonga provides a tragic reminder of the potential impacts of disasters in the Pacific. This tsunami left 150 people dead and some 5,300 people—2.5 percent of Samoa's population—homeless. It also caused extensive damage to Samoa's infrastructure. The total cost of the tsunami—restoring infrastructure, maintaining access to basic social services, providing social safety nets to the affected population, and investing in DRM—is estimated to be a staggering 21 percent of GDP over the next three to four years (World Bank, 2010a).

In 2007, the World Bank established the Pacific Catastrophe Risk Assessment and Financing Initiative (PCRAFI) to develop disaster risk assessment tools and practical technical and financial applications to reduce and mitigate the vulnerability of Pacific Island countries to natural disasters. This was a joint initiative of the World Bank, the Secretariat of the Pacific Community Applied Geoscience Technology Division (SOPAC), and the Asian Development Bank, with financial support from government of Japan and the Global Facility for Disaster Reduction and Recovery, and technical input from Geoscience Australia, GNS Science, and AIR Worldwide.

Under the PCRAFI initiative, the largest regional collection of geospatial information on disaster risks was created and made available for the 15 Pacific Island countries: the Cook Islands, the Federated States of Micronesia, Fiji, Kiribati, Nauru, Niue, Palau, Papua New Guinea, the Marshall Islands, Samoa, the Solomon Islands, Tonga, Tuvalu, Vanuatu, and Timor-Leste.[48] This information is now housed in the Pacific Risk Information System (PacRIS) platform (hosted and managed at the SOPAC) and includes the following:

- *Database of Historical Tropical Cyclones and Earthquakes (hazard database).* The database is the result of an exhaustive effort to collect, merge, and process data from multiple sources regarding historical Pacific earthquakes and tropical cyclones, along with the monetary losses and impact on populations associated with these events. The historical earthquake catalog currently includes about 115,000 events of magnitude 5 or greater that occurred in the region between 1768 and 2009, while the tropical cyclone catalog includes 2,422 events from 1948 to 2008.
- *Database of Accumulated Losses (consequence database).* Most of the events included in the hazard database did not have major consequences for the human population, infrastructure, residential buildings, or crops, but some did. A consequence database was assembled containing approximately 450 events from 1831 to 2009 that affected at least one of the 15 PICs. This database, which is the most complete in existence for the Pacific region, shows that, on average, these countries have collectively experienced losses in the order of US$1 billion per decade, rising to US$4 billion in both the 1980s and the 1990s.

[48] Timor-Leste is technically not in the Pacific but was included in the PCRAFI program.

- *Database of Assets Exposed to Disasters (exposure database).* This database contains components for buildings and infrastructure, agriculture, and population. The exposure database was created by collecting existing data sets, remote sensing analysis, and field surveys. Country-specific data sets were used to characterize buildings (residential, commercial, and industrial), major infrastructure (such as roads, bridges, airports, ports, and utility assets), major crops, and population. For the building and infrastructure data set, more than 500,000 footprints of structures were digitized from high-resolution satellite images. These buildings represent about 15 percent (36 percent without Papua New Guinea) of the estimated total number of buildings in the PICs. Of these, about 80,000 buildings were physically checked, photographed, and classified. An additional 3 million, primarily rural buildings, were geo-located and classified using remote-sensing techniques. In addition to information on infrastructure and residential buildings, the database also includes topological maps and information on major cash crops, ground cover, and population. To date, this database is the most comprehensive of its kind for this part of the world.
- *Database of Modeled Probabilistic Hazards and Losses.* The effort generated a variety of risk-related information, including hazard maps for earthquake and tropical cyclones for different return periods, maps of annual average losses, and summaries of key return-period levels of loss for various disaggregated subnational administration units.

The PCRAFI project used these data sets to develop catastrophe risk profiles for 15 Pacific Island nations using state-of-the-art risk modelling that simulated thousands of cyclones, earthquakes, and tsunamis. These risk models provide a robust estimation of the economic losses caused by natural disasters with different return periods. They also were the basis for maps of the geographic distribution of hazards, assets at risk, and potential losses, which can be used to prioritize DRM interventions. This analysis determined that the average annual loss caused from natural hazards across the 15 countries is about US$284 million, or 1.7 percent of regional GDP. Vanuatu, Niue, and Tonga were also found to experience the largest average annual losses, equivalent respectively to 6.6 percent, 5.5 percent, and 4.4 percent of their national GDPs. The analysis also found that in a given year, there is a 2 percent chance that the Pacific region will experience disaster losses in excess of US$1.3 billion from tropical cyclones and earthquakes.

Key outcomes of this work include the following:

1. A substantial investment in improving the underpinning data sets that enable robust risk modelling in the Pacific.

2. Substantial efforts to ensure all data and analytical results produced under this initiative are available to all stakeholders in the Pacific, for DRM purposes, but also more broadly for development planning.

3. Support to PICs to highlight the potential impact of disasters from a physical and financial perspective, and assistance to nations to improve their macroeconomic planning for natural disasters.

4. Establishment of a catastrophe risk pool for five Pacific Island nations—the Cook Islands, the Marshall Islands, Samoa, the Solomon Islands, and Vanuatu. This pilot program tests a risk transfer arrangement modelled on an insurance plan that uses parametric triggers, such as cyclone intensity, to determine payouts, so disbursements are quick. This insurance program recently paid out US$1.27 million to Tonga following the damage from Cyclone Ian in January 2014.[49]

In the future, the data provided in PacRIS can also support efforts aimed at the following:

- *Urban and development planning.* Planners can use the information to evaluate the impact of changes to land use and zoning based on natural hazard risk, to develop investment plans to retrofit buildings for earthquakes, or determine the benefits of raising floor levels to avoid flooding due to tropical cyclones. The data can also be used in cost-benefit analyses of proposed disaster prevention or mitigation investments.
- *Improved building codes.* The earthquake and tropical cyclone hazard models provide critical information for creating and revising building codes that include country-specific seismic and wind loads; these will guide building designs that ensure adequate shelter for the population.
- *Rapid disaster impact estimation.* The aim of this application is to model the expected losses from a catastrophic event immediately after a disaster using already collected baseline information on assets. Rapid assessments after a disaster will facilitate a faster flow of funds.
- *Understanding the impacts of disasters as the climate changes.* PCRAFI and the World Bank, in partnership with Geoscience Australia and the Pacific Australian Climate Change Science and Adaptation Program, are undertaking analyses to understand future cyclone risk to critical assets in the Pacific.[50]

---

[49] World Bank, "Tonga to Receive US$1.27 Million Payout for Cyclone Response," press release, January 23, 2014, http://www.worldbank.org/en/news/press-release/2014/01/23/tonga-to-receive-payout-for-cyclone-response.

[50] This work is described in part III, in "Delivering Cyclone Risk Information for a Future Climate in the Pacific."

Participation, Collaboration, and Communication

From Multi-Risk Assessment to Multi-Risk Governance: Recommendations for Future Directions[51]

Anna Scolobig (Institute for Environmental Decisions, ETH Zurich; Risk, Policy and Vulnerability Program, International Institute for Applied Systems Analysis); Alexander Garcia-Aristizabal (Analisi e Monitoraggio del Rischio Ambientale); Nadejda Komendantova, Anthony Patt (Institute for Environmental Decisions, ETH Zurich; Risk, Policy and Vulnerability Program, International Institute for Applied Systems Analysis); Angela Di Ruocco, Paolo Gasparini (Analisi e Monitoraggio del Rischio Ambientale); Daniel Monfort, Charlotte Vinchon, Mendy Bengoubou-Valerius (Bureau de Recherches Géologiques et Minières); Roger Mrzyglocki (German Committee for Disaster Reduction [DKKV]); Kevin Fleming (Helmholtz Centre Potsdam, German Research Centre for Geosciences [GFZ], Potsdam)

Disasters caused by natural hazards can trigger chains of multiple natural and man-made hazardous events over different spatial and temporal scales. Multi-hazard and multi-risk assessments make it possible to take into account interactions between different risks. Classes of interactions include triggered events, cascade effects, and the rapid increase of vulnerability during successive hazards (see Marzocchi et al. 2012; Garcia-Aristizabal, Marzocchi, and Di Ruocco 2013).

Recent research has greatly increased the risk assessment community's understanding of interactions between risks. Several international sets of guidelines and other documents now advocate adopting an all-hazard approach to risk assessments (for example, see UNISDR [2005]; European Commission [2010a, 2010b]; for an overview, see Council of European Union [2009, section 2]).

Nevertheless, barriers to the application of multi-risk assessment remain. The challenges for the development of multi-risk approaches are related not only to the applicability of results, but also to the link between risk assessment and decision making, the interactions between science and practice in terms of knowledge transfer, and more generally to the development of capacities at the local level. So far, research has focused on the scientific aspects of risk assessment. But the institutional aspects, such as the issues arising when multi-risk assessment results need to be implemented within existing risk management regimes, are also important, though they have received less attention.

[51] This paper presents the results of interdisciplinary research undertaken within the framework of the MATRIX (New Multi-HAzard and MulTi-RIsK Assessment MethodS for Europe) project. The research was supported by the European Community's Seventh Framework Programme through the grant to the budget of the MATRIX project (New methodologies for multihazard and multi-risk assessment methods for Europe [FP7/2007-2013]) under grant agreement no. 265138. The paper reflects the authors' views and not those of the European Community. Neither the European Community nor any member of the MATRIX Consortium is liable for any use of the information in this paper. We wish to thank all who offered professional advice and collaboration. We are especially grateful to the practitioners who discussed with us the challenges of multi-risk assessment.

The project described here focused on the institutional context of disasters, which includes a variety of elements ranging from sociopolitical to governance components.[52] It looked at how to maximize the benefits arising from, and overcome the barriers to, the implementation of a multi-hazard and multi-risk assessment approach within current risk management regimes. Working at two test sites, one in Naples and one in Guadeloupe, the research team engaged with local authorities and practitioners to better understand how to effectively implement the results of multi-risk assessment. Among the hazards considered were earthquakes, volcanic eruptions, landslides, floods, tsunamis, wildfires, cyclones, and marine inundation. Beside the practitioners working in the two test sites, risk and emergency managers from 11 countries also provided feedback. In total, more than 70 practitioners took part in the research.

Research Design. The project, which aimed to encourage interaction between researchers and practitioners/decision makers, began with a policy/institutional analysis—that is, desk studies of legal, regulatory, and policy documents—to provide a description of the institutional and regulatory framework for risk governance within different natural hazard contexts and countries.

To identify the barriers to effective decision making in the case of multiple hazards, we then engaged practitioners in interviews and focus group discussions. In parallel, we performed multi-risk assessments of some specific scenarios at the two test sites. During workshops with practitioners, we presented the results and also discussed the barriers to and benefits of implementing multi-risk assessments. Table 10 summarizes the key research phases, the methods employed, and the accompanying aims.

Table 10. Research Phases

Research phase	Methods	Aims
Institutional/policy analysis	Desk study of legal, regulatory, and policy documents (Naples and Guadeloupe)	To provide a description of the institutional and regulatory framework for risk governance within different natural hazard contexts To identify comparable sets of governance characteristics across hazards and countries
Interviews and focus groups	Semi-structured and in-depth interviews; focus group with a total of 44 participants (Naples and Guadeloupe)	To identify the social and institutional barriers to effective decision making in the case of multiple hazards To propose initial options for overcoming multiple hazards To provide feedback on the results of the institutional analysis

[52] See Scolobig et al. (2013).

Workshops	Interdisciplinary workshops in Naples, Guadeloupe, and Bonn attended by a total of 73 participants from 11 countries (Italy, France, Norway, Germany, Hungary, Bulgaria, Sweden, United Kingdom, Iceland, Croatia, Austria)	To present the new multi-hazard and multi-risk assessments and scenarios developed within the MATRIX project[a] To discuss the barriers to and benefits of implementing multi-risk assessment in the test sites and receive feedback from a wider audience in order to identify results applicable to other multi-risk environments
Feedback	In-depth interviews with and questionnaires submitted to workshop participants (Naples and Guadeloupe)	To collect feedback on the workshops' results To collect feedback on the recommendations for decision support developed by the research team in the previous research phases

a. For more on the MATRIX project, see footnote at start of this paper.

Both test sites face multiple hazards. Naples, the biggest municipality in southern Italy, has a widely recognized high volcanic hazard and is also exposed to interconnected hazards such as earthquakes, floods, landslides, and fires. The French overseas department of Guadeloupe (Département-Région d'Outre Mer), an archipelago in the Lesser Antilles, is exposed to similar hazards (though it is less exposed to fires) and has a high risk of cyclones and tropical storms; its major geological risk is from the active volcano of la Soufrière and the seismic activity along the inner Caribbean arc, both of which can trigger tsunamis and landslides.

Both Naples and Guadeloupe have plans and policies designed to protect their citizens from these risks, and both have deployed scientists, engineers, and policy makers to reduce risk and vulnerability. Moreover, both sites have performed multi-risk assessments. In Naples, two scenarios of risk interactions were considered for quantitative analysis: the effect (on seismic hazard and risk) of seismic swarms triggered by volcanic activity, and the cumulative effect of volcanic ash and seismic loads. Both cases can be combined into a single scenario of interactions at the hazard and the vulnerability level; the combination highlights the different aspects of risk amplification detected by the multi-risk analysis (Garcia-Aristizabal, Marzocchi, and Di Ruocco 2013). In Guadeloupe, researchers conducted a scenario analysis of cascade effects and systemic risk. Following a deterministic approach, the analysis considered interaction between earthquake and landslide phenomena, along with its consequences on the local road network in Guadeloupe and the transport of injured people to hospitals and clinics (Monfort and Lecacheux 2013).

Results. A first (and expected) finding is that risk and emergency managers rarely have the opportunity to deal with multi-risk issues, including triggered events, cascade effects, and the rapid increase of vulnerability during successive hazards. Moreover, multi-risk assessments for different scenarios are at present rarely performed by practitioners at either the national or local level. A second finding is that most participants saw the benefits of including a multi-risk approach in their everyday activities, especially in land-use planning, as well as in emergency management and risk mitigation.

Practitioners identified the following as among the greatest benefits of a multi-risk approach:

1. Multi-risk assessment improves land-use planning.
According to practitioners, a multi-risk approach provides a holistic view of the risks affecting a territory and is appropriate in all geographic areas susceptible to several types of hazards. It would be helpful to have clear criteria to use in determining which scenarios would be most appropriate for a multi-risk assessment. For landslide, for example, hazard and risk mapping may not address the specific effects of different possible triggering events (intense rainfall, earthquakes, etc.). In the case of Naples, a detailed map with the areas susceptible to landslides is available, but it does not include information about the possible short-term effects of volcanic eruptions, even though an eruption could produce unstable ash-fall deposits (even in low-susceptibility areas) that afterward contribute to the generation of lahars (mud flows) triggered by rainfall events.

Urban planners emphasized how a multi-risk assessment could influence decisions about building restrictions, which themselves influence urban and economic planning—for example, by permitting or forbidding construction of new houses and/or economic activities.

2. Multi-risk assessment enhances response capacity.
Practitioners asserted that emergency management would greatly benefit from adopting a multi-hazard and multi-risk approach. Civil protection managers were especially interested in developing multi-hazard and multi-risk scenarios to facilitate management of emergency situations in real time (Monfort and Lecacheux 2013). In Guadeloupe, for example, evidence suggests that failure to consider cascade effects (earthquake-landslide interactions) and to employ a systemic approach may result in gross underestimation of risk. The work undertaken in Guadeloupe considered the interaction between earthquake and landslide phenomena and its consequences for road networks and the removal of injured people to medical facilities. A landslide triggered by an earthquake in the northwest of Basse-Terre might cut off a main east-west road, one critical for moving the injured to hospitals and clinics. Damage to some lifelines (water, electricity) was also taken into account. The final results of the scenario determined realistic times required for the evacuation of the injured, either considering or not considering the damage to the road network and the connectivity to lifelines of the hospitals (Desramaut 2013; Monfort and Lecacheux 2013).

3. Multi-risk assessment identifies priorities for mitigation actions.
The quantified comparison of risks that would allow a multi-risk approach was also seen as a benefit. Quantified comparison is particularly useful for identifying priorities for actions—a difficult task for policy makers, who generally rely on assessments that do not take cascade and conjoint effects into account. The quantified comparison of risks has policy implications for the planning of mitigation actions. It can show, for example, that prioritizing a particular hazard may mean giving insufficient weight to other hazards, and that mitigation measures against a prioritized hazard could actually increase the area's vulnerability to a different hazard.

4. Multi-risk assessment encourages risk awareness and cooperation.

Multi-risk assessment can help to increase a population's awareness of natural risks, of multi-risk, and of associated cascade effects. Practitioners in Guadeloupe working for municipal authorities noted that while the culture of primary risks, such as cyclones, earthquakes, and volcanoes, is well established in Guadeloupe, the culture of secondary risks, such as tsunamis, landslides, marine and inland floods, and coastal and slope erosion, is less established. Practitioners from other countries indicated that communicating the results of multi-risk assessment to the general population would help to increase awareness of secondary risk.
A multi-risk approach can also enhance cooperation and foster needed partnerships between policy makers, private sector actors, and scientists. One key to promoting such partnerships is to establish a common understanding of what multi-risk assessment is, what the preferences and needs of practitioners are, and what the implications for regulatory instruments (related for example to urban planning) may be. Interviewees and workshop participants, especially from the private sector, cited the importance of partnerships between insurers and policy makers in using improved risk information for the development of risk financing schemes that cover large losses after multi-hazard catastrophic events.

Barriers to multi-risk assessment in the science domain. Barriers to effectively implementing multi-risk assessment are found in both the science and practice domains. In the science domain, a major barrier involves differences between the geological and meteorological sciences and the research carried out under their auspices. These differences extend to concept definitions, databases, methodologies, classification of the risk levels and uncertainties in the quantification process, and more. Thus each type of risk has its own scale or unit of measure for quantifying risk or damages (e.g., damage states for seismic risk and loss ratios for floods). These differences may make it harder for the various risk communities to share results and may represent a barrier to dialogue on multi-risk assessment.

A barrier that is more worrying for risk managers than for researchers is the lack of open access to risk and hazard databases, the lack of tools for sharing knowledge, and the difficulties associated with accessing new research results. According to a practitioner working for a meteorological service, "The researchers want to keep the data because they want to publish." Another practitioner stated: "Private companies and research institutions often do not make their data available . . . for the benefit of their competitiveness." Scientists view the matter differently and maintain that research results are freely available online. The same is not true for the databases, however, although the reason for this is simple: most practitioners do not know how to use them. The issue, then, is not whether data are available, but who uses and interprets the data and for what purpose—or more fundamentally, who is able to access and present information in a meaningful and useful manner. Scientists maintain that data collected by private actors (such as private consultants or insurers) are often not available to them, or that these data are not collected systematically and thus cannot be used for scientific purposes.

Practitioners and researchers also have different views about the preferred agenda for future research on multi-risk assessment. Researchers working on the technical/scientific aspects want to improve knowledge of the physical processes and models related especially to cascade effects; harmonize terminology and databases; make uncertainty assessment a focus; combine single-risk analyses into integrated multi-risk analyses; integrate the results of multi-risk assessment into existing emergency scenarios and capture cascading effects in probabilistic terms; and conduct multi-vulnerability assessment.

Practitioners prioritize collecting evidence about lives and property saved using a multi- versus a single-risk approach, gaining an overview of multi-risk contexts at the town level, and especially learning to use and integrate new research results in existing emergency and urban plans. Depending on the practitioners themselves (risk versus emergency managers, regional officers, insurers, etc.), the needs and expectations vary extensively.

Barriers to multi-risk assessment in the practice domain. Differences in the approaches, tools, and methodologies used for single-risk assessment have resulted in a lack of integrated practices for multi-risk governance. Especially where risks are managed by authorities acting at different governmental levels, cooperation among institutions and personnel is a challenge. The priorities of the various agencies vary extensively, and there may be insufficient financial capacity to cover them all. In some cases a multi-risk approach is perceived as competing with (rather than complementing) single-risk approaches.

Capacities, mainly financial, but sometimes also technical and institutional, are especially lacking at the local level, even though responsibility for DRM often falls to local authorities or private actors. The transfer of responsibility for disaster risk reduction to the local level (to the municipal level in many European countries) has often occurred without sufficient resources for implementing necessary programs (UNISDR, 2005b, 2013). Private actors, especially property owners, are being given increasing risk-related responsibilities, which—depending upon the risk, the country, and the availability of insurance schemes—may differ. Different levels of responsibility are attributed to property owners in geological versus meteorological risk prevention, for example. In the case of earthquakes, the level of individual responsibility is high (given that property owners are usually in charge of household vulnerability reduction measures). In the case of floods, public authorities have responsibility for decisions about risk mitigation measures such as protection works, and the costs are covered collectively. In general, there are few options for public-private responsibility sharing, especially for households exposed to multiple risks (and especially where insurance schemes are not available, as is the case in some European countries).

Disasters and Climate Change Adaptation Management: A Guide for Local Governments

Robert Black (Black Shield Preparedness Solutions Inc), Jim Bruce (Scientific and Technical Committee, IDNDR), Mark Egener (Summit Enterprises International)

Global climate change is widely recognized as an environmental, social, and economic threat. In Canada, climate changes observed over the past 35 to 40 years account in part for the exponential rise in economic losses from extreme weather events, premature weathering of infrastructure, stresses on water supplies, worsening air quality, and related health and economic impacts. Efforts to adapt to and manage climate-related risks are not keeping pace with the challenges. Canadians are becoming more vulnerable to impacts related to climate variability and change, due in part to increasing urbanization, a growing and aging population, and deteriorating public infrastructures.

Most Canadians live in municipalities, and this level of government bears much of the responsibility for managing risks from a changing climate. Municipalities have tended to perceive assessment and management of risks related to climate change as difficult, complex, and resource-intensive. To address this issue, and to meet the need for a straightforward and easy-to-use strategic tool for managing risk related to climate change, the authors developed *Climate Change Adaptation Management: A Guide for Local Government*. The guide is designed to assist municipal planners, health officials, emergency management staffs, and conservation authorities in making optimal choices for adapting to a changing and more variable climate and to extreme events.

The guide presents a risk-based approach that can facilitate municipalities' efforts to adapt to climate change through both short- and long-term responses. It is envisioned as

- A reference manual that allows users to incorporate risk management into ongoing municipal planning and management activities, particularly those related to climate adaptation, and that guides comprehensive strategic planning initiatives focused on climate adaptation for all municipal operations.
- An illustration of successful examples and methods for managing climate-related risks to help build support for adaptation efforts.
- A training facilitation tool for municipal staff.

Challenges for addressing climate change at the local government level. There are three main challenges involved in addressing climate change at the municipal level. First, officials may not be accustomed to dealing with climate change. The implications of climate change are not well understood across departments in many municipalities. Nor is adaptation to climate change addressed in most municipal strategic or long-range plans.

Second, climate change–related issues may lack urgency for municipal officials, who tend to focus on issues that have an immediate impact on municipal operations. To pursue a new initiative relating to climate change risk management, municipal staff will have to give it explicit priority.

Third, emergency managers typically manage risk as it stands today and use historical data. Because of the longer time frames associated with climate change, emergency managers may not incorporate climate change–related risks in their hazard and risk assessments and may miss opportunities to identify and implement risk mitigation measures in a timely and cost-effective manner.

To overcome these challenges, we designed a guide that is easy to use, results oriented, and strategically focused. Use of the guide requires a minimum of training and relies on existing standards-based risk management processes. It makes tangible recommendations for adaptation measures and implementation plannings. It offers a strategic overview of climate change–related risk management and makes it possible to prioritize certain mitigation procedures for future evaluation and detailed technical planning.

A summary of the guide. The guide follows the framework for risk management described in *ISO 31000* (ISO, 2009) with the addition of a sixth step (see Box 9). It is designed to address high-level or strategic issues and opportunities over a broad range of climate impacts during a 40-to-50-year time frame, though it can also be used in a more detailed technical analysis of a specific issue or event.

Box 9. Six Steps to Risk Management

1. *Establishing the context.* Team membership and responsibilities are established; teams decide on terms of reference (especially the specific climate change risk issues to be examined), identify stakeholders, and draft an initial work plan.

2. *Risk identification.* The team analyzes climate change impacts and identifies the risk events (such as increased rainfall leading to flash flooding) and opportunities (such as a longer growing season) that these impacts create. The team conducts a preliminary estimation of frequency or likelihood and consequence to initially estimate the level of risk. Some lower-level risk events are discarded at this stage and not considered further.

3. *Risk analysis.* The team conducts a more detailed estimate of the frequency or likelihood and consequences of the risk events and opportunities identified in step 2. The analysis also considers perceptions of people or groups affected.

4. Risk evaluation. The team compares the risk levels estimated in step 3; the acceptability of the risks is considered from the team's and from stakeholders' perspectives. Low-level risks are again discarded, and the remaining risks are ranked. The team gives preliminary consideration to potential risk controls or adaptation measures.

5. *Risk treatment or adaptation measures*. For risks assessed as unacceptable in step 4, the team identifies adaptation measures or risk control strategies to reduce risks to acceptable, practicable levels. It then evaluates the effectiveness of the adaptation measures, including their costs and benefits. Finally, it selects the optimal measures, weighs the acceptability of residual risks, and considers how the opportunities identified in the previous steps could be optimized or improved.

6. *Implementation plan.* The team considers how the adaptation measures could be implemented, how the opportunities could be exploited, and how both should be monitored. The team needs to consider the plan's effect on stakeholders along with stakeholders' perception of the plan.

The six-step risk management process should be repeated or reviewed periodically, and whenever significant new information becomes available on climate change impacts, risk events, adaptation measures or opportunities. Adaptation measures and opportunity exploitation plans should also be monitored to determine whether the anticipated risk reductions or benefits are being achieved and whether plans should be modified or revisited. The review and monitoring process should also address the residual risks that were accepted in the initial planning process and determine whether they have altered or their acceptability has changed.

Lessons learned during development. Development of the guide has been an iterative process that included four earlier projects.[53] Among the lessons learned during this process are the following:

---

[53] Development of the guide began in 2001 and addressed climate change adaptation in the Caribbean. The second version modified the guide for use by local governments in Canada. The third version was developed specifically for municipalities in Ontario. The fourth was for the government of Alberta. Through its various

- *Customize for users.* A customized version of the guide was developed for Arctic and Northern communities, with versions in several Northern languages (available at http://ccrm.cier.ca/). In general, the guide's language has become simpler and less formal over time.
- *Offer simplified climate predictions.* To assist users in understanding climate predictions, we developed a simple template that reduced the effects of climate change in the targeted area to a short list of key factors and that used terminology and measurements understandable to the average user. (For an example, see Table 11).
- *Rely on templates.* So that risk management practitioners need not spend time and effort in developing unique tables and charts to record data, we include standardized tables and charts along with instructions for using them. (Table 12 shows a sample template.) These templates help users capture and display essential information and present results to senior management.
- *Consult with stakeholders.* Soliciting input from potential users is crucial. Local knowledge of the environment and understanding of the processes followed by local authority were essential to customizing the guide to the final user.

---

iterations the guide has had the support and input of the Canadian International Development Agency, Natural Resources Canada, Aboriginal Affairs and Northern Development Canada, Insurance Bureau of Canada, Institute for Catastrophic Loss Reduction, provincial governments of Ontario, Alberta, and British Columbia, Metro Vancouver, and the Centre for Indigenous Environmental Resources. The guide is currently in use, or available for use, in CARICOM, Ontario, Alberta, British Columbia, Nunavut, the Northwest Territories, and the Yukon.

Table 11. Climate Change Projection Example (Northern Ontario)

	Observed trends	By 2050 (from 2010)	Some potential impacts
Temperature	Temperature °C (1950–2007) °C		Permafrost thaw most
	Max. °C Min. °C	°C	of northern half.
	Annual 1.5N to 2.5S 0.5N to 2.5S	2 to 5	Ice season shorter.
See note 1	Winter 1.5 to 2.5 0.5 to 2.5	4 to 6N 2 to 4S	Shorter winter road
	Spring 1.5 to 3.5 1.5 to 2.5	2 to 4	season.
	Summer 1.5 to 2.5 -0.5 to 1.5	2 to 4	Structural problems.
	Autumn 0.5 to 1.5 -1.5 to 1	2 to 4	Increased
			freeze/thaw.
	Temperature Extremes (1950–2007)	T_{max20} 2 to 4°C	Agricultural
		T_{min20} 4 to 6°C	opportunities in
	Frost-free season 10 to 20 days	20 days	southern half.
	Warm days T_{max} >25 °C: 10 to 15 days	15 days	
Precipitation	Precipitation (1950–2007)		
	%	%	
	Annual -20 to 20	5 to 15	Snowfall increases
See note 2	Winter -10 to 5	20 to 30N 10 to 20S	especially in northern
	Spring -10 to 5	10 to 20	parts.
	Summer 0 to 10	0 to 10	
	Autumn 0 to 15	0 to 10	
	Ratio of Snow to Total Precipitation		
	(1950–2007) %	%	
	Annual -5 to -10	-15	Winter recreation
	Winter 0 to 3	-10	season shorter and
	Spring -6 to 3	-5	interrupted.
	Autumn -3 to 0	-15	
	Intense Precipitation (1958–2007)		
	Amounts in severe events	P_{20}: 5% to 10% severity	In southern half more
	(>99%): 31% (adjacent USA)	$P_{20} \rightarrow P_{10\text{ to }15}$	flash floods.
	Frequency heavy rain amounts	frequency	Drainage overflows.
	(>99%): 27% (adjacent USA)		Water contamination
	Number of days with amounts ≥ 95^{th} percentile:		episodes.
	3 to 6		
	Freezing precipitation (rain and drizzle)	60% to 85% increase in	Power and communications
	average (1961–1990)	freezing rain events	outages.
	Precipitation: <35hrs		Transportation chaos.
	Rain: <10hrs		Ecosystem damages.

Riverflow	Dates of Spring Breakup (1950–2002) Earlier, mostly significant	Earlier still	Winter and spring peak flows and ice jams, flooding more frequent, especially in north-flowing rivers.
See note 3	Snow Pack	As ice-free season on Hudson and James Bays increases toward late November and into December, greater snow pack will develop in early winter in coastal areas.	
See note 4	Ice Cover (1973–2008) Lake Superior: from 40% to 10% average in winter	Continued decrease	Higher water temperature. Water quality decline. Easier shipping.
	<u>Streamflow</u> (1967–1996) % Annual -40 to 10 Minimum Daily -30 to 10 Maximum daily -40 to 10	% -20 -20 -10	Reduced summer water availability. Cold-water ecosystems negatively affected.
Forest Fires	Area burned increased 27% from 1981–1990 to 1991–2000 (But large fire year 1980)	50% to 500% increase in area	Greater threats of fire. Greater threats to economies in forestry-based communities.
Permafrost and Peat lands	Thawing evident southern edge of permafrost	Greatest impact Northern area with peat lands drying out	Infrastructure and construction problems.

Note 1. Ranges in observed and projected values indicate differences over the region.

Note 2. Wind disaster records of Public Safety Canada indicate for storms >100km/h national frequency rose 16% from 1970 to 1990, with most in coastal regions, except for tornadoes.

Note 3. Major floods and landslides (from Public Safety Canada database), from intense rains or rain on snow, apparently increased 80 percent nationally between the 1970s and 1990s. However, 1970s event recording may have been less thorough than in 1990s. Database extends only to 2005. Spring floods earlier but summer rain–induced floods more frequent.

Note 4. Wind speeds over warmer waters with less ice cover on Lake Superior have been increasing (Austin and Colman, 2007). This suggests greater possibility of shoreline damages due to wind set up and higher waves.

Table 12.Template Used in the Risk Management Process

Probability range Type of event	Very low	Low	Moderate	High	Very high
Significant single event; or	Not likely to occur in period	May occur once between 30 and 50 years	May occur between 10 and 30 years	Likely to occur at least once a decade	Likely to occur once or more annually
Ongoing/ cumulative occurrence	Not likely to become critical in period	May become critical in 30–50 years	Likely to become critical in 10–30 years	Likely to become critical in a decade	Will become critical within several years

Challenges. Based partly on feedback from users, we have identified the following challenges involved in the guide's use:

- Because municipal governments tend to focus on immediate risks and issues and are highly resource constrained, it is difficult to get them to focus attention on risk assessments that show changes in long-term risk.
- "Champions" are vitally important for getting local governments to commit to undertaking climate change risk assessments.
- Some organizations dedicate considerable resources to developing their own climate change risk assessment process rather than using the existing ISO 31000 process with its associated terminology, definitions, and method. The value of beginning with a simple, high-level strategic screening to identify the highest-priority areas is often lost in this development process.
- The climate change risk assessment process should be accompanied by a process to monitor results and measure progress in order to ensure that risk reduction measures are implemented and actually work.

Future versions of the guide will seek to address these challenges. Other plans for improvements to the guide include the possibility of partnering with national organizations concerned with climate change and disaster reduction (such as insurance companies, engineering firms, and medical/health associations) and publication of a generic version of the guide online.

A Hazard Identification and Risk Assessment Tool for the Province of Ontario and Communities

P. M. Martel (Office of the Fire Marshal and Emergency Management, Ontario)

Background. The province of Ontario, Canada, has recently developed and disseminated a new risk assessment process that could be adopted by communities. This process—formally called the hazard identification and risk assessment (HIRA) program—is designed both to increase awareness of the hazards and risks that could affect Ontario and to provide a more comprehensive and less subjective approach to assessing risk.

The HIRA program developed at least in part in response to a new risk management approach articulated in Ontario's Emergency Management and Civil Protection Act (2006). This approach sought to treat risk proactively rather merely reactively, and put a stronger emphasis on prevention, preparedness, and mitigation as ways to promote disaster resilience. The program also takes into account the guidance provided by the HFA 2005–2015 and includes recommended practices for increasing the resilience of both the province and its communities.

Developing the HIRA methodology. In order to develop a methodology that reflected recommended practices and that was suitable for use at both the provincial and community levels, the team performed an extensive literature review. The methodology for the Ontario HIRA was selected only after reviewing the literature and consulting with risk assessment professionals and ministries. The methodological requirements were as follows:

- The tool had to be risk based.
- It had to be able to assess different types of hazards (natural, technological, and human-caused).
- It had to be revisable—that is, allow for the addition of currently unknown and evolving hazards.
- It had to incorporate both qualitative and quantitative information.
- It had to incorporate as much scientific information as possible.
- It had to be applicable to a range of event consequences and frequencies.
- It had to be scalable (usable at both the provincial and municipal levels).
- It had to serve the needs of Emergency Management Ontario in coordinating preparedness, prevention, mitigation, and response and recovery activities.
- It had to consider the variety of consequences arising from some hazards.
- It had to be easily understood by a diverse group of people with different professional backgrounds (Emergency Management Ontario, 2012).

Results of a survey questionnaire distributed to the communities a year after the release of the provincial HIRA suggest that some of the benefits of this approach are being recognized. The survey responses indicate that before the release of the 2012 HIRA methodology, municipalities varied in the types of methodologies and even terminology used for risk assessments. This variation meant that risk assessments were not comparable to one another. Many of the respondents indicated that their approach had been based on community records and the memories of the people, an approach that resulted in a very subjective report. Many noted that their risk assessments were based almost solely on historical records and could not easily account for new, evolving, and infrequent hazards and risks. Very few reported using scientific information to develop their risk assessments (for example, risk ratings were based on roundtable discussions), and respondents were aware that this approach made it difficult to justify their results.

While 60 percent of respondents believed that their previous methodology gave a fairly accurate overview of their risk, 40 percent were either uncertain or believed that it did not. Nearly all respondents (96 percent) said they planned to use or would consider using the new methodology for the next required revision of their risk assessments. About 83 percent believe that the new methodology provides a better understanding of the hazards and risks facing their municipalities than the old; the remaining respondents believe that the outcomes for the new HIRA methodology will be comparable to those of the old. No respondent indicated that the new methodology would provide a worse understanding of hazards and risk facing communities.

Lessons learned. The process of developing, disseminating, and using the new HIRA methodology gave rise to number of lessons:

1. *Community participation and engagement is vital.* Since data collection and risk analysis must be updated to account for changes in community risk profiles, ongoing engagement with the community is important in developing a risk assessment. Engagement also leads to increased knowledge of the risks and vulnerabilities facing particular communities. Based on the experience of disseminating the Ontario HIRA, multiple methods of engagement should be pursued, from making documents available online to holding workshops.

2. *Data availability can be a limiting factor.* Significant variation in data availability for different hazards, risks, and areas was reported as a problem at multiple levels. There were also variations in the type of data collected, the length of the historical records, and whether the data were qualitative or quantitative. While some communities have amassed their own historical data on past emergencies, risks, and vulnerabilities, others have much sparser records to draw from. Standardized databases of hazard, risk, and vulnerability information could help to mitigate this problem and save time for the communities.

3. *Greater focus on addressing risks is required.* The purpose of a risk assessment is to provide information on the hazards, risks, and vulnerabilities that should be a priority for emergency management agencies. A HIRA is not a stand-alone program; it is the cornerstone for the many activities involved in preparedness, mitigation, and planning. The next step after completing a risk assessment should be to study the feasibility of addressing the identified risks. Ideally, as measures are taken to address the identified risks and vulnerabilities, the risk ranking of the hazard will decrease, allowing for focus on other hazards. In communities where other priorities compete for funding and resources, taking measures to address risks can be difficult. Increased political will for emergency management can sometimes help with this issue.

4. *Hazards, risks, and vulnerabilities are dynamic.* Changing environmental factors (such as climate change or land-use changes) and social factors (such as population changes or building material changes) can alter an area’s risk patterns. Risk assessments based solely on historical information are not likely to truly capture the present level of risk. They should draw on scientific information to take into account possible changes in risks.

5. *Awareness of the relationships between cascading hazards and impacts is increasing.* High-profile emergencies resulting from a cascading series of hazards, such as the

earthquake, tsunami, and nuclear facility emergency in Japan in 2011,have increased awareness of cascading events. Capturing such events in a risk assessment is difficult, however. More work needs to be done to determine how such information can be incorporated in risk assessment (such as by scenario planning and exercises).

6. *Methodologies should move toward standardization.* The move toward standardization may not be instantaneous, especially in the absence of a requirement to adopt a new risk assessment method. Still, adopting a standard method should be appealing to communities—for example, it allows for the comparison of risk assessments between communities and the development of regional risk assessments, and it can also provide a standard for tracking changes in risk levels over time.

Build Back Better: Where Knowledge Is Not Enough

Authors: Jason Brown (Australia-Indonesia Facility for Disaster Reduction) and Jonathan Griffin (Geoscience Australia)

Understanding risk and knowing how to prepare for and mitigate the potential effects of natural disasters are critical for saving lives and reducing economic losses. But is knowledge enough? Between 2009 and 2013, the Australia-Indonesia Facility for Disaster Reduction tested the premise that improved knowledge would result in changed risk behavior among earthquake-affected populations. AIFDR's work in West Sumatra found that better risk knowledge had limited impact on risk behavior, even among communities that had recently experienced a traumatic earthquake event. This finding raises important considerations for governments, donors, and program implementers seeking improved DRM outcomes, particularly in the early recovery and disaster rehabilitation phases.

The magnitude 7.6 earthquake that struck West Sumatra on September 30, 2009 claimed more than 1,100 lives, injured 3,000, destroyed or damaged over 270,000 houses, and affected more than 1.25 million people in 13 of West Sumatra's 19 districts. Water, electricity, and telecommunications were severed, and many government office buildings collapsed, paralyzing services and making emergency response difficult. Damage and losses were estimated at US$2.3 billion, with about 78 percent of all needs concentrated in the housing sector (BNBP and Bappenas, 2009).

The earthquake exposed a combination of poor housing design, poor housing construction, and weak settlement planning (BNPB and Bappenas 2009). The enormity of the damage, the need for reconstruction and repair of hundreds of thousands of houses, and the potential for even larger earthquakes within the next few decades (Sieh et al., 2008) made clear that the affected population would need to start building back better to avoid a similar catastrophe in the future.

A post-disaster engineering survey in October-November 2009 assessed how different types of building performed during the earthquake. The survey was followed by an 18-month province-wide Build Back Better campaign based on the slogan *Bukan Gempanya Tapi Bangunannya!* (It's Not the Earthquakes, But the Buildings!). Finally, an evaluation was undertaken to analyze the impact of the campaign and specifically to learn about recovering communities' motivations for engaging in safer building practice. Each of these elements is discussed below.

Engineering survey. Though the damage done by the 2009 earthquake was reasonably well documented (it destroyed 119,005 houses and damaged 152,535,[54] there was little documentation of how many houses were undamaged and what made those structures more resilient. Nor was the information on damaged structures disaggregated by construction type, age of construction, and ground shaking experienced.

To fill this gap, AIFDR and the Indonesian National Disaster Management Agency (BNPB) supported a comprehensive engineering survey jointly led by the Institute of Technology, Bandung, and Geoscience Australia, with additional expertise supplied by Andalas University, Padang. This team consisted of 70 members with engineers from Indonesia, Australia, New Zealand and Singapore.

The engineering survey included a comparison of two common housing types: (a) unreinforced masonry—typically houses built from bricks, river stone, or similar material, and mortar (Figure **21**); and (b) confined masonry—houses built from bricks and mortar with simple concrete and steel reinforcing (Figure **22**). The results were unambiguous. Overall, unreinforced masonry houses in heavily shaken areas were 5 times more likely to suffer damage than confined masonry and 10 times more likely to collapse (Sengara et al., 2010).

Figure 21 (left). Example of unreinforced masonry construction from Padang. In this case the house was build from river stone and mortar with no reinforcement.
Source: Australian Department of Foreign Affairs and Trade, 2009.

Figure 22 (right). Example of confined masonry construction from Padang. Note the steel-reinforced concrete columns in the corners and tops of walls.
Source: Australian Department of Foreign Affairs and Trade, 2009.

Build Back Better campaign. The AIFDR and BNPB expected that the rebuilding process would motivate the people of West Sumatra to prepare themselves for future earthquakes.

[54] Data are from the Data dan Informasi Bencana Indonesia (Disaster Data and Information Indonesia) database, BNPB (Indonesian National Disaster Management Agency), 2009, http://dibi.bnpb.go.id.

This preparation seemed even more important because the risk of a larger, potentially tsunamigenic earthquake in the same general area within the next few decades had not been diminished (Sieh et al., 2008; McCloskey et al., 2010). Despite the increased costs associated with building earthquake-resistant houses (estimated at around 30 percent more than a typical house), it was assumed that—given the impact experienced by the West Sumatra population and the trauma felt by many families—residents who rebuilt their houses would be open to applying new knowledge of safe building techniques to build safer houses.

For West Sumatrans to build back safer, individuals needed to understand that building a safer house was possible, and they needed to know how to get technical assistance if they needed it. Between February 2010 and June 2011, the Build Back Better campaign ran public service announcements 8,192 times on radio and 2,275 times on television. An estimated 1 million people were exposed to the campaign's messages by radio, and an estimated 2.7 million people by television.

Evaluation. To determine how successful the campaign was in reducing barriers to behavior change, an evaluation was carried out to see whether homeowners had been influenced to adopt earthquake-safe building techniques.[55]

The evaluation of the Build Back Better campaign found that knowledge does not translate into action. "The population in West Sumatra has received and internalised general information about earthquake safer construction," the study found, but "when rebuilding their homes, they failed to act on this knowledge" (Janssen and Holden, 2011, 7). More specifically: approximately half of the families in West Sumatra were knowledgeable about earthquakes, related risks, and available mitigation strategies, partly as a result of the campaign; respondents found it difficult to remember exact technical specifications; there was a high level indifference to, and no social or political pressure for, promoting safer building techniques for housing (Janssen and Holden, 2011).

Perhaps the most intriguing finding of the evaluation was that the earthquake itself had little impact on people's resistance to change. Specifically, the campaign's key assumption, that the experience of the earthquake would lead the population of West Sumatra to be more willing to build back better, was not true. Janssen and Holden (2011) found that those living in the worst-affected areas demonstrated possibly higher resistance to change than those in less-affected areas. The influence of the earthquake on safe building practice seemed to be limited to those who had gone through a traumatic, first-hand experience during the earthquake, such as being trapped or injured by falling debris.

The evaluation found that reducing people's resistance to change was a precondition for getting them to contemplate change, but it also found that actual exposure to the

[55] The evaluation's theoretical framework was the Transtheoretical Model for Behavior Change (Prochaska, Norcross, and DiClemente, 1994). The five steps identified in the framework are resistance, contemplation, preparation, action, and maintenance.

earthquake did not affect the degree to which they were contemplating change. Exposure to loss of assets or even loss of life appeared to make no difference.

The researchers identified and tried to understand a dramatic gap between knowledge and practice—that is, to understand *why the information and knowledge did not translate into action.* This conundrum was highlighted in answers to the following line of questioning:

1. When asked what would be the most disruptive event that could take place in a person's life, *most* respondents answered "a natural disaster."

2. When asked what would be the worst possible consequence of a natural disaster, *62 percent* replied: "A family member getting killed."
3. When asked what was the main cause of people getting killed in an earthquake*, 80 percent* replied: "Collapsing buildings."

4. When asked whether their houses were strong enough to withstand an earthquake, *67 percent* said "No."

5. When asked what could be done to make their houses safer to withstand an earthquake, *68 percent* could provide three correct building techniques to improve the house.

6. Considering that retrofitting a house takes about three months, the respondents were asked what they would do if they were certain an earthquake would hit in six months: *68 percent* said they would run away, while *1.2 percent* said they would retrofit their houses to make them earthquake safe.

The Build Back Better campaign highlights two key lessons: Knowledge is important for reducing resistance to change and for promoting contemplation of change to safer building techniques. But it is not enough to ensure action. The post-campaign evaluation found several barriers that kept people from moving past contemplation of change to action. These included a lack of resources (more than half of respondents said safer building techniques were too expensive); inadequate access to technical information; mistrust of construction workers or building supply store employees, who respondents feared were trying to mislead or cheat them; and incentives and disincentives, such as a lack of enforced building standards for local housing and a lack of social and/or financial incentives.

As a follow-up to the Build Back Better campaign evaluation, a laboratory-style safe construction program showed that given the correct combination of timely information, technical training, community supervision, and financial and nonfinancial incentives and disincentives, individual homeowners will put knowledge into practice. Furthermore, the timing of interventions is critical. Janssen and Holden (2013) propose that government subsidies be invested in immediate needs (including the provision of easy-to-build, cheap, temporary shelter) concurrently with livelihood support programs that enable communities to more quickly recover from the disaster event. Immediately after an earthquake, most people are trying to get on with their lives with the resources available to them, and the effect of the earthquake on reducing resistance to change is negligible. Once livelihoods are reestablished, programs to facilitate construction of permanent, earthquake-resistant housing may be more effectively implemented using appropriately targeted incentives/disincentives.

The AIFDR initiatives have unveiled a rich array of data and experience that can assist in the design of both pre- and post-disaster programs into the future. The Build Back Better experience showed that understanding and effectively communicating risk information and risk reduction strategies is necessary but does not on its own lead to behavioral changes. Interventions must consider, and experiment with, incentives and disincentives for acting on risk knowledge. Because communities recovering from a major disaster may not prioritize disaster risk reduction to the extent we would intuitively assume, interventions may be more successful after livelihoods and a sense of normalcy have been reestablished. Identifying barriers to action within the local context is crucial to achieving change.

InaSAFE: Preparing Communities to Be a Step Ahead

National Disaster Management Agency, Indonesia (BNPB);[56] World Bank; Global Facility for Disaster Reduction and Recovery; Australia Government[57]

Indonesia is one of the most disaster-prone and populous countries in the world. Its disaster managers and local government planners recognize the importance of investing in preparedness, but have faced many obstacles to accessing and using up-to-date and accurate data from hazard and risk assessments. Unfortunately, there is a tendency for technical studies that analyze risk to end up on a shelf or archived on a hard drive. InaSAFE (originally the Indonesian Scenario Assessment for Emergencies), an open source disaster impact modelling tool, was launched in 2012 to help overcome obstacles to using risk information. Developed by Australia[58] and Indonesia in collaboration with the World Bank[59] and GFDRR, InaSAFE enables communities, local governments, and disaster managers to use realistic natural hazard scenarios for floods, earthquakes, volcanoes, and tsunamis to underpin emergency planning, disaster preparedness, and response activities.

To date, InaSAFE has been used to develop scenarios for national government disaster exercises in Indonesia, including the 2014 International Mentawai Megathrust Tsunami Exercise. It has been implemented in Jakarta, East Java, and South Sulawesi to develop realistic flood scenarios for contingency planning. During 2014, the Australia-Indonesia

[56] Contribution from Dr. Agus Wibowo, Head of Data Division, Center for Data, Information and Public Relations, Badan Nasional Penanggulangan Bencana (BNPB).

[57] Contribution from Geoscience Australia staff members Kristy van Putten, Charlotte Morgan, and David Robinson.

[58] The Australian government agencies involved in developing InaSAFE include the Department of Foreign Affairs and Trade–Development Corporation and Geoscience Australia through Australia-Indonesia Facility for Disaster Reduction.

[59] The World Bank’s participation was supported by AusAid’s East Asia and Pacific Infrastructure for Growth Trust Fund.

Facility for Disaster Reduction and Indonesia's National Disaster Management Agency (BNPB) will focus on helping district disaster management facilitators and universities to develop the necessary skills to use, and train others to use, the InaSAFE methodology.

The subnational focus of InaSAFE is intended to improve the capacity of local governments and communities to make more informed disaster preparedness decisions. The InaSAFE tool is linked to Indonesia's disaster response standards, and as part of its analysis it suggests various actions for local governments to consider in response to a hazard scenario. So far InaSAFE core partners at AIFDR have trained more than 150 Indonesian disaster managers across six provinces to use InaSAFE, and have provided the necessary skills for disaster risk managers to collect their own hazard and exposure information through links with science and mapping agencies and the use crowdsourcing techniques. Furthermore, complementary programs in partnership with the Humanitarian OpenStreetMap Team (HOT) have promoted the use of OpenStreetMap participatory mapping technology to supplement government baseline data and prepare key inputs for InaSAFE, leading to over 1.4 million buildings being mapped throughout high-risk areas in Indonesia.

.

Figure 23. Trevor Dhu, representative of the AIFDR, discussing InaSAFE with Indonesia's president, Susilo Bambang Yudhoyono, at the fifth Asian Ministerial Conference on Disaster Risk Reduction on October 24, 2012, shortly after BNPB's launch of InaSAFE.

Source: Claire Price, Australian Government.

How InaSAFE works. InaSAFE is useable by anyone with basic computer skills. Users answer a series of questions about a potential disaster scenario posed by the tool, which then combines hazard models or footprints with exposure information to produce impact analysis. The analysis produces maps and reports estimating the potential damage caused to people and facilities, along with a list of recommended actions to assist disaster managers with decision making. InaSAFE is capable of integrating a wide range of data sets developed by various groups (scientists and engineers; international, national, and local institutions; NGOS and communities). Table 13 lists the currently available hazard inputs for InaSAFE 2.0, the version released in February 2014; Table 14 lists the available exposure data; and Table 15 lists sample impact functions.

Table 13. Hazard Data Accepted in InaSAFE 2.0

Hazard	Input	Hazard footprints
Earthquake	Ground shaking (Modified Mercalli Intensity)	
Tsunami	Maximum inundation depth (meters)	
Volcanic eruption–ash fall	Ash load (kg^2/m^2)	Hazard zones
Flood	Maximum inundation depth (meters)	Flood-prone areas
Tropical cyclone, storm surge	Wind speeds, inundation depth (meters)	

Table 14. Exposure Data Accepted in InaSAFE 2.0

Exposure	Type
Population	Density ($people/units^2$)
Buildings	Schools, hospitals, public buildings
Other structures	Bridges, telecommunications, etc.
Roads	Major, minor
Land use	Agriculture, industrial

Table 15. Sample Impact Functions

Event	Output
Earthquake	Number of fatalities and displaced; number of buildings affected
Tsunami	Number of people affected; number of people to be evacuated
Volcanic ash fall	Number of buildings affected
Flood	Number of people affected; number of people needing evacuation; number of buildings closed and/or damaged

InaSAFE's openness, scalability, and adaptability make it an especially valuable tool for users seeking information about risks and hazards. A variety of other characteristics contribute to its appeal:

- *Integration of latest science and local knowledge.* To ensure disaster managers have access to the best information to support their decisions, AIFDR is working through Geoscience Australia in partnership with the Indonesian Geological Agency (Badan Geologi) and Metrological, Climatology and Geophysics Agency (BMKG) to improve the scientific knowledge about hazards in Indonesia and to supply up-to-date hazard information to subnational disaster management agencies. In addition to using population data and demographic information from the national census, AIFDR piloted a participatory mapping program through a grant to the HOT to map buildings in Indonesia starting in 2011. This program successfully mapped more than 1.4 million structures, and OSM now forms a key part of the ongoing capture of local knowledge. These valuable data sources are critical elements of the InaSAFE engagement, where new analyses can be dynamically run whenever the information is updated.
- *Focus on social vulnerability.* InaSAFE has been designed to take into account gender and age as part of the impact analysis for vulnerable groups. For example, the impact analysis results specify steps that must be taken to meet the needs of pregnant or lactating women (such as providing additional rice) and of infants and the elderly (such as providing extra blankets).
- *Demand-driven development.* InaSAFE started through a partnership with BNPB and was intended to address the needs of subnational disaster management agencies conducting emergency contingency planning. Disaster managers and scientists are still working collaboratively to develop InaSAFE, with the majority of requests for new development coming from Indonesian government officials and provincial disaster managers, who continue to request (and receive training) in use of InaSAFE. These trainings increase the capacity of local governments and communities to use scientific and local knowledge to inform disaster preparedness decisions**.**
- *Client focus.* Since its beta release at the Understanding Risk Conference in Cape Town in July 2012, InaSAFE has been downloaded over 1,000 times—which suggests that the tool has been well received by users. Because InaSAFE is an open source tool, the InaSAFE user community is helping national governments to tailor the software to members' needs.
- *Effectiveness across DRM decision making.* Begun as a tool to aid in preparing for disasters, InaSAFE has been used effectively to visualize critical infrastructure (such as schools, roads, or hospitals) in flood-prone areas across Jakarta. As InaSAFE develops in response to client requirements, its relevance to all parts of the DRM cycle increases. In the future, InaSAFE could support risk-based land-use planning, determine priorities for infrastructure retrofitting, generate real-time impact forecasts, and contribute to postdisaster needs assessments or pre/post damage and loss assessments.
- *User contributions.* As part of the InaSAFE approach to developing contingency planning and preparedness scenarios, OSM tools are used to capture high-resolution baseline data on critical infrastructure. In Jakarta in 2012, in partnership with AIFDR,

HOT, World Bank, and UN Office for the Coordination of Humanitarian Affairs, the provincial disaster management agency (BPBD-DKI Jakarta) pioneered a data collection program to map over 6,000 critical infrastructure locations and 2,668 subvillage boundaries within OSM.

- *Real-time analysis.* Through its collaboration with AIFDR and BNPB, BMKG produces ground-shaking maps following an earthquake. These are automatically pushed to a BNPB server, where an InaSAFE impact assessment is produced within minutes to inform rapid disaster response. The results are also shared with the public on the BNPB website (http://bnpb.go.id).
- *Tested in multiple contexts***.** InaSAFE has been used to produce impact assessments for earthquakes in Yogyakarta, for a tsunami in Padang, and for community-level flood scenarios. Most recently, during the Jakarta floods of 2012–2013 and 2013–2014, reports of flooding from village heads were joined with the subvillage boundaries captured through participatory mapping. This flood footprint was used by the Jakarta disaster management agency and the vice governor of Jakarta to illustrate the change in flooding over time.
- *Award-winning software development.* InaSAFE was called one of the top 10 "open source rookies of the year in 2012"—alongside software developed by Microsoft, Yahoo!, and Twitter.[60] This recognition not only affirms the technical merits of the software and its commitment to open source, but also highlights the exemplary multi-institutional collaborative development of InaSAFE that has taken place over the last two years.
- *Dynamic and inclusive software development***.** In February 2014, InaSAFE 2.0 was released with new features that had been requested by disaster managers, including road exposure data, additional map customization, and InaSAFE reporting. This version marks the first release with contributions from developers focused on applications outside of Indonesia, such as the addition of new population impacts from the Philippines by partners at Environment Science for Social Change Inc.

Next steps for InaSAFE. Preparing for a disaster requires people from various sectors and backgrounds to work together and share their experience, expertise, and resources. Using InaSAFE to develop a scenario requires the same spirit of cooperation and same sharing of expertise and data. The more sharing of data and knowledge there is by communities, scientists, and governments, the more realistic and useful the InaSAFE scenario will be.

It is in this spirit that further application of the platform in other countries and regions is being planned as part of the GFDRR–World Bank Open Data for Resilience Initiative. InaSAFE has shown itself to be an efficient and credible way to save agencies time and resources in developing risk assessment information and hazard impact modeling tools. Hence a number of governments in other countries have expressed interest in using, improving, and refining the InaSAFE tool.

[60] The "rookies" were chosen by Black Duck, a software and consulting company. See Klint Finley, "Microsoft, Yahoo Among Open Source 'Rookies of the Year,'" *Wired*, http://www.wired.com/wiredenterprise/2013/01/open-source-rookies-of-year/.

In the Philippines, a partnership between the World Bank and Local Government Units (LGUs) focused on the preparation of risk-sensitive land-use plans, structural audits of public infrastructure, and disaster contingency plans. Three LGUs were assisted with the mapping of critical public buildings using OSM and with analysis of flood impacts using InaSAFE. This initiative has also supported customization of InaSAFE based on localized needs, including functionality for analysis of detailed population data and the integration of InaSAFE with the web-based tools of the Philippines Department of Science and Technology's Project NOAH (Nationwide Operational Assessment of Hazards).[61]

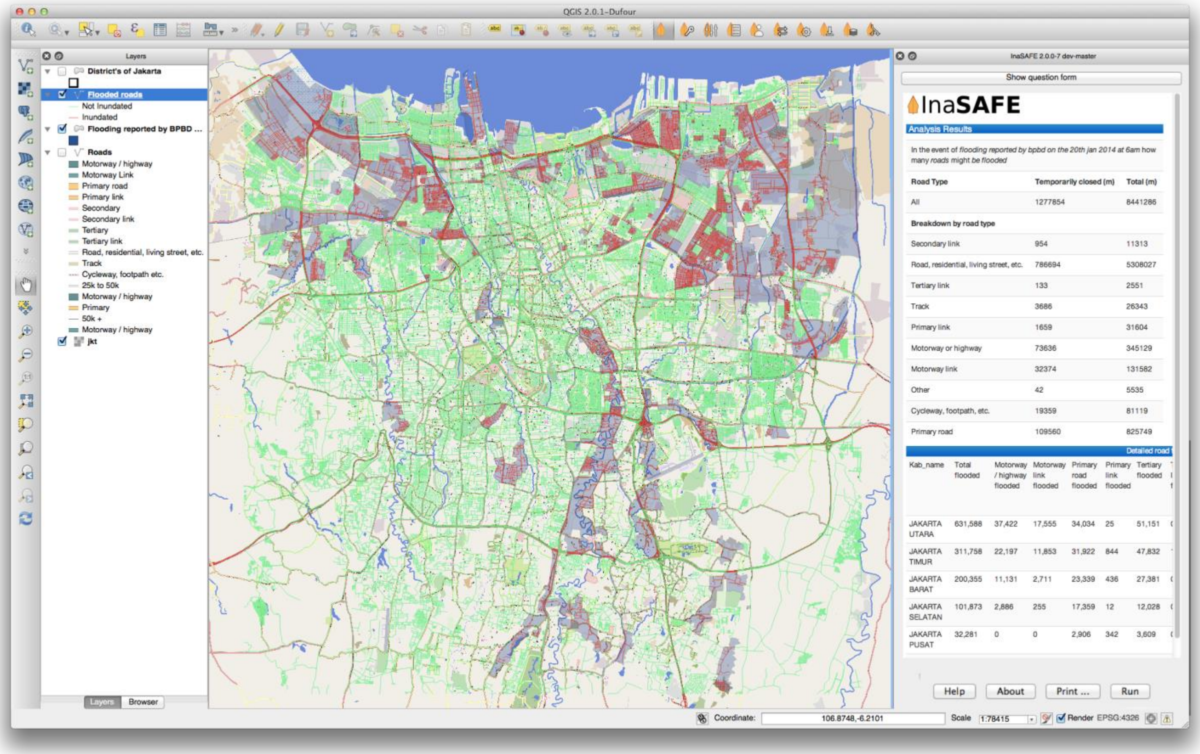


Figure 24. QGIS2.0 with the InaSAFE2.0 dock showing a map and indicative results for an assessment of the impact of flooding on roads in Jakarta.

In Sri Lanka, significant investment by the government in OSM is being capitalized through InaSAFE and QGIS training; see section X. This work has demonstrated the power of InaSAFE to dynamically pull data from OSM and the Sri Lanka GeoNode for analysis. In particular, it has triggered significant interest in InaSAFE as a fundamental tool for disaster management in Sri Lanka and has led to widespread interest in the open source QGIS software, both of which will continue to be supported in years to come.

[61] For more information, see the project website at http://noah.dost.gov.ph/.

Future of Risk

Global River Flood Risk Assessments

Philip J. Ward (Institute for Environmental Studies and Amsterdam Global Change Institute, VU University Amsterdam); contributing authors Brenden Jongman Ward, Jeroen C. J. H. Aerts (Institute for Environmental Studies and Amsterdam Global Change Institute, VU University Amsterdam); Arno Bouwman (PBL Netherlands Environmental Assessment Agency); Rens van Beek, Marc F. P. Bierkens (Department of Physical Geography, Utrecht University); Willem Ligtvoet (PBL Netherlands Environmental Assessment Agency); Hessel C. Winsemius (Deltares)

The economic losses associated with flooding are huge. Reported flood losses (adjusted for inflation) have increased globally from US$7 billion per year during the 1980s, to US$ 24 billion per year in the period 2001–2011.[62] In response, the scientific community has developed a range of models for assessing flood hazard, flood exposure, and flood risk at the global scale[63]. These are being used to assess and map the current risk faced by countries and societies. Increasingly, they are also being used to assess future risk, under scenarios of climate change and/or socioeconomic development.

The growing number of global-scale flood risk models being used for an increasing range of applications is mirrored by the growth of events and networks specifically focusing on global-scale floods and global-scale flood risk assessment. For example, the Global Flood Working Group[64] has been established by the Joint Research Centre of the European Commission and the Dartmouth Flood Observatory.

A large number of studies have attempted to assess trends in past (flood) risk, based on reported losses in global loss databases, such as the EM-DAT database[65] and Munich Re's NATHAN and NatCatService databases (e.g., Barredo, 2009; Bouwer, 2011; Neumayer & Barthel, 2011). These studies have found that reported losses have increased over the last half century, mainly because of increased exposure, such as population growth and the location of assets in flood-prone regions (IPCC, 2012; Kundzewicz, Pińskwar, and Brakenridge, 2013). However, Gall et al. (2011) also found evidence for non-exposure-

[62] Kundzewicz et al., 2013, based on Munich Re NatCatSERVICE data.

[63] See Pappenberger et al., 2012; Jongman, Ward, and Aerts, 2012; Dilley et al., 2005; UNISDR, 2009b; Hirabayashi et al., 2013; Ward et al., 2013a; Winsemius et al., 2013; Arnell and Lloyd-Hughes, 2014 for more details.

[64] See the Global Flood Working Group portal at http://portal.gdacs.org/Expert-working-groups/Global-Flood-Working-Group.

[65] EM-DAT: The OFDA/CRED International Disaster Database, www.emdat.be, Université catholique de Louvain, Brussels, Belgium.

driven increases in disaster losses in the United States over the period 1960–2009, pointing to changes in hazard frequency/intensity as possible drivers of risk.

Several global flood risk assessment models have been developed in the last decade. Initially, these models provided estimates of risk under current conditions (i.e., they did not account for changes in climate and/or socioeconomic development).

The earliest of these was the "hot spots" project of the World Bank, which sought to provide "a spatially uniform first-order, global disaster risk assessment," including the risk of flooding (Dilley et al., 2005). Maps were developed showing risk severity at a spatial resolution of about 2.5′ x 2.5′ (about 5km x 5km at the equator), categorized into deciles. The maps were based on a georeferenced data set of past extreme flood events between 1985 and 2003 from the Dartmouth Flood Observatory, combined with gridded population maps. The flood extent data were based on regions affected by floods, not necessarily on actual flooded areas. Nevertheless, the project was successful in identifying global disaster risk hot spots, and since then improved flood risk maps have been developed for the GAR2009 (UNISDR, 2009b), which based flood extent data on the modelling approach of Herold and Mouton (2011) and produced global hazard maps for a limited number of flood return periods. These data were combined with high-resolution maps of population and economic assets, as well as indicators of vulnerability, to develop maps of current flood risk at a spatial resolution of 1km x 1km. Pappenberger et al. (2012) have developed a model cascade for producing flood hazard maps showing flooded fraction at a 1km x 1km resolution (resampled from a more coarse 25km x 25km grid). The cascade can be used to develop flood hazard maps for different return periods but has not yet been used to assess risk.

As part of recent efforts to project changes in risk in the future under scenarios of climate change and socioeconomic development, Jongman, Ward, and Aerts (2012) assessed and quantified changes in population and assets exposed to 100-year flood events between 1970 and 2050. Combining the flood hazard maps developed for the GAR with projections of changes in population and gross domestic product (GDP), they found that socioeconomic development alone is projected to drive an increase in the global economic exposure to flooding between 2010 and 2050 by a factor of 3.

In 2013 and 2014, three new global flood risk assessment models were presented. The first of these was GLOFRIS (GLObal Flood Risk with Image Scenarios) (Ward et al., 2013a; Winsemius et al., 2013). GLOFRIS estimates flood risk at a spatial scale of 30″ x 30″ (about 1km x 1km at the equator), whereby risk is expressed as several indicators (annual exposed population, annual exposed GDP; annual expected urban damage, and annual affected urban area). A description of the model framework (Winsemius et al., 2013) included a case study application for Bangladesh (Figure **25**), in which changes in annual expected damage were projected between 2010 and 2050. These preliminary results showed that over that period, risk was projected to increase by a factor of 21–40. Both climate change and socioeconomic development were found to contribute importantly to this increase in risk, although the individual contribution of socioeconomic development is greater than that of climate change. The model was then further developed and applied at the global scale (Ward et al., 2013a). GLOFRIS is currently being used within and outside the scientific community to assess changes in flood risk at the global scale under a wide range of climate and socioeconomic scenarios.

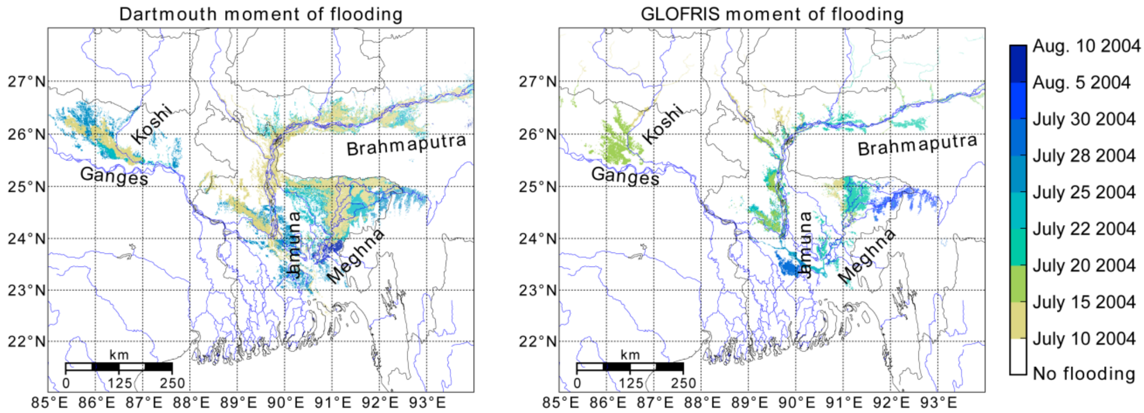


Figure 25. Observed flood extents in Bangladesh during July and August 2004: Dartmouth Flood Observatory database versus GLOFRIS model.

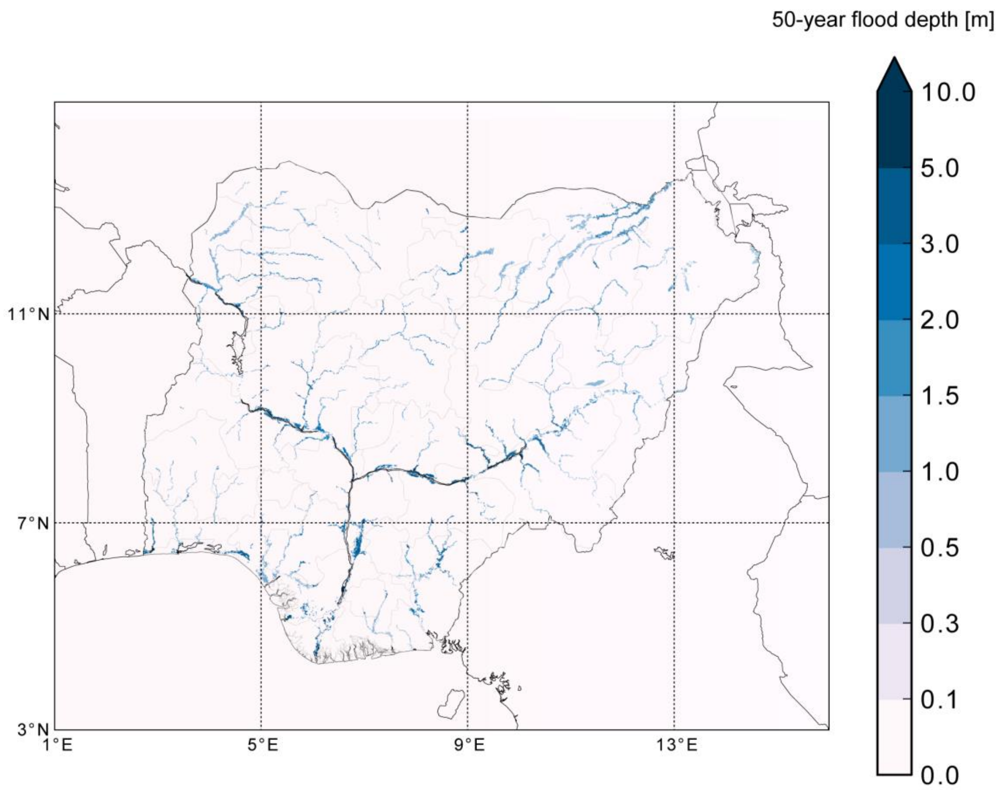
Also in 2013, Hirabayashi et al. (2013) developed a global inundation model, and combined this with high-resolution population data, to assess and map the number of people exposed to 10- and 100-year flood events at a spatial resolution of 15′ x 15′ (about 30km x 30km at the equator). They then used this model to quantify the change in the number of people affected by 10- and 100-year floods between the periods 1970–2000 and 2070–2100. The study used discharge data from 11 global climate models and for four different scenarios of climate change.

Since then, Arnell and Lloyd-Hughes (2014) used a simpler method to assess changes in flood risk between 1960–1990 and two future time periods (2050s and 2080s), using results from 19 global climate models, four climate scenarios, and five scenarios of socioeconomic development. This study found that under a "middle-of-the-road" socioeconomic scenario, climate change by 2050 would lead to an increased exposure to river flood risk for between 100 and 580 million people, depending on the climate change scenario.

Using the results of global-scale river flood risk assessments in practice. The results of global-scale river flood risk assessment have been applied in practice, with selected examples shown below.

Nigeria. In 2012, floods in Ibadan, Nigeria, killed hundreds of people, displaced over 1 million people, and destroyed crops. A post disaster needs assessment carried out by the GFDRR urgently recommended strengthening the country's resilience to flooding, and in response the World Bank Africa Disaster Risk Management team implemented the National Flood Risk Management Implementation Plan for Nigeria.

At the time, little information was available for assessing the level of flood risk in Nigeria. On the request of the GFDRR and World Bank's Africa team, GLOFRIS was used to carry out a rapid assessment of flood risk per state in Nigeria. Maps were produced showing the expected extent of flooding for different return periods (see Figure **26**), as well as the annual affected population per state (Figure **27**). The model and its results were "a great first step in providing a national map showing vulnerability to floods for Nigeria, where previously, no such methodologies were in place."[66] However, an assessment of the number of people affected by different inundation depths was found to be critical, as the difference between 10 cm and 1 m of flood inundation is clearly significant. Since GLOFRIS had been developed in a flexible manner, it was easy to integrate this request into the model structure, and tailor the output to the needs of the model's end-users.



[66] The quotation is from D. Wielinga, senior disaster risk management specialist, World Bank Africa Region; see GFDRR, "GFDRR Connects Science with Policy to Help Address Flood Risk in Nigeria," https://www.gfdrr.org/node/27850.

Figure 26. Map of modelled inundation extent and depth in Nigeria using GLOFRIS. Maps of this type can be used to assess which areas are exposed to flooding.

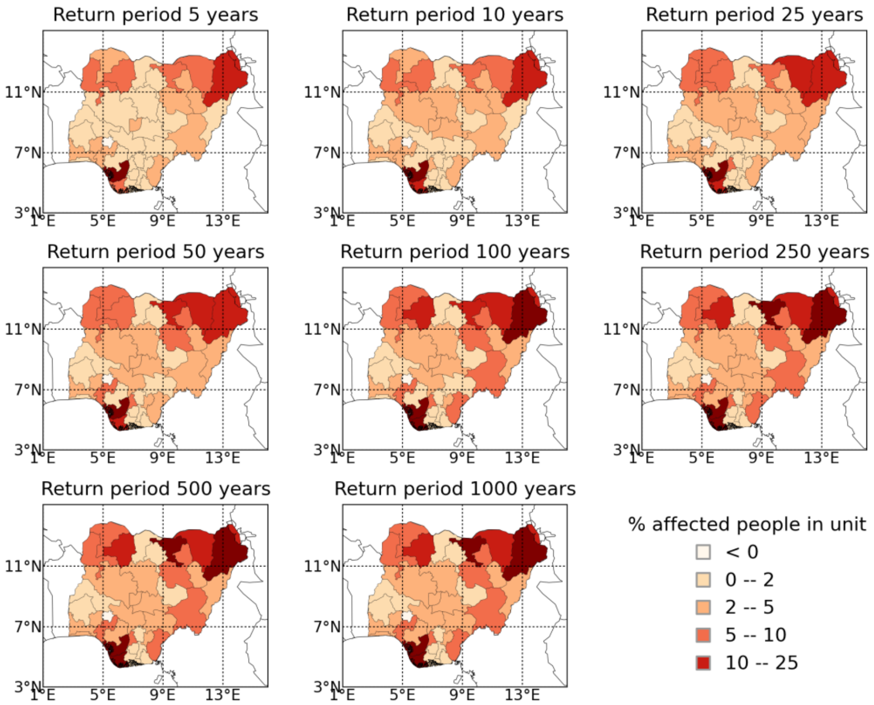


Figure 27. Maps of Nigeria showing the modelled results of the number of people affected per state (expressed as a percentage of the total population per state) for floods of different severities. Maps of this type can be used for identifying risk hot spots.

Present and Future Flood Risk. In 2014, UN-HABITAT will publish the fourth edition of its report on urban water and sanitation. This is the first edition to project conditions into the future and to treat flood risk. GLOFRIS is being used to project present and future flood risk in the world's cities (PBL, 2014), based on the scenario study for the Organisation for Economic Co-operation and Development Environmental Outlook to 2050 (OECD 2012).

GLOFRIS has been used to project changes in annual exposed population and annual exposed GDP to flooding, aggregated to the World Bank regions. Projections of the number of people living in flood-prone areas, defined as areas exposed to floods with a return period of 1,000 years or less, are shown in Figure **28**. In all regions, the urban population living in flood-prone areas is projected to grow rapidly between 2010 and 2050, while in almost all regions the rural population living in flood-prone areas is projected to decline. An exception is Sub-Saharan-Africa, where the rural population living in flood prone areas is projected to continue growing after 2030.

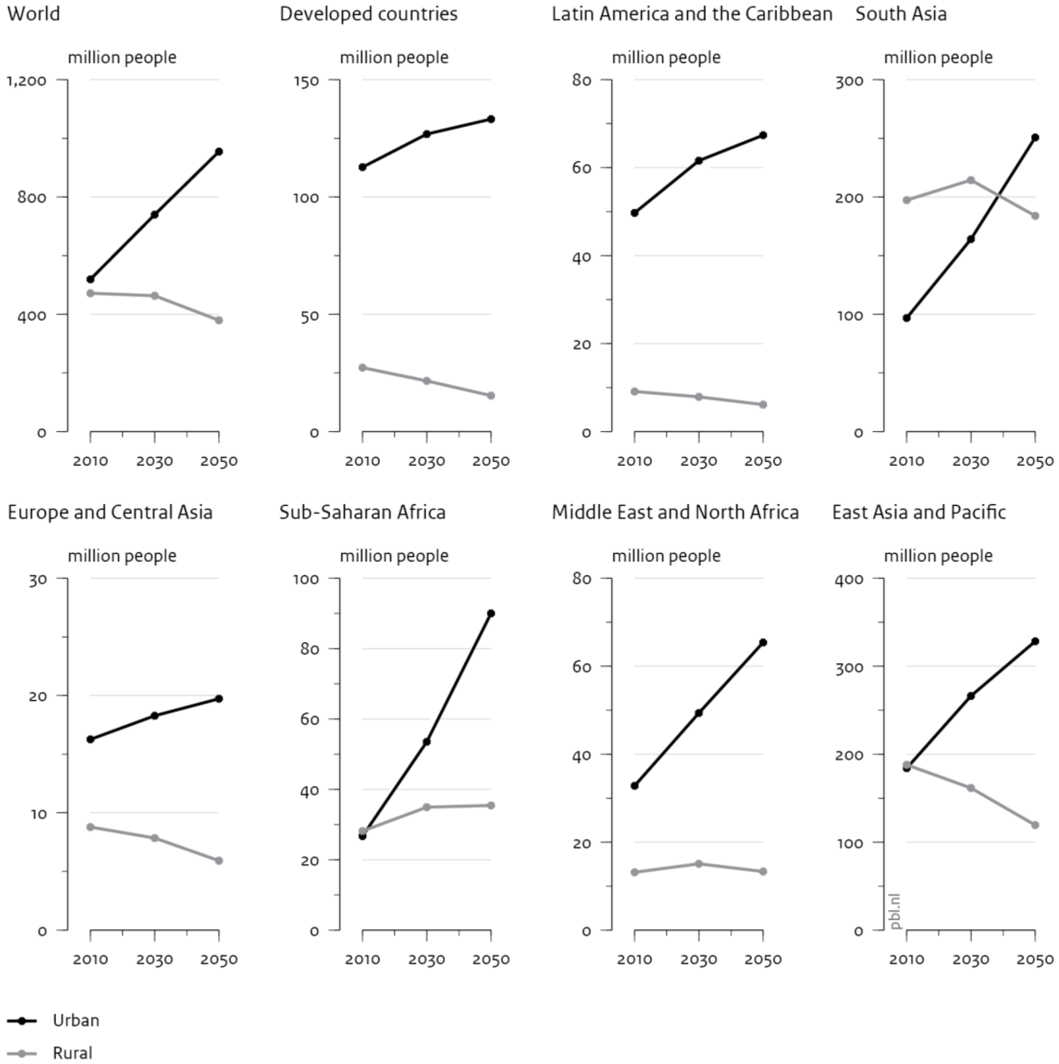


Figure 28. People living in flood-prone areas in different regions, 2010–2050.
Source: PBL, 2014.
Note: Flood-prone areas are defined as areas with a probability of a flood once in a thousand year or less. Note different scales on y-axes.

GLOFRIS has also been used to assess the increase in annual exposed GDP between 2010 and 2050, as well as to give a preliminary assessment of how much the overall risk could be reduced by improving flood protection standards. Figure **29** shows the annual exposed GDP in urban and rural areas for 2010 and 2050, assuming different flood protection standards. The figure suggests that in all regions, the risk is projected to increase substantially between 2010 and 2050, and also that better protection standards could significantly reduce flood risk.

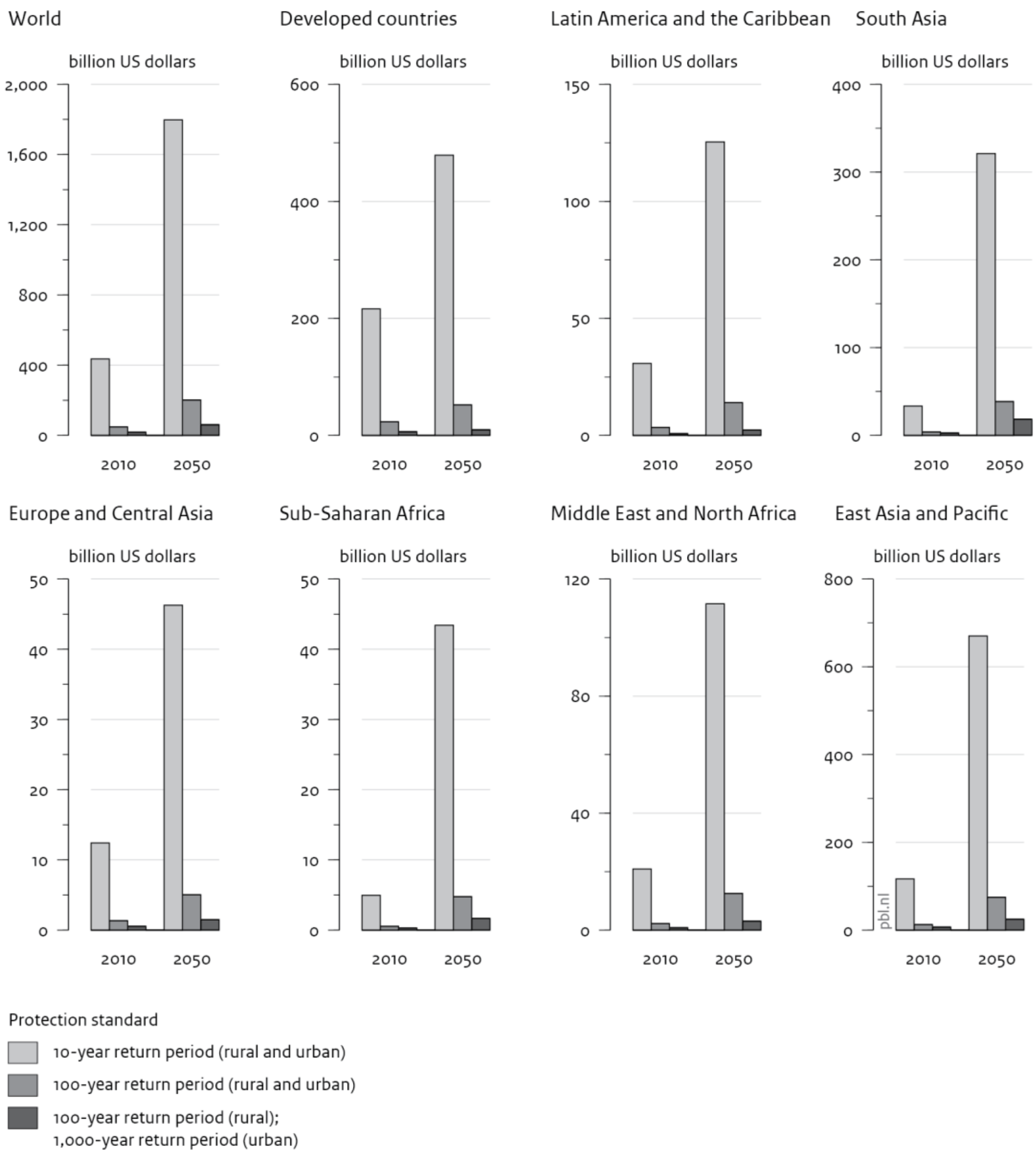


Figure 29. Annual exposed GDP to flooding in 2010 and 2050, under different assumptions of flood protection standards.
Source: PBL, 2014.
Note: Y-axes use different scales.

The World Resources Institute's Aqueduct Water Risk Atlas (http://aqueduct.wri.org/) offers a suite of interactive maps that help people better understand where and how water risks and opportunities are emerging worldwide. Most of the current available map layers focus on water resource availability and droughts. Aqueduct will be extended to include global-scale flood risk maps based on GLOFRIS. The maps will show the current level of river flood risk, per sub-catchment, across the globe, expressed in indicators such as the annual affected number of people and level of economic risk. Future scenarios of risk will also be provided. These new Aqueduct map layers will help identify where new flood risks will emerge and how severe they will be, what their potential causes are, and how best to adapt to, mitigate, or prevent them.

Changes in future flood risk due to inter-annual variability are less well developed. GLOFRIS is currently being used to determine whether flood risk might be increased or reduced as a result of naturally occurring variations in the climate system, like the El Niño Southern Oscillation (ENSO), and if so, how this information might be used by the (re)insurance industry. Research is beginning to show that flood hazard and risk are indeed strongly correlated to ENSO at the global scale (Ward et al., 2010, 2013b, 2014), and the Risk Prediction Initiative, based at the Bermuda Institute of Ocean Science, is facilitating the translation of this research into usable results for insurance and reinsurance companies. For example, claims may increase (or decrease) in particular ENSO phases, affecting the amount of financial resources necessary for covering eventual losses.

Limitations of global-scale river flood risk assessments, and how they should *not* be used in practice. Global-scale flood risk assessment models are coarse by their very nature, and represent both physical and socioeconomic processes in simplified ways. This is not a problem when the limitations are recognized and communicated, and the models are used to answer appropriate questions. However, the models have clear limitations, and their results should not be used in all situations.

The matter of spatial resolution is very important. Although many global hydrological models run with grid cells of approximately 50km x 50km, for modelling impacts a higher resolution is preferable, since the impacts of flooding are dependent on physical and socioeconomic processes at a much finer scale. Hence, flood risk research should aim to simulate floods at a higher resolution than the native 50km x 50km grid size of global hydrological models.

Geographical scale is also an issue. Although a 1km x 1km grid may be appropriate for calculation purposes, the actual model outcomes at this resolution are subject to huge uncertainties. Presenting results for a given grid cell is not encouraged, since it may give a false sense of safety, or indeed of risk. Moreover, global models are not intended to give assessments of risk at this high resolution, but rather to indicate risk, and relative changes in risk, across larger regions, such as continents, countries, river basins, and states. A high-resolution detailed flood risk map for a city, district, street, or building requires a more detailed modelling approach, as well as more detailed local knowledge and interaction with local stakeholders.

To date, global-scale river flood risk models have generally assessed flood risk under the assumption that no flood protection measures are in place (see also Section X). In reality, many regions are protected by infrastructural measures up to a certain design standard. Ward et al. (2013a) assessed the sensitivity of global flood risk modelling results to this assumption. Under the assumption of no flood protection measures, they simulated annual expected urban damage of about US$ 800 billion (PPP) per year. However, assuming protection standards of 5 and 100 years globally, this estimate fell dramatically, by 41 percent and 95 percent, respectively. Clearly, then, existing flood protection standards should be included in global flood risk assessment models.

It is possible to incorporate flood protection standards in flood risk assessments to assess the impacts of different strategies to reduce risk (see for example Jongman et al. (2014) for such an assessment on continental scale). But such assessments should be used only for assessing the large-scale effects of strategies, and not for the detailed effects of individual measures. For example, the global model could be used to assess how much a country could reduce its risk by increasing the protection standard of its dikes and levees. But it should *not* be used to dimension individual dike sections.

A final limitation of the global modelling approaches described here is that they do not capture pluvial floods or local-scale flash flood events. While flash floods cause many human fatalities in some parts of the world (Gaume et al., 2009), their local-scale character makes it challenging to simulate their probability and extent at the global scale.

Main research needs for the coming 5-10 years. Increases in available computational power are allowing global hydrological models to adopt finer spatial resolutions, a development that will create new scopes for application and raise new research questions.

To date, the accurate representation of vulnerability has been one of the largest obstacles in large-scale flood risk assessment. Large-scale risk studies either have not incorporated the vulnerability of exposed people and assets (Hirabayashi et al., 2013; Jongman, Ward, and Aerts, 2012; Nicholls et al., 2008), or have done so in a highly stylized manner (e.g. Feyen et al., 2012; Ward et al., 2013a; Rojas, Feyen, and Watkiss, 2013). Anecdotal evidence from studies at more local to regional scales suggests that societies become less vulnerable over time. An improved understanding of temporal changes in vulnerability, and their influence on risk, is a research priority.

Another priority is improving the representation of exposure in global flood risk models. While high-resolution and high-quality gridded data sets of current population, GDP, and land use are available, and provide useful proxies for representing current exposure, high-resolution projections for population and GDP are only beginning to become available; and land-use projections at the required resolution are still scarce. Recently, a first global forecast model of urban development was presented that simulates urban expansion at a horizontal resolution of 1km x 1km resolution, based on empirically derived patterns (Seto, Güneralp, and Hutyra, 2012). Once available publicly, such high-resolution data could provide important new information in global flood risk studies.

The need for a coherent database of current flood protection standards is becoming more and more important. Preliminary efforts to include flood protection standards in large-scale flood risk assessments have been presented (Hallegatte et al., 2013, Ward et al., 2013a; Jongman et al., 2014) using simplified assumptions and scenarios. These studies show that the flood protection standards assumed in the modelling process have a huge effect on the overall modelled risks. This finding illustrates the potential benefits of adaptation, but also shows that uncertainty in flood protection standards can strongly affect model outcomes. In particular, flood protection measures will modify the magnitude and frequency along the drainage network and locally change the duration, depth, and flow velocities attained during inundation events. This fact has severe implications for the resulting hazard, and its simulation requires an improved representation of the relevant processes in hydrological models. In addition, new research suggests that natural ecosystems should be incorporated as important means of protection against floods, for both river flooding (Stürck, Poortinga, and Verburg, 2013) and coastal flooding (Arkema et al., 2013).

Delivering Risk Information for a Future Climate in the Pacific

W. C. Arthur, H. M. Woolf (Geoscience Australia); P. Dailey (AIR Worldwide)

Tropical cyclones are the most common disaster in the Pacific, and among the most destructive. In December 2012, Cyclone *Evan* caused over US$200 million damage in Samoa, nearly 30 percent of Samoan GDP. Niue suffered losses of US$85 million following Cyclone *Heta* in 2004—over five times its GDP. As recently as January 2014, Cyclone Ian caused significant damage throughout Tonga, resulting in the first payout of the Pacific Catastrophe Risk Insurance Pilot system operated by the World Bank.[67]

According to the Intergovernmental Panel on Climate Change (IPCC), intense tropical cyclone activity in the Pacific basin will likely increase in the future (IPCC, 2013). But such general statements about global tropical cyclone activity provide little guidance on how impacts may change locally or even regionally, and thus do little to help communities and nations prepare appropriate adaptation measures.

This study[68] assesses climate change in terms of impact on the human population and its assets, expressed in terms of financial loss. An impact focus is relevant to adaptation because changes in hazard do not necessarily result in a proportional change in impact. This is because impacts are driven by exposure and vulnerability as well as by hazard. For example, a small shift in hazard in a densely populated area may have more significant consequences than a bigger change in an unpopulated area. Analogously, a dense population that has a low vulnerability to a particular hazard might not need to adapt significantly to a change in hazard. Even in regions with high tropical cyclone risk and correspondingly stringent building codes, such as the state of Florida, a modest 1 percent increase in wind speeds can result in a 5 percent to 10 percent increase in loss to residential property. Quantifying the change impact thus supports evidence-based decision making on adaptation to future climate risk.

The quantitative, locally specific information needed to guide adaptation decisions at the national or community level can best be generated by adopting a multidisciplinary approach. Climate model simulations alone are insufficient, since they deal with extreme events that are by their nature rare and unlikely to be generated in a limited set of general circulation model (GCM) runs. Moreover, features having the greatest impact are highly localized and hence impossible to resolve in a global model. The analysis described here joined climate GCMs forced by emission scenarios to catastrophe modelling methods—a hybrid approach that drew on the respective strengths of climate science and risk management.

[67]World Bank, "Tonga to Receive US$1.27 Million Payout for Cyclone Response," press release, January 23, 2014, http://www.worldbank.org/en/news/press-release/2014/01/23/tonga-to-receive-payout-for-cyclone-response.

[68] Analysis benefited from funding provided under a grant from the Global Facility for Disaster Reduction and Recovery.

Using catastrophe models, it is possible to estimate the financial impacts caused by tropical cyclones at a local scale. Catastrophic risk models do not have the computational overhead of a GCM, and so can be run in a probabilistic framework using a catalog of events (built from statistics about past cyclones, including intensity, frequency, and tracks) that represents the likely true distribution of loss-causing cyclones. By analyzing the projections from GCMs, it is possible to determine how the distributions of loss-causing cyclones may change; and by adjusting the catastrophe model's hazard catalogue to be consistent with the GCM projections, it is possible in turn to produce objective projections of hazard, damage, and loss.

The project described here analyzed current and future cyclone hazard and risk for 15 Pacific Island countries involved with PCRAFI project; see section X for more information by combining data produced through the PCRAFI project with information on tropical cyclone activity in the Pacific region extracted from model runs produced for the IPCC Fifth Assessment Report.

Approach. Over 20 modelling groups have conducted modelling experiments that contribute toward the fifth phase of the Coupled Model Intercomparison Project (CMIP5), based on the latest emission scenarios used in the Fifth Assessment Report of the IPCC (Taylor, Stouffer, and Meehl, 2012). Five models from the CMIP5 collection were analyzed by Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) as part of the Pacific-Australia Climate Change Science and Adaptation Planning (PACCSAP) program,[69] in order to identify and track tropical-cyclone-like vortices (TCLVs).[70] Figure **30** shows sample track data from GCMs and the comparison to historical tropical cyclones.

[69] The five models were ACCESS 1.0, Can ESM, CSIRO Mk3.6.0, IPSL CM5A, and NorESM-1M. More information is available about the PACCSAP program on the Australian Department of the Environment website, http://www.climatechange.gov.au/climate-change/grants/pacific-australia-climate-change-science-and-adaptation-planning-program.

[70] The identification and tracking algorithm used was based on the works of Nguyen and Walsh (2001), Walsh and Syktus (2003), and Abbs et al. (2006), and uses eight criteria to identify a tropical cyclone. Further details of the method can be found in Abbs (2012).

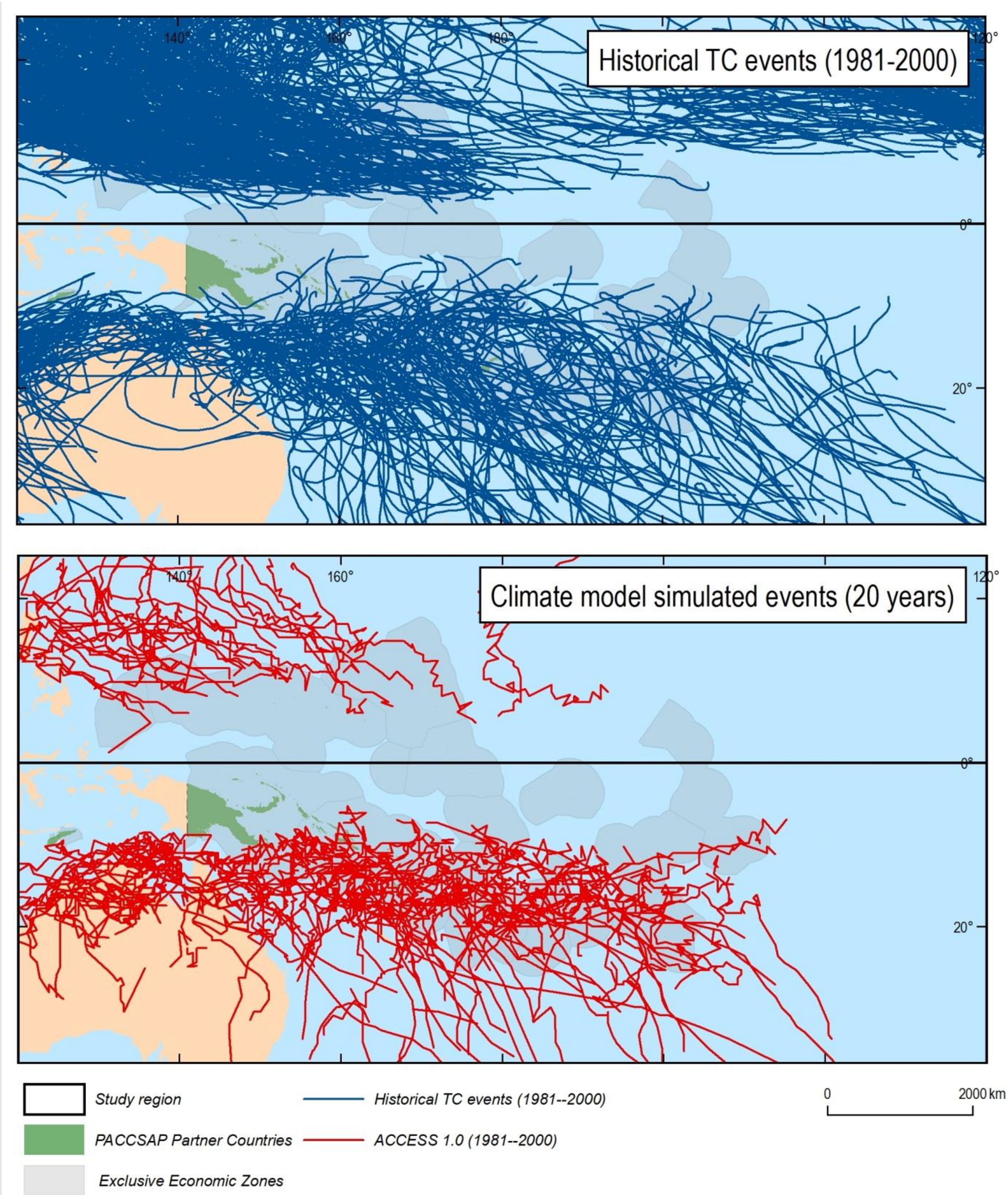


Figure 30. Historical tropical cyclone tracks for the period 1981–2000 (top) and tropical-cyclone-like vortices extracted from a 20-year simulation using a general circulation model (bottom).
Source: Geoscience Australia.

The analysis focused on the RCP8.5 scenario (the most extreme Representative Concentration Pathway, or RCP, projection), under which annual mean global temperature anomalies reach +4°C by 2100 (IPCC, 2013). However, the approach described here is applicable to any scenario where climate model data are available. Two time periods were analyzed: 1981–2000, representing current climate conditions, and 2081–2100, representing future climate conditions under this scenario.

The climate-conditioned catalogues were validated by a cross-discipline group of scientists within and outside the project teams at Geoscience Australia and AIR Worldwide. Statistical and physical checks assured that the distribution of storm track, intensity, evolution, wind speed, storm surge, and other dynamical parameters properly correlated in space and time with the changes informed by the climate model projections. The experimental framework was designed to incorporate peer review at all stages of the project and to include vetting of the results. This approach has been used successfully to model hazard and loss for future climate conditions in other studies, such as Dailey et al. (2003) and Arthur and Woolf (2014).

Results. Table 16 presents the change in cyclone hazard for the five-model ensemble mean. The matrix contains current, future, change, and relative change values for seven parameters that inform the resampling of the 10,000-year synthetic event catalogue. Of all the parameters, only one (genesis longitude in the Northern Hemisphere domain) shows a significant change.[71]

Table 16. Changes in Key Tropical Cyclone–related Parameters for the Five-member Ensemble

Field	Domain	Current climate	Future climate	Change	Relative change (%)
Annual frequency (tropical	NH	16.1	17.9	1.81	11.2
cyclones/year)	SH	11.6	11.3	-0.34	-2.9
Genesis latitude (°N)	NH	14.0	13.4	-0.64	-4.6
	SH	-13.8	-13.2	0.53	-3.9
Genesis longitude (°E)	NH	159.7	170.4	10.77	6.7
	SH	157.3	160.4	3.12	2.0
Mean latitude of maximum sustained	NH	18.5	18.1	-0.37	-2.0
wind (°N)	SH	-18.6	-19.0	-0.34	1.8
Mean latitude of minimum pressure (°N)	NH	18.9	18.7	-0.18	-0.9
	SH	-19.0	-19.1	-0.14	0.7
Mean minimum central pressure (hPa)	NH	963.2	965.7	2.46	0.3
	SH	968.5	969.5	0.98	0.1
Mean maximum sustained wind (m/s)	NH	41.2	39.4	-1.8	-4.4
	SH	38.5	37.4	-1.1	-2.9

Source: Arthur and Woolf, 2013.
Note: Bold, italicized values indicate that change in the ensemble mean is greater than the inter-model standard deviation. NH = Northern Hemisphere; SH = Southern Hemisphere.

Figure **31** shows the changes in tropical cyclone intensity distribution between current and future time periods for the mean of all climate models. There is a shift in the distribution, with fewer midrange events (tropical cyclone categories 1–4), more weak events (tropical depressions and tropical storms) and more very intense events (tropical cyclone category 5). shows that mean maximum sustained winds will decrease in both hemispheres, but as the changes in wind speeds at both ends of the distribution largely balance, the mean intensity does not change significantly in either hemisphere.

[71] Significant change was considered where the ensemble mean change is greater than the inter-model standard deviation.

The interaction of changes in frequency and intensity distributions brings about nonlinear changes in the corresponding hazard levels. For example, it is possible that a reduction in frequency, coupled with an increase in the share of intense tropical cyclones, could increase the probability that the most extreme winds would occur—and as a result, increase the likelihood of experiencing larger losses. Return period losses for current conditions and for the five future scenarios over the whole Pacific region show that for two scenarios, losses will significantly increase (Figure **32**). However, local losses may differ from the regional trends.

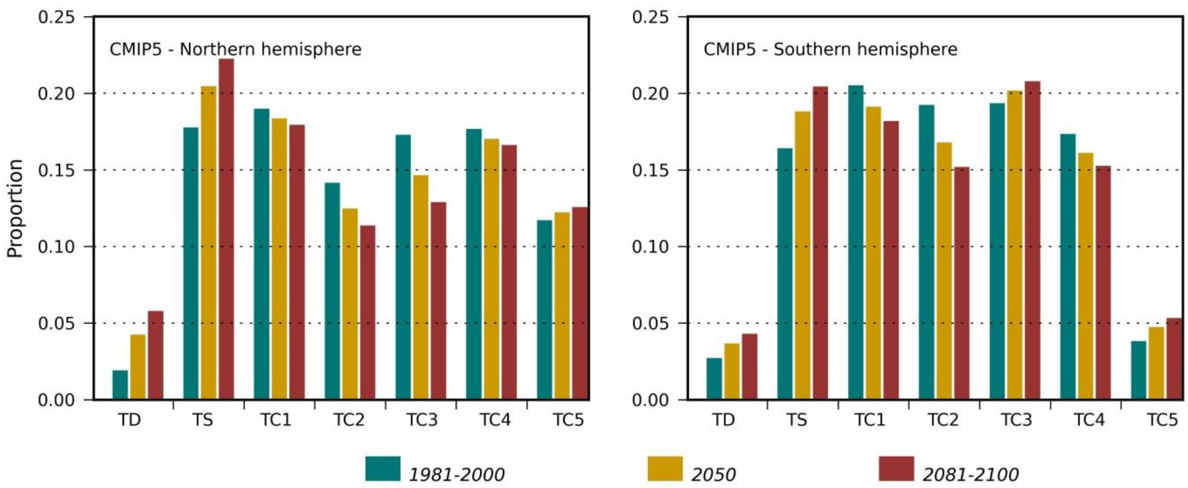


Figure 31. Ensemble mean proportion of cyclones for current and future climate in the Northern Hemisphere (left) and Southern Hemisphere (right).
Source: Arthur and Woolf, 2013.
Note: Classification is based on the Saffir-Simpson hurricane wind scale. Values for 2050 were determined using a linear interpolation between the midpoint of the 1981–2000 and 2081–2100 periods. TD = tropical depression; TS = tropical storm; TC = tropical cyclone.

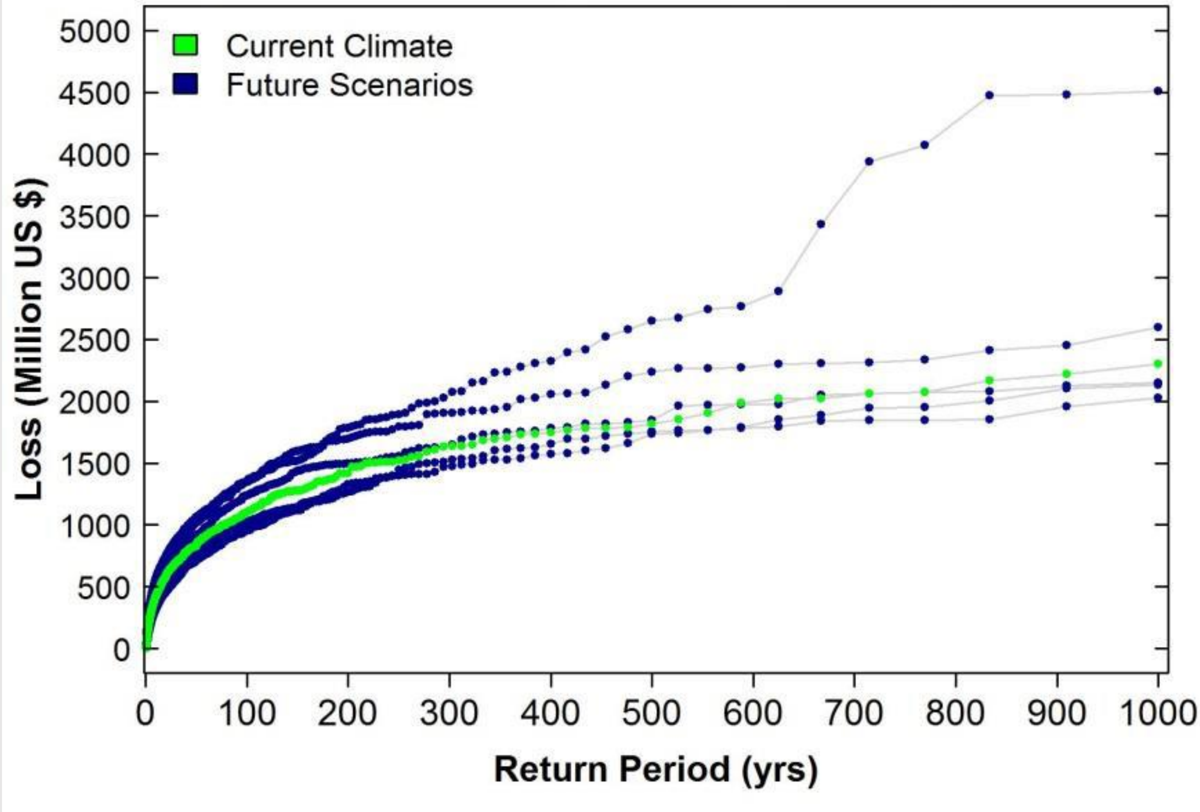


Figure 32. Individual regional end-of-century exceedance probability curves for ensemble members (blue) compared to the current climate exceedance probability curve (green).
Source: Air Worldwide.
Note: Each curve represents the loss across all asset types arising from tropical cyclone impacts.

The 250-year return period losses are presented inFigure **33**, based on the ensemble mean for the current climate. Across the entire Pacific region, a 250-year return period loss is around 9 percent of GDP. However, examining individual countries produces a wide range of results. The 250-year loss is nearly 280 percent of GDP for Niue, is 99 percent of GDP for the Federated States of Micronesia, and is 79 percent of GDP for the Marshall Islands.

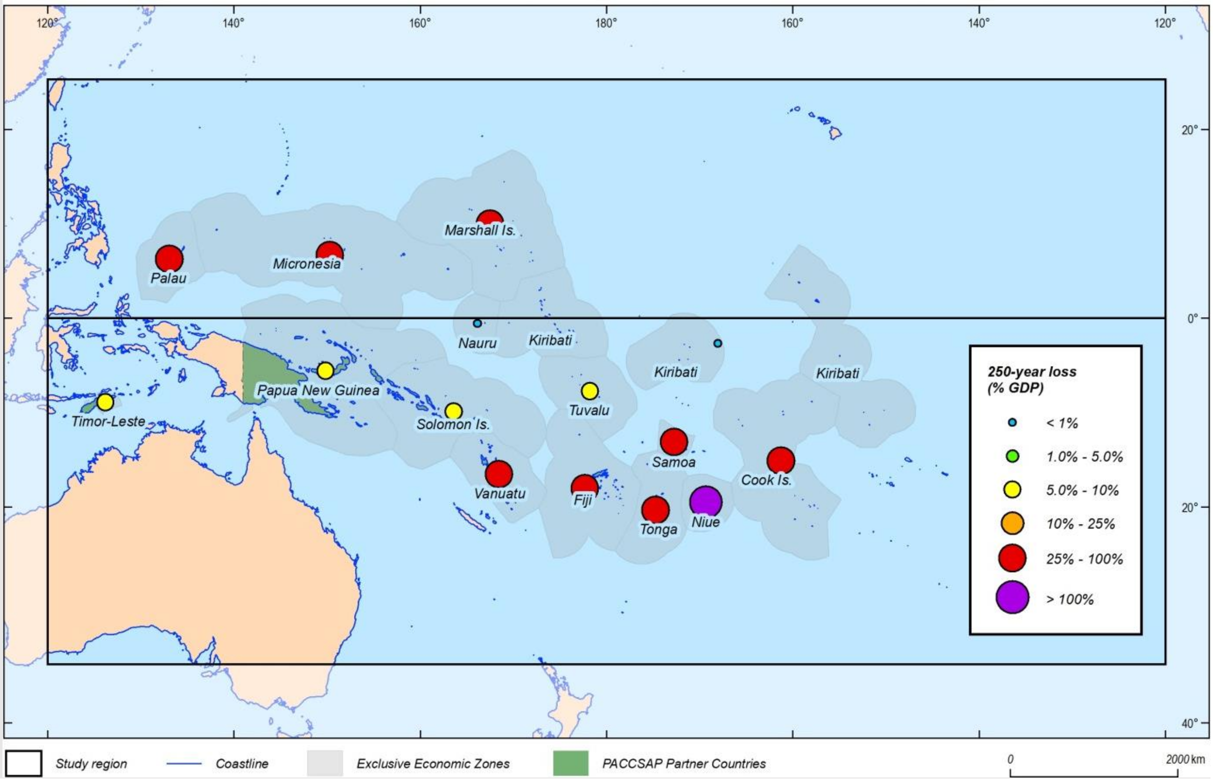


Figure 33. Ensemble mean 250-year losses across the Pacific as a proportion of Pacific Island Countries' GDP for current climate conditions (1981–2000).
Source: Geoscience Australia.

Figure **34** shows that 250-year return period losses increase in most countries under future climate conditions; however their significance depends on the GDP. The biggest increases are seen in Vanuatu (11 percent), Niue (29 percent); and Samoa (35 percent); there is a decrease in Nauru and Kiribati. The changes in tropical cyclone intensity or frequency are not nearly as large as these changes in loss. The nonlinear nature of the vulnerability models leads to major increases in loss levels for only minor increases in the hazard level.

However, of all the projected changes in loss, only the change in 250-year return period loss for Samoa (total losses) could be considered statistically significant. The mean change in loss across the five models exceeds the standard deviation of those changes for this location. For no other country can the changes in loss be considered significant under this metric. This result suggests the spectrum of changes in tropical cyclone activity that can be drawn from the climate model projections.

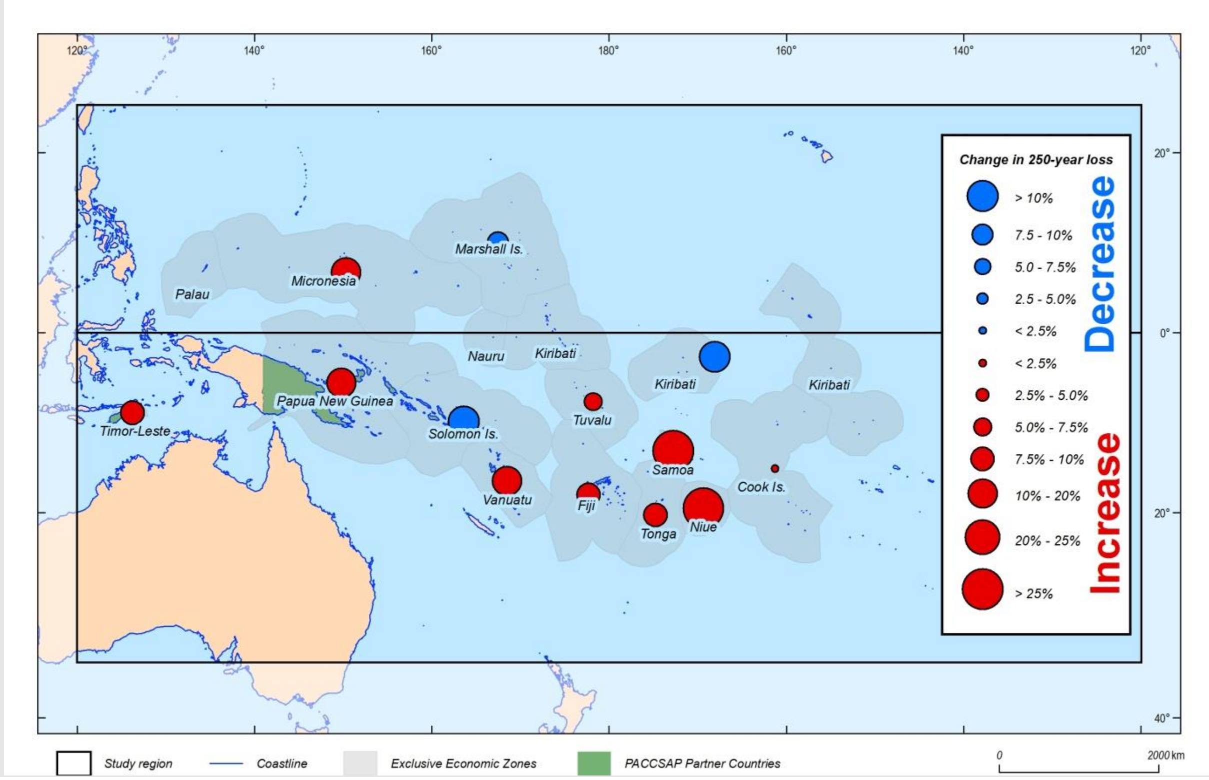


Figure 34. Ensemble mean change in 250-year return period loss.
Source: Geoscience Australia.

Discussion. The change in wind risk in the future modelled climate is neither simple nor uniform across the region. Determining appropriate adaptation measures requires quantitative information beyond generic "up or down" statements. Changing intensity and frequency can balance out in a complex interaction. This means the average peak intensity may remain constant or decline, while long return period wind speeds increase due to a rise in the relative proportion of very intense tropical cyclones.

The analysis here has focused on regional (basin-wide) changes in key tropical cyclone parameters. However, tropical cyclone–related risk depends on changes in tropical cyclone activity at the country scale, and on actions taken at the national and community level. It is highly likely that some countries will experience changes in tropical cyclones that are at odds with the basin-wide changes. Adaptation options need to recognize the localized nature of the changing hazard and risk, and be tailored to suit the local capacity for implementing possible options.

The results of this study demonstrate that assessing the impact of climate change on hazard alone is not sufficient. The large increase in risk in many regions, compared to the relatively small changes in hazard, highlights the significance of exposure and vulnerability. The nonlinear nature of vulnerability means losses can increase dramatically as a result of only small changes in hazard. This is an important finding because it suggests that the most effective way to reduce financial risk is to reduce vulnerability. At the country scale, little can be done to minimize changes in hazard, and exposure to tropical cyclones is likely to continue to increase as populations grow. By improving the resilience of exposed assets (reducing vulnerability), risks can be significantly lowered. Some examples include preemptive vegetation reduction to minimize chance of tree crops suffering damage in a tropical cyclone, improved site selection for vulnerable crops and other land-use planning measures, or changes in and/or more stringent enforcement of local building standards.

Using an ensemble of climate models for this work makes it possible to understand the robustness of the projected changes. Analyzing loss changes derived from a single climate model could be misleading if it were an outlier compared to the ensemble. A consistent trend across several models would give end-users much greater confidence in the robustness of the results, even if the mean result is not statistically significant. As it is, our analysis found several models with statistically significant changes in tropical cyclone frequency, while the ensemble mean change was not statistically significant. Given that over 20 modelling groups conducted RCP8.5 experiments, using an ensemble of only five may in itself lead to skewed results. Careful selection of the members, based on quantitative measures of performance in the region, would minimize the risk of biased results. More-reliable results are more likely to be accepted, and to hence more likely to prompt action.

Assessing results from multiple climate models also encourages stakeholders to consider a range of potential outcomes for which they could prepare adaptation options. While the ensemble mean can provide greater confidence than any individual model result, using a worst-case result that provides an upper limit of the potential impacts may be desirable in some applications. This conservative approach would be appropriate, for example, for standards for building design, given the expected lifetime of built assets, especially large infrastructure (e.g., hospitals or port facilities). For longer planning timelines, the expense and time needed to modify the asset as projections of risk change make it harder to change adaptation options. At shorter timelines (e.g., annual crop planting), risk reduction options can be more readily evaluated, making a mean estimate of risk more suitable for consideration.

Finally, it should be noted that this study did not consider projections of future exposure. It is widely acknowledged that increased exposure has been the most significant driver of increased disaster losses over the past decades (Barthel and Neumayer, 2012). Thus future studies of the kind described here would benefit from considering exposure projections, although the complex nature of exposure modelling is likely to add significantly to the uncertainty in the results. For policy makers, decisions about climate change adaptation (particularly decisions related to assets with a long lifetime) may need to be made in the absence of unambiguous evidence.

A Framework for Modelling Future Urban Disaster Risk[72]

David Lallemant, Steven Wong, Anne Kiremidjian (Stanford University)

This paper proposes a framework to understand and model the drivers of new risk creation, with a particular focus on dynamic urban environments. Such a framework will help policy

[72] This paper draws on D. Lallemant, S. Wong, K. Morales, and A. Kiremidjian, "A Framework and Case Study for Dynamic Urban Risk Assessment" (paper presented at the 10th National Conference in Earthquake Engineering, Earthquake Engineering Research Institute, Anchorage, AK, July 2014).

makers to understand and predict risk as it relates to dynamic changes in urban environments—such as increases in population, specific urban growth patterns over an evolving multi-hazard landscape, and evolving vulnerability—and in turn help them promote resilient and sustainable future cities.

By 2030, the global population will reach 9 billion, of which 60 percent will reside in cities (United Nations, 2007). To put these numbers in perspective, twice as many people will live in cities in 2030 as there were total people living in 1970. This population shift has made cities the major source of global risk, in large part because of the increase in exposure linked to increases in population in hazard-prone areas (Bilham 2009). Cities often emerge in locations with favorable economic conditions (coastal zones, river crossings, fertile volcanic soils, valleys), but these often correlate with increased hazard probability (floods, hurricanes, volcanoes, earthquakes). Furthermore, since urbanization typically has occurred during a time frame that is very short as compared to the return period of damaging natural hazards, there has been little learning from past disasters, and hazards that in the past affected villages and towns will now be affecting large urban agglomerations.

Evidence suggests that the risk linked with such increases in exposure at the macro scale (increase in population in hazard-prone areas) is significantly exacerbated by trends in distribution of this new urban population within the urban boundary. Intense competition for land in urban environments, driven mostly by accessibility to livelihood, means that hazardous areas such as floodplains and steep slopes will be settled.

Cities shift the economic balance of risk mitigation, since expected losses are so high (Lall and Deichmann 2012; World Bank, 2010b). This suggests a great opportunity for city officials and policy makers to implement risk mitigation policies and projects. Because cities are growing, officials also have a unique chance to affect the distribution and quality of future constructions, so that all new city growth is resilient.

To capitalize on these opportunities, policy makers need urban risk assessment models that take projections of future risk into account. Current probabilistic risk assessment models use static—current—conditions for hazard, exposure, and vulnerability. They therefore have the effect of underestimating risk, and they also constrict policy makers to a hopeless catch-up mode: since conditions are always evolving past the latest data, their scope of action is limited to mitigating risk to existing assets, rather than proactively seeking to reduce future risk. The model proposed here, by contrast, is a dynamic urban risk analysis framework that accounts for time-dependent changes in exposure and vulnerability in order to project risk into the future.

By focusing on modelling future risk, the framework enables the investigation of risk consequences from various policy and planning decisions. It can therefore readily inform risk-sensitive urban and regional policy and planning to promote resilient communities worldwide.

Dynamic urban risk framework. Probabilistic disaster risk assessment consists of taking the convolution of the hazard, exposure, and vulnerability. Hazard refers to the potential occurrence of an event that may have adverse impacts on vulnerable and exposed elements (people, infrastructure, the environment, etc.). Exposure describes the elements that are impacted by the hazard due to their spatial and temporal overlap. Vulnerability describes the propensity to suffer adverse effects from exposure to particular hazard intensity. These definitions make clear that the fundamental components of risk are not fixed in time, particularly in rapidly changing urban environments (see Figure 35).

Risk = Hazard ⊗ Exposure ⊗ Vulnerability

Time-dependent hazards	Time-dependent exposure	Time-dependent vulnerability
• Large earthquakes do not occur following a Poisson process. The occurrence of an event depends on the time since the last event, consistent with elastic rebound theory of earthquakes. • Similarly, hydrometeorological hazards (e.g., floods and hurricanes) have recently received a lot of attention as research is predicting increasing rate and intensity of extreme weather events.	• Population growth and migration are rapidly changing the global landscape of risk exposure. • Cities in particular are sites of very rapid exposure change, often reflecting significant migration into and within cities. • Urban land markets often create pressures to settle on increasingly hazardous land, including steep slope, flood-planes and reclaimed land.	• The vulnerability of buildings changes in time due to deterioration, retrofits, and alterations. • Most buildings in the world's growing cities are not static, but are continually being expanded upward or outward. These practices have significant impact on building vulnerability. • New construction practices further result in changes in vulnerability of the built environment.

Figure 35. The three components of risk and their time dependence.
Source: Lallemant et al., 2014.

Dynamic exposure modelling. Current risk assessment methodologies characterize exposure in its present state. This approach is a significant limitation for assessing risk in rapidly changing environments, in particular cities. The proposed approach builds on current practices by integrating urban growth models to forecast exposure. The resulting risk assessment is more accurate and enables policy makers to take preventative measures to reduce future risk.

The simplest method for modelling future exposure is to project exposure trends based on past data. Census data for population or building inventory at a minimum of two separate dates can be used to develop projections for the future. Auxiliary data—such as general migration rate, natural population growth, and economic growth—can further be used to improve these projections. Alternatively, agent-based models can be developed and calibrated to simulate patterns of urban growth, creating numerous alternatives of future urban form (Batty 2007).

Dynamic vulnerability modelling. Current risk assessment models implicitly assume that vulnerability is constant over time. Increase in vulnerability of structures with deterioration has been the subject of increasing study (Frangopol, Lin, and Estes, 1997; Ghosh et al. 2013; Rokneddin et al. 2013). Recent work by Anirudh Rao provides a time-dependent framework for modelling structural deterioration of individual bridges and their resulting increased seismic risk.[73] The framework proposed here builds on this research to incorporate time-dependent fragility into large-scale risk assessment models, and looks at other common

[73] Rao's Ph.D. thesis, entitled "Structural Deterioration and Time-Dependent Seismic Risk Analysis," is being completed at the Blume Earthquake Center, Stanford University.

drivers influencing fragility. In particular it investigates incremental construction as a significant cause of changes in vulnerability, and also looks at the role of changing building practices and structural deterioration.

In rapidly urbanizing areas, the pay-as-you-go process of informal building construction and expansion is the de facto pattern of growth. Indeed, the informal sector builds an estimated 70 percent of all urban housing in developing countries (Goethert 2010). This process starts with a simple shelter and, given enough resources and time, transforms incrementally to multi-story homes and rental units. However, no robust studies have investigated the effect of these incremental expansions on vulnerability, particularly to seismic hazards.

Using seismic risk as a case study, the proposed framework defines typical stages within building evolution, along with associated earthquake fragility curves reflecting the changes in vulnerability induced by each building expansion (see Figure 36). Earthquake fragility curves describe the probability of experiencing or exceeding a particular level of damage when subjected to a specific ground motion intensity, usually measured in terms of peak ground motion acceleration or spectral. Alternatively, instead of linking building expansions to new fragility curves, these increments can be treated as additional vulnerability indicators in multivariate fragility models.

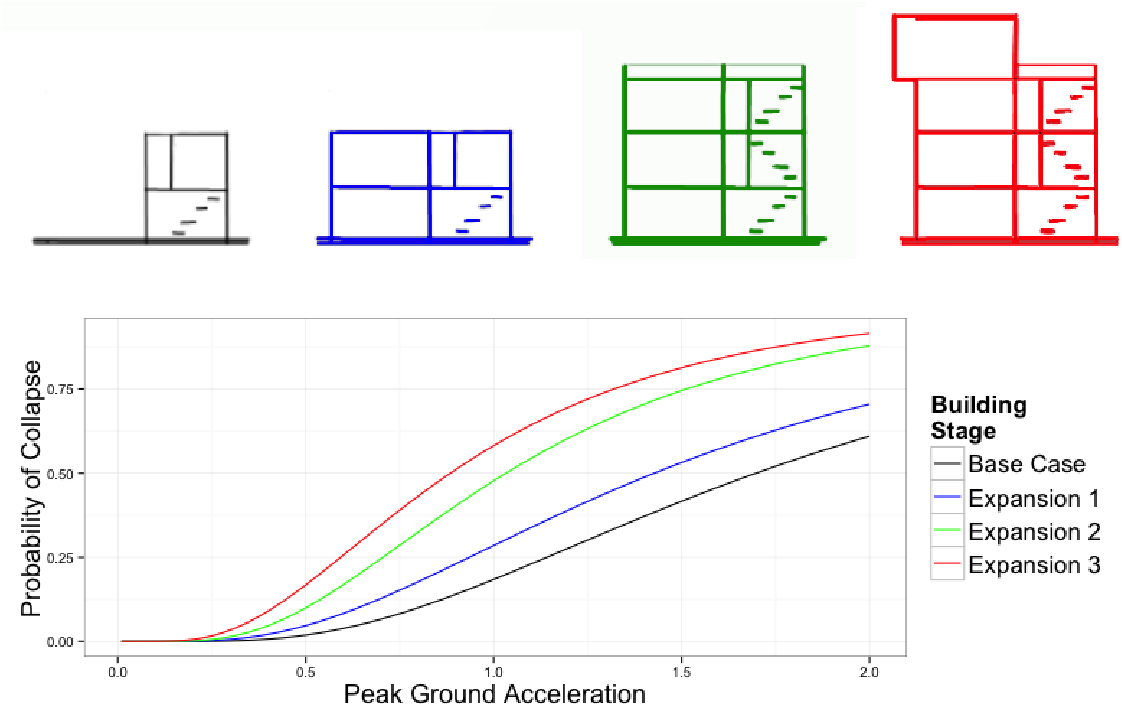


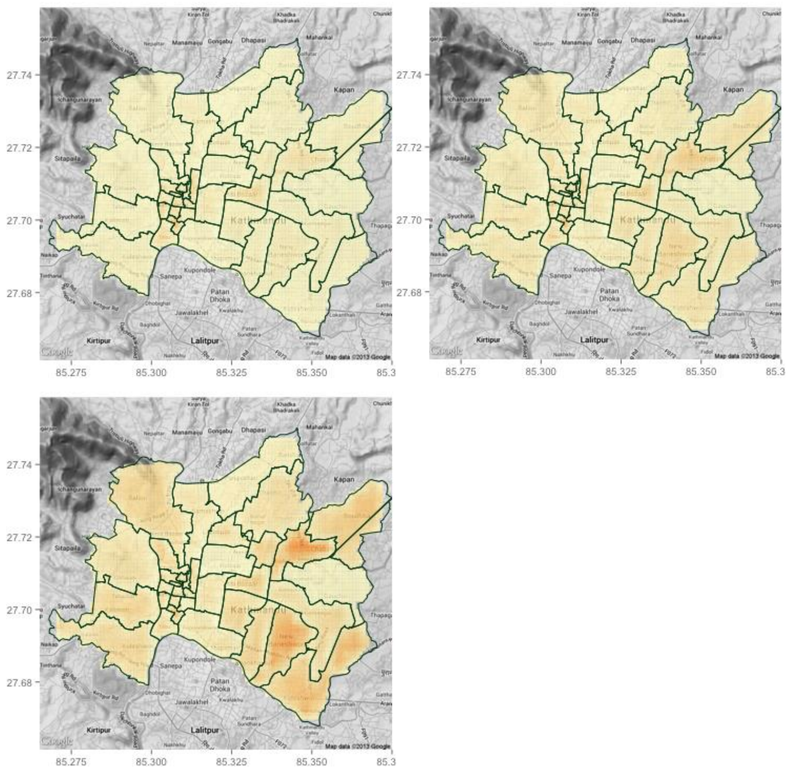
Figure 36. Incrementally expanding buildings and corresponding changes in vulnerability.
Note: The top panel illustrates incremental building construction typical of cities throughout the world; the bottom panel illustrates the increase in vulnerability in hypothetical fragility curves as floors are added and discontinuous expansions occur.

Simplified case study of Kathmandu, Nepal. The framework described above was applied in order to forecast the earthquake risk of Kathmandu, Nepal. Since the main interest is to capture changing risk driven by time-dependent exposure and vulnerability, the study describes the risk at different time periods based on a single earthquake scenario: a reproduction of the 8.1 magnitude Bihar earthquake of 1934.

This simplified application of the framework uses very limited data and simple models. The results themselves are therefore not aimed at accuracy of risk forecasting but are simply intended to demonstrate the importance of including urban dynamics in risk assessment of cities. A discussion is included explaining how the model could be made more complex to better reflect the uncertainties and real urban dynamics.

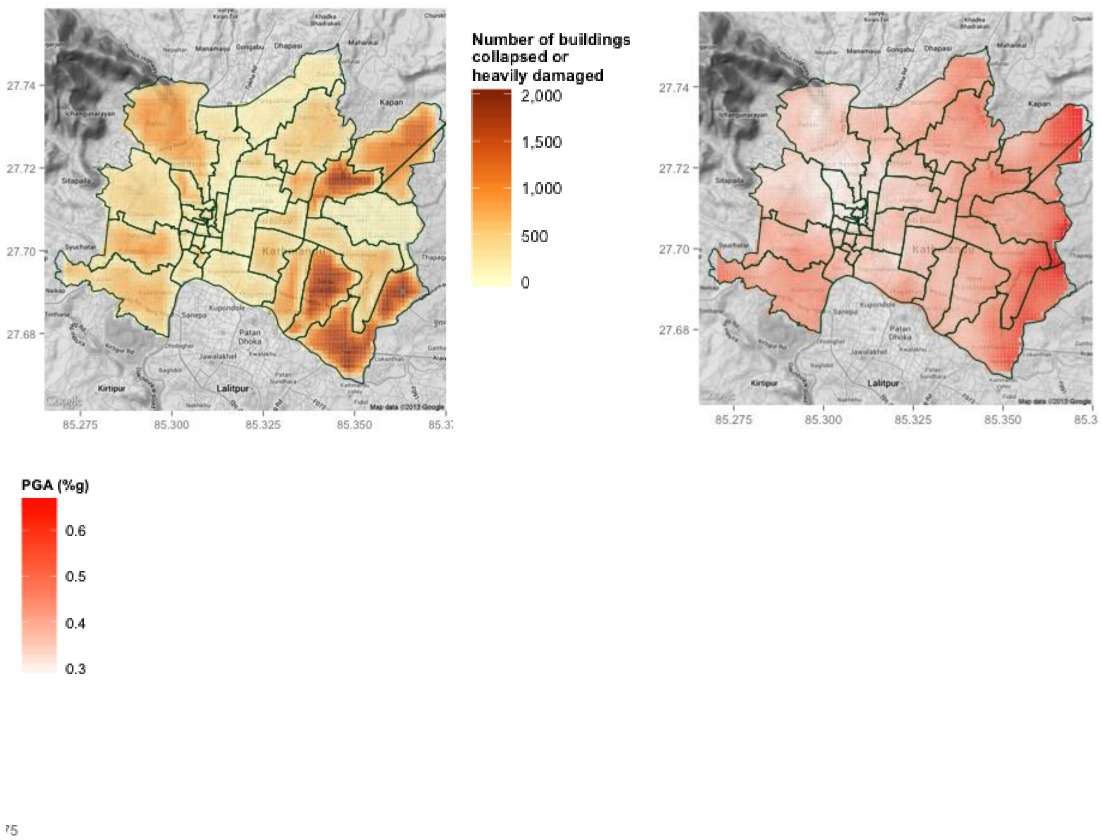
The seismic hazard was developed by simulating 2,500 equally likely scenarios of the 1934 Bihar earthquake (spatially correlated ground motion intensity fields) using the OpenQuake (GEM 2013).[74] Four exposure models were used, corresponding to years 1991, 2001 (from the ward-level census), 2010, and 2020 (projected based on a simple compounded growth rate model for each ward). Vulnerability curves used are those derived from Arya (2000), who has developed many vulnerability curves for typical buildings in the area.

For simplicity, rates and distribution of "heavy damage or collapse" are used as metrics to measure time-varying risk. Figure 37 shows the distribution of the number of heavily damaged or collapsed buildings for each of the four exposure models, based on a single ground motion field simulation.



a. 1991 b. 2001 c. 2010

[74] OpenQuake 2013 release, Global Earthquake Model, http://www.globalquakemodel.org/openquake/.



d. 2020

e. Ground motion field

Figure 37. Number of buildings sustaining heavy damage or collapse from a single ground motion field, at four different time periods.
Note: PGA = peak ground acceleration.

The results clearly show significant changes in risk driven by urban growth patterns and changes in primary construction type. The changing risk reflects both the high growth rates of specific wards, as well as the distribution/redistribution of vulnerable building types. However, the values predicted are an example from a single ground motion simulation (panel e), and very different results would be generated from a different simulation.

The east side of the city sustains heavier damage in large part as a result of higher ground motions from this specific simulation (panel e). In order to characterize the full distribution of heavy building damage for the entire Kathmandu municipality, the process above is repeated for every ground motion field simulation (n = 2,500). The total number of heavily damaged or collapsed buildings is computed for every ground motion field simulation. We can then compute the expected (mean) risk due to changing exposure and vulnerability, as well as the full empirical probability distribution of damage.

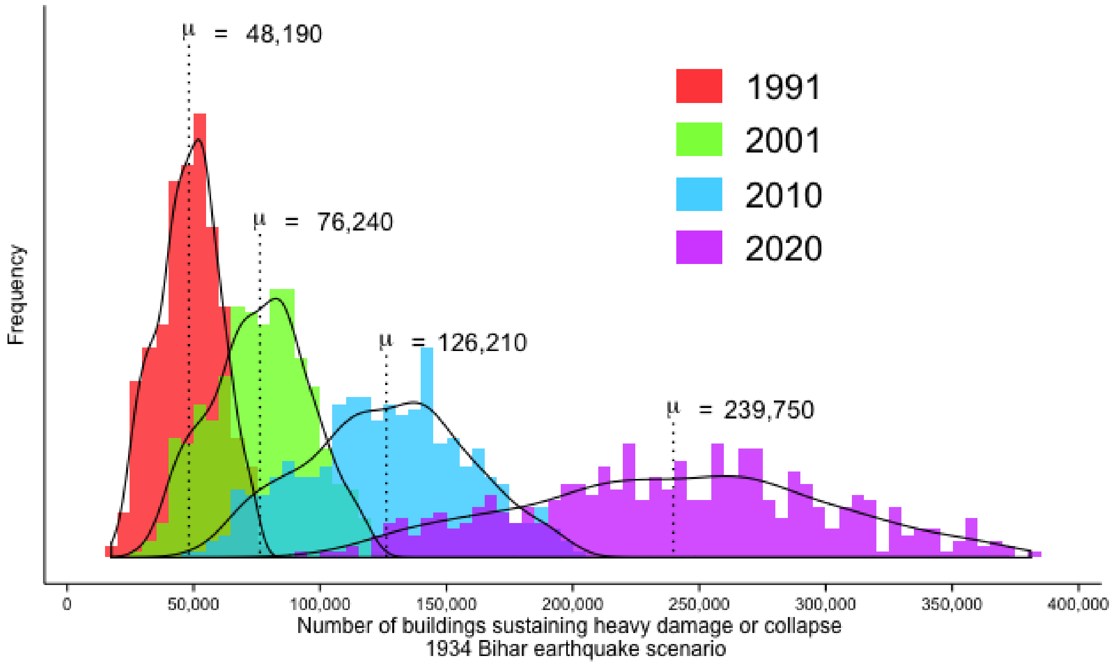


Figure 38. Full distribution of the number of buildings sustaining heavy damage or collapse, for four different time frames. *Source:* Lallemant et al., 2014.

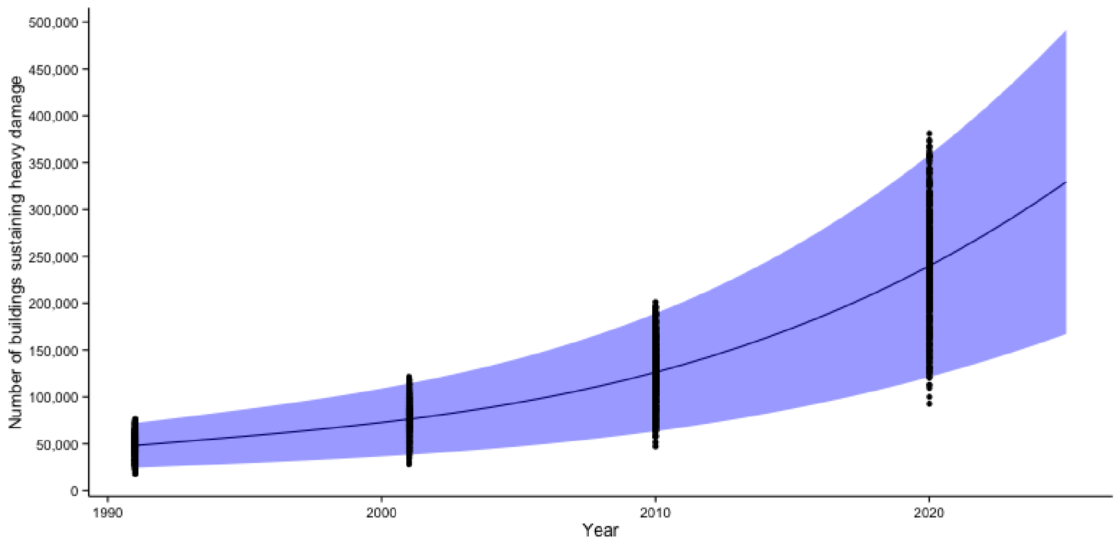


Figure 39. Expected number of buildings sustaining heavy damage or collapse as a function of time, with confidence interval. *Source:* Lallemant et al., 2014.

The results shown in Figure **38** and Figure **39** demonstrate that changes in exposure and vulnerability in Kathmandu drive a significant increase in risk. The expected number of buildings sustaining heavy damage or collapsing (mean values shown in Figure **38**) nearly doubles every 10 years. Furthermore, the spread of the probability distribution of damage also increases. This increase is most likely the result of increased concentration of exposure.

Given additional data, this preliminary study of Kathmandu could be extended to more accurately capture the urban dynamics. Instead of using the constant compound growth model over entire wards, different population growth patterns could be explored. In addition, the model could directly incorporate changing vulnerability due to incremental construction. The failure to do so tends to underestimate damage, since incremental construction typically leads to increased vulnerability. In Kathmandu, the addition of floors to existing buildings is a ubiquitous practice and is not accompanied with proper seismic strengthening. Conversely, models could be developed reflecting potential vulnerability reduction policies, such as improvements in construction practices, building height restrictions, or risk-sensitive zoning, among others. Finally, the effects of urban dynamics on exposure to secondary seismic hazards, in particular liquefaction and landslides, could also be modeled.

The proposed framework for assessing risk as it changes in time includes dynamic exposure and vulnerability models in order to forecast future losses. The basic framework can be applied for various levels of data availability and resolution. By focusing on modelling future risk, the framework enables the further investigation of risk consequences from various policy and planning decisions. It therefore can readily serve to inform risk-sensitive urban and regional policy and planning to promote resilient communities.

References

Abbs, D. 2012. The Impact of Climate Change on the Climatology of Tropical Cyclones in the Australian Region. CSIRO Climate Adaptation Flagship Working Paper No. 11. CSIRO. Canberra.

Abbs, D. J., S. Ayral, E. Campbell, J. L. McGregor, K. C. Nguyen, M. Palmer, A. S. Rafter, I. G. Watterson, and B. C. Bates. 2006. *Projections of Extreme Rainfall and Cyclones: Final Report to the Australian Greenhouse Office*. Canberra: CSIRO.

ADRC (Asian Disaster Reduction Center). 2006. Report on Survey on Tsunami Awareness in Indonesia: Banda Aceh and Aceh Besar Area of Aceh Province. ADRC. http://www.adrc.asia/publications/Indonesia_Survey/Banda%20Aceh/en/index.html.

Ahmad Al Waken. 2011. Evolution of the Impact of an Earthquake on Aqaba and Jordan Economy and Public Finances. In: *Disaster Risk Assessment for Aqaba*. UNDP and ASEZA. http://www.preventionweb.net/files/31205_aqabasraeisei1.pdf.

Amarasinghe, S. 2007. Identifying Vulnerability Using Semi-structured Interviews. In*: Rapid Vulnerability Assessment in Sri Lanka: Post-Tsunami Study of Two Cities: Galle and Batticaloa*. SOURCE Publication No. 7, 47–53. http://ihdp.unu.edu/file/get/3992.pdf.

Annaka, T., K. Satake, T. Sakakiyama, K. Yanagisawa, and N. Shuto. 2007. Logic-tree Approach for Probabilistic Tsunami Hazard Analysis and Its Applications to the Japanese Coasts. *Pure and Applied Geophysics* 164: 577–92.

Aon Benfield. 2012. *Annual Global Climate and Catastrophe Report: Impact Forecasting, 2011*, http://thoughtleadership.aonbenfield.com/Documents/20120110_if_annual_global_climate_cat_report.pdf.

Arkema, K. K., G. Guannel, G. Verutes, S. A. Wood, A. Guerry, M. Ruckelshaus, P. Kareiva, M. Lacayo, and J. M. Silver. 2013. Coastal Habitats Shield People and Property from Sea-level Rise and Storms. *Nature Climate Change* 3: 913–18. doi:10.1038/nclimate1944.

Arnell, N. W., and B. Lloyd-Hughes. 2014. The Global-scale Impacts of Climate Change on Water Resources and Flooding under New Climate and Socio-economic Scenarios. *Climatic Change* 122: 127–40. doi:10.1007/s10584-013-0948-4.

Arnold, Margaret, Maxx Dilley, Uwe Deichmann, Robert S. Chen, and Arthur L. Lerner-Lam. 2005. *Natural Disaster Hotspots: A Global Risk Analysis*. Washington, DC, U.S.: World Ban.

Arthur, W. C., and H. M. Woolf. 2013. Assessment of Tropical Cyclone Risk in the Pacific Region: Analysis of Changes in Key Tropical Cyclone Parameters. Record 2013/23. Geoscience Australia. Canberra, Australia.

Arya, A. S. 2000. Non-engineered Construction in Developing Countries—An Approach toward Earthquake Risk Prediction. *Bulletin of the New Zealand Society for Earthquake Engineering* 33(3): 187–208.

Atkins. 2012. Shire Integrated Flood Risk Management Project. http://www.masdap.mw/documents/182/download.

Barredo, J. I. 2009. Normalised Flood Losses in Europe: 1970–2006. *Natural Hazards and Earth System Sciences* 9: 97-104. doi:10.5194/nhess-9-97-2009.

Barthel, F., and E. Neumayer. 2012: A Trend Analysis of Normalized Insured Damage from Natural Disasters. *Climatic Change* 113: 215–37.

Batty, M., 2007. Cities and Complexity: Understanding Cities with Cellular Automata, Agent-Based Models, and Fractals. Cambridge, MA: MIT Press.

Bautista, M. L. P., B. C. Bautista, I.C. Narag, A. G. Lanuza, J. B. Deocampo, K. L. Papiona, R. A. Atando, R. U. Solidum, T. A. Allen, M. Jakab, H. Ryu, M. Edwards, K. Nadimpalli, M. Leonard, and M. A. Dunford. 2012. Strengthening Natural Hazard Risk Assessment Capacity in the Philippines: An Earthquake Impact Pilot Study for Iloilo City, Western Visayas. Record 2012/070. Geoscience Australia. Canberra. http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_74132.

Bear-Crozier, A. N., N. Kartadinata, A. Heriwaseso, and O. Nielsen. 2012. Development of Python-Fall3D: A Modified Procedure for Modelling Volcanic Ash Dispersal in the Asia-Pacific. *Natural Hazards* 64(1): 821–38.

Beaulieu, A., D. Begin, and D. Genest. 2010. Community Mapping and Government Mapping: Potential Collaboration? Symposium of ISPRS Commission I, Calgary, Canada, June 16–18. http://www.isprs.org/proceedings/xxxviii/part1/10/10_01_Paper_163.pdf.

Bilham, R., 2009. The Seismic Future of Cities. *Bulletin of Earthquake Engineering* 7(4): 839–87.

BNBP (National Disaster Management Agency) and Bappenas (National Development Planning Agency), with provincial and district/city governments of West Sumatra and Jambi. 2009. *West Sumatra and Jambi Natural Disasters: Damage, Loss and Preliminary Needs Assessment.* https://www.gfdrr.org/sites/gfdrr.org/files/documents/GFDRR_Indonesia_DLNA.2009.EN_.pdf.

Bouwer, L. M. 2011. Have Disaster Losses Increased Due to Anthropogenic Climate Change? *Bulletin of the American Meteorological Society* 92: 39-46. doi:10.1175/2010BAMS3092.1.

Burbidge, D., P. Cummins, R. Mleczko, and H. Thio. 2008. A Probabilistic Tsunami Hazard Assessment for Western Australia. *Pure and Applied Geophysics* 165: 2059–88.

Burbidge, D., P. R. Cummins, R. Mleczko, and H. K. Thio. 2009. A Probabilistic Tsunami Hazard Assessment for Western Australia. In: *Tsunami Science Four Years after the 2004 Indian Ocean Tsunami* , edited by Phil R. Cummins, Laura S. L. Kong, and Kenji Satake, 2059–88. Basel, Switzerland: Birkhäuser.

Chapman, K. 2012. *Community Mapping for Exposure in Indonesia.* Humanitarian OpenStreetMap Team.

Chapman, K., A. Wibowo, and Nurwadjedi. 2013. Filling the Data Gap with Participatory Mapping for Effective Disaster Preparedness. http://www.jointokyo.org/files/cms/news/pdf/(Final)_Session_2_Summary.pdf.

CIMNE (Centro Internacional de Métodos Numéricos en Ingeniería) et al. 2013. Probabilistic Modeling of Natural Risks at the Global Level: Global Risk Model. Background Paper prepared for the 2013 Global Assessment Report on Disaster Risk Reduction. UNISDR. Geneva, Switzerland. www.preventionweb.net/gar.

Cornell, C. A. 1968. Engineering Seismic Risk Analysis. *Bulletin of the Seismological Society of America* 58: 1583–1606.

Council of European Union. 2009. Council Conclusions on a Community Framework on Disaster Prevention within the EU. Minutes of the 2979th Justice and Home Affairs Council Meeting, Brussels, November 30.

Crowley, John. 2014. *Open Data for Resilience Initiative Field Guide*. Washington, DC, U.S.: World Bank.

Cummins, P., and M. Leonard, M. 2004. Small Threat but Warning Sounded for Tsunami Research. *AusGeo News* 75: 4–7. September.

Cummins, P. R., D. R. Burbidge, R. Mleczko, D. H. Natawidjaja, and H. Latief. 2009. *Probabilistic Assessment of Tsunami Hazard in the Indian Ocean.* Canberra: Geoscience Australia.

Cyranoski, D. 2011. Japan Faces Up to Failure of Its Earthquake Preparations. *Nature* 471: 556–57.

Dailey, P., M. Huddleston, S. Brown, and D. Fasking. 2009. *The Financial Risks of Climate Change.* ABI Research Paper 19. http://static.weadapt.org/knowledge-base/files/1040/504a19b1e3d0efinancial-risks-of-climate-change-pdf.pdf.

De Bono, 2013. The Global Exposure Database for GAR 2013. Background Paper prepared for the 2013 Global Assessment Report on Disaster Risk Reduction. UNISDR. Geneva, Switzerland. www.preventionweb.net/gar.

Desramaut, N. 2013. Functional Vulnerability: Report on the Functional Vulnerability Assessment of a System Prone to Multiple Hazards. Technical Report D4.3, MATRIX project.

Dilley, M., R. S. Chen, U. Deichmann, A. Lerner-Lam, M. Arnold, J. Agwe, P. Buys, O. Kjekstad, B. Lyon, and G. Yetman. 2005. *Natural Disaster Hotspots. A Global Risk Analysis*. Washington, DC, U.S.: World Bank.

Elmer, F., J. Hoymann, D. Düthmann, S. Vorogushyn, and H. Kreibich. 2012. Drivers of Flood Risk Change in Residential Areas. *Natural Hazards and Earth System Science* 12(5): 1641–57.

Elmer, F., A. H. Thieken, I. Pech, and H. Kreibich. 2010. Influence of Flood Frequency on Residential Building Losses. *Natural Hazards and Earth System Science* 10(10): 2145–59.

Emergency Management Ontario. 2012. *The 2012 Provincial Hazard Identification and Risk Assessment Report*. Ontario: Ministry of Community Safety and Correctional Services, Government of Ontario.

Erdik, M. 2013. Earthquake Risk in Turkey. *Science* 341: 724–25.

Erian, Wadid, Bassem Katlan, Bassem Ouldbedy, Haider Awad, Ebrahim Zaghtity, and Sanaa Ibrahim. 2012. Agriculture Drought in Africa and Mediterranean. Background Paper prepared for the 2013 Global Assessment Report on Disaster Risk Reduction. UNISDR. Geneva, Switzerland. www.preventionweb.net/gar.

European Commission. 2010a. The EU Internal Security Strategy in Action: Five Steps towards a More Secure Europe. Communication from the Commission to the European Parliament and the Council, COM(2010) 673 final. European Commission. Brussels, Belgium.

———. 2010b. *Risk Assessment and Mapping Guidelines for Disaster Management*. Commission Staff Working Paper, SEC(2010) 1626 final. European Commission. Brussels, Belgium.

Falter, D., V. N. Dung, S. Vorogushyn, K. Schröter, Y. Hundecha, H. Kreibich, H. Apel, F. Theisselmann, and B. Merz. Forthcoming. Continuous, Large-scale Simulation Model for Flood Risk Assessments: Proof-of-concept. *Journal of Flood Risk Management.* doi:10.1111/jfr3.12105.

Feyen, L., R. Dankers, K. Bódis, P. Salamon, and J. I. Barredo. 2012. Fluvial Flood Risk in Europe in Present and Future Climates. *Climatic Change* 112: 47–62. doi:10.1007/s10584-011-0339-7.

Frangopol, D. M., K.-Y. Lin, and A. C. Estes. 1997. Reliability of Reinforced Concrete Girders under Corrosion Attack. *Journal of Structural Engineering* 123 (3): 286–97.

Fraser, A., and D. Vincent Lima. 2012. Survey Results Report: Regional Technical Assistance Initiative on Climate Adaptation Planning in LAC Cities. Latin America and Caribbean Regional Urban, Water and Disaster Risk Management Unit, World Bank, Washington, DC, U.S.

Gadjah Mada University and HOT Team. 2012. Evaluation of OpenStreetMap Data in Indonesia. Final Report http://openstreetmap.or.id/docs/Final_Report-OSM_Evaluation_in_Indonesia_2012.pdf.

Gall, M., K. A. Borden, C. T. Emrich, and S. L. Cutter. 2011. The Unsustainable Trend of Natural Hazard Losses in the United States. *Sustainability* 3: 2157–81. doi:10.3390/su3112157.

Garcia-Aristizabal, A., W. Marzocchi, and A. Di Ruocco. 2013. Probabilistic Framework for Multi-hazard Assessment. Technical Report D3.4, MATRIX project.

Gaume, E., V. Bain, P. Bernardara, O. Newinger, M. Barbuc, A. Bateman, L. Blaškovičová, G. Blöschl, M. Borga, A. Dumitrescu, I. Daliakopoulos, J. Garcia, A. Irimescu, S. Kohnova, A. Koutroulis, L. Marchi, S. Matreata, V. Medina, E. Preciso, D. Sempere-Torres, G. Stancalie, J. Szolgay, I. Tsanis, D. Velasco, and A. Viglione. 2009. A Compilation of Data on European Flash Floods. *Journal of Hydrology* 367(1): 70–78. doi:10.1016/j.jhydrol.2008.12.028.

Geller, R. J. 2011. Shake Up Time for Japanese Seismology. *Nature* 472: 407–9.

Ghosh, Jayadipta, Keivan Rokneddin, Jamie E. Padgett, and Leonardo Dueñas–Osorio. 2013. Seismic Reliability Assessment of Aging Highway Bridge Networks with Field Instrumentation Data and Correlated Failures. I: Methodology. *Earthquake Spectra*. doi:http://dx.doi.org/10.1193/040512eqs155m.

Goethert, R., 2010. Incremental Housing. *Monday Developments*. September. http://monthlydevelopments.org/sites/monthlydevelopments/files/MD_Sept_10_small.pdf.

Gonzalez, F., E. Geist, B. Jaffe, U. Kanoglu, H. Mofjeld, C. Synolakis, V. Titov, D. Arcas, D. Bellomo, D. Carlton, T. Horning, J. Johnson, J. Newman, T. Parsons, R. Peters, C. Peterson, G. Priest, A. Venturato, J. Weber, F. Wong, and A. Yalciner. 2009. Probabilistic Tsunami Hazard Assessment at Seaside, Oregon, for Near- and Far-field Seismic Sources. *Journal of Geophysical Research* 114: C11023.

Government of Malawi. 2010. National Disaster Risk Reduction Framework 2010–2015.

Government of Malawi. Department of Disaster Management Affairs. 2011. National Disaster Risk Management Policy.

Government of Morocco. 2012. Evaluating Direct and Indirect Economic Impacts of Natural Disasters: The Development of an Input-Output and a CGE Models for Morocco.

Hallegatte, S., C. Green, R. J. Nicholls, and J. Corfee-Morlot. 2013. Future Flood Losses in Major Coastal Cities. *Nature Climate Change* 3: 802–6. doi:10.1038/nclimate1979.

Herold, C., and F. Mouton. 2011. Global Flood Hazard Mapping Using Statistical Peak Flow Estimates. *Hydrology and Earth System Sciences Discussions* 8: 305–63. doi:10.5194/hessd-8-305-2011.

Herold, C., and Rudari R. 2013. Improvement of the Global Flood Model for the GAR 2013 and 2015. Background paper prepared for the 2013 Global Assessment Report on Disaster Risk Reduction. UNISDR. Geneva, Switzerland. www.preventionweb.net/gar.

Hirabayashi, Y., M. Roobavannan, K. Sujan, K. Lisako, Y. Dai, W. Satoshi, K. Hyungjun, and K. Shinjiro. 2013. Global Flood Risk under Climate Change. *Nature Climate Change* 3: 816–21. doi:10.1038/nclimate1911.

ICHARM (International Centre for Water Hazard and Risk Management). 2013. *Technical Assistance for Supporting Investments in Water-related Disaster Management: Main Volume*. Manila: Asian Development Bank. http://www.adb.org/projects/documents/supporting-investments-water-related-disaster-management-tacr.

IKSE (International Commission for the Protection of the Elbe). 2004. *Dokumentation des Hochwassers vom August 2002 im Einzuggebiet der Elbe.* Mageburg, Germany: IKSE.

IPCC (Intergovernmental Panel on Climate Change). 2012. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. A special report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge, UK, and New York, U.S.: Cambridge University Press.

———. 2013. Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P. M. Midgley. Cambridge, UK: Cambridge University Press.

ISO (International Organization for Standardization). 2009. *ISO 31000. Risk Management: Principles and Guidelines*.

Jankaew, K., B. F. Atwater, Y. Sawai, M. Choowong, T. Charoentitirat, M. E. Martin, and A. Prendergast. 2008. Medieval Forewarning of the 2004 Indian Ocean Tsunami in Thailand. *Nature* 455: 1228–31.

Janssen, G., and D. L. Holden. 2011. *External Independent Evaluation of AIFDR 'Build Back Better' Campaign: Final Evaluation Report.* Australia-Indonesia Facility for Disaster Reduction, Jakarta, Indonesia.

———. 2013. *Rumah Aman Gempa Andalan Masyarakat (RAGAM): Independent Completion Report*. Australia-Indonesia Facility for Disaster Reduction, Jakarta.

Jayanthi, H., and G. J. Husak. 2012. A Probabilistic Approach to Assess Agricultural Drought Risk. Background paper prepared for the 2013 Global Assessment Report on Disaster Risk Reduction. UNISDR. Geneva, Switzerland. www.preventionweb.net/gar

Jayasinghem, T., and J. Birkmann. 2007. Vulnerability Comparison between Galle and Batticaloa based on the Household Survey using Questionnaires. In: *Rapid Vulnerability Assessment in Sri Lanka: Post-Tsunami Study of Two Cities: Galle and Batticaloa*. SOURCE Publication No. 7, 39–47.

Jenkins, S., C. Magill, K. McAneney, and R. Blong. 2012a. Regional Ash Fall Hazard I: A Probabilistic Assessment Methodology. *Bulletin of Volcanology* 74: 1699–1712.

Jenkins, S., K. McAneney, C. Magill, and R. Blong. 2012b. Regional Ash Fall Hazard II: Asia-Pacific Modelling Results and Implications. *Bulletin of Volcanology* 74: 1713–27.

JICA (Japan International Cooperation Agency). 2011. The Study on Integrated Water Resources Management for Poverty Alleviation and Economic Development in the Pampanga River Basin. National Water Resources Board, Philippines.

———. 2013. Project for the Comprehensive Flood Management Plan for the Chao Phraya River Basin. Thailand.

Jongman B., S. Hochrainer-Stigler, L. Feyen, J. C. J. H. Aerts, R. Mechler, W. J. W. Botzen, L. M. Bouwer, G. Pflug, R. Rojas, and P. J. Ward. 2014. Increasing Stress on Disaster Risk Finance Due to Large Floods. *Nature Climate Change.* http://dx.doi.org/10.1038/nclimate2124.

Jongman, B., P. J. Ward, and J. C. J. H. Aerts. 2012. Global Exposure to River and Coastal Flooding— Long Term Trends and Changes. *Global Environmental Change* 22: 823–35. doi:10.1016/j.gloenvcha.2012.07.004.

Kagan, Y. Y., and D. D. Jackson. 2013. Tohoku Earthquake: A Surprise? *Bulletin of the Seismological Society of America* 103(2B): 1181–94. doi:10.1785/0120120110.

Keef, C., J. A. Tawn, and R. Lamb. 2013. Estimating the Probability of Widespread Flood Events. *Environmetrics* 24(1): 13–21.

Krysanova, V., D. Müller-Wohlfeil, and A. Becker. 1998. Development and Test of a Spatially Distributed Hydrological/Water Quality Model for Mesoscale Watersheds. *Ecological Modelling* 106: 261–89.

Kundzewicz, Z. W., S. Kanae, S. I. Seneviratne, J. Handmer, N. Nicholls, P. Peduzzi, R. Mechler, L. M. Bouwer, N. Arnell, K. Mach, R. Muir-Wood, G. R. Brakenridge, W. Kron, G. Benito, Y. Honda, K. Takahashi, and B. Sherstyukov. 2013. Flood Risk and Climate Change: Global and Regional Perspectives. *Hydrological Sciences Journal*, doi:10.1080/02626667.2013.857411.

Kundzewicz, Z. W., I. Pińskwar, and G. R. Brakenridge. 2013. Large Floods in Europe, 1985–2009. *Hydrological Sciences Journal* 58: 1–7. doi:10.1080/02626667.2012.745082.

Kwak, Y., K. Takeuchi, K. Fukami, and J. Magome. 2012. A New Approach to Flood Risk Assessment in Asia-Pacific Region Based on MRI-AGCM Outputs. *Hydrological Research Letters* 6: 70–75.

Lall, S. V., and U. Deichmann. 2009. *Density and Disasters: Economics of Urban Hazard Risk.* Policy Research Working Paper 5161. World Bank. Washington, DC, U.S.

Lall, S. V., and U. Deichmann. 2012. Density and Disasters: Economics of Urban Hazard Risk. *World Bank Research Observer* 27(1): 74–105.

Lallemant, D., S. Wong, K. Morales, and A. Kiremidjian. 2014. A Framework and Case Study for Dynamic Urban Risk Assessment. Paper presented at the 10th National Conference on Earthquake Engineering, Anchorage, AK, July.

Lamb, R., C. Keef, J. Tawn, S. Laeger, I. Meadowcroft, S. Surendran, P. Dunning, and C. Batstone. 2010. A New Method to Assess the Risk of Local and Widespread Flooding on Rivers and Coasts. *Journal of Flood Risk Management* 3 (4): 323–36.

Lansang, M., and R. Dennis. 2004. Building Capacity in Health Research in the Developing World. *Bulletin of the World Health Organisation* 82: 764–70.

Løvholt, F., D. Kühn, H. Bungum, C. B. Harbitz, and S. Glimsdal. 2012. Historical Tsunamis and Present Tsunami Hazard in Eastern Indonesia and the Philippines*. Journal of Geophysical Research– Solid Earth*. doi:10.1029/2012JB009425.

Marzocchi, W., A. Garcia-Aristizabal, P. Gasparini, M. L. Mastellone, and A. Di Ruocco. 2012. Basic Principles of Multi-risk Assessment: A Case Study in Italy. *Natural Hazards* 62(2): 551–73.

McCloskey, J., D. Lange, F. Tilmann, S. S. Nalbant, A. F. Bell, D. H. Natawidjaja, and A. Rietbrock. 2010. The September 2009 Padang Earthquake. *Nature Geoscience* 3(2): 70–71.

McKee, T. B., N. J. Doesken, and J. Kleist. 1993. The Relationship of Drought Frequency and Duration of Time Scales. Paper presented at Eighth Conference on Applied Climatology, American Meteorological Society, Anaheim CA, January 17–23.

Merz, R., G. Blöschl, and G. Humer. 2008. National Flood Discharge Mapping in Austria. *Natural Hazards* 46(1): 53–72.

MLIT (Ministry of Land, Infrastructure, Transport and Tourism). 2006. *Basic Plan for the Tone River Improvement*. Tokyo: MLIT.

Monfort, D., and S. Lecacheux. 2013. West Indies Test Site. Technical Report D7.4, MATRIX project.

———. 2013. Significant Natural Catastrophes 1980–2012, 10 Deadliest Worldwide Events. Geo Risks Research, NatCatSERVICE, available at: https://www.munichre.com/site/corporate/get/documents_E-1233315815/mr/assetpool.shared/Documents/0_Corporate%20Website/_NatCatService/Focus_Analyses/1980-2012-geophysical-events-worldwide-en.pdf.

Nadim, F., and T. Glade. 2006. *On Tsunami Risk Assessment for the West Coast of Thailand*. ECI Symposium Series 7. Engineering Conferences International. New York. http://dc.engconfintl.org/cgi/viewcontent.cgi?article=1000&context=geohazards.

Neumayer, E., and F. Barthel. 2011. Normalizing Economic Loss from Natural Disasters: A Global Analysis. *Global Environmental Change* 21(1): 13–24. doi:10.1016/j.gloenvcha.2010.10.004.

NGI (Norwegian Technological Institute). 2013. Landslide Hazard and Risk Assessment in El Salvador. Background Paper prepared for the 2013 Global Assessment Report on Disaster Risk Reduction. UNISDR. Geneva, Switzerland. www.preventionweb.net/gar.

Nguyen, K. C., and K. J. E. Walsh. 2001. Interannual, Decadal, and Transient Greenhouse Simulation of Tropical Cyclone-like Vortices in a Regional Climate Model of the South Pacific. *Journal of Climate* 14: 3043–54.

Nicholls, R. J., S. Hanson, C. Herweijer, N. Patmore, S. Hallegatte, J. Corfee-Morlot, J. Chateau, and R. Muir Wood. 2008. *Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes: Exposure Estimates*. OECD Working Papers No. 1. OECD Publishing. Paris.

OECD (Organisation for Economic Co-operation and Development). 2012. *OECD Environmental Outlook to 2050.* Paris: OECD Publishing. http://dx.doi.org/10.1787/9789264122246-en.

Ordaz, M., F. Martinelli, A. Aguilar, J. Arboleda, C. Meletti, and V. D'Amico. 2012 CRISIS 2012, Program for Computing Seismic Hazard. Instituto de Ingeniería, Universidad Nacional Autónoma de México.

ORNL (Oak Ridge National Laboratory). 2007. LandScanTM Global Population Distribution Data (Raster dataset). Oak Ridge National Laboratory, U.S. Department of Energy. www.ornl.gov/sci/landscan/index.shtml.

Pacheco, B. M., J. Y. Hernandez Jr., E. A. J. Tingatinga, P. P. M. Castro, F. J. Germar, U. P. Ignacio, M. C. L. Pascua, L. R. E. Tan, I. B. O. Villalba, D. H. M. Aquino, R. E. U. Longalong, R. N. Macuha, W. L. Mata, R. M. Suiza, and M. A. H. Zarco. 2013. *Development of Vulnerability Curves of Key Building Types in the Greater Metro Manila Area, Philippines*. Quezon City: Institute of Civil Engineering, University of the Philippines Diliman.

Pacific Consultants International, OYO Cooperation, JICA, and IMM. 2002. The Study on A Disaster Prevention / Mitigation Basic Plan in Istanbul including Seismic Microzonation in the Republic of Turkey. ftp://ftp.ecn.purdue.edu/sozen/Istanbul%20at%20the%20Threshold/JICA_REPORT/PDF/PDF/e_summary%20pdf/01.pdf.

Pappenberger, F., E. Dutra, F. Wetterhall, and H. L. Cloke. 2012. Deriving Global Flood Hazard Maps of Fluvial Floods through a Physical Model Cascade. *Hydrology and Earth System Sciences* 16: 4143–56. doi:10.5194/hess-16-4143-2012.

Parsons, T., and E. Geist. 2009. Tsunami Probability in the Caribbean Region. *Pure and Applied Geophysics* 165: 2089–2116.

Parsons, Tom, Shinji Toda, Ross S. Stein, Aykut Barka, and James H. Dieterich. 2000. Heightened Odds of Large Earthquakes Near Istanbul: An Interaction Based Probability Calculation. *Science* 288: 661–65.

Pektas, Mesut, and Polat Gulkan. 2004. A Metropolitan Municipality Prepares for the Worst: Istanbul Earthquake Master Plan. Paper presented at 13th World Conference on Earthquake Engineering, Vancouver, August 1–6, 2004.

PBL (Netherlands Environmental Assessment Agency). 2014. *Towards a World of Cities in 2050: An Outlook on Water-related Challenges.* PBL background report for UN Habitat Global Report. The Hague: PBL Netherlands Environmental Assessment Agency.

Peduzzi, P., B. Chatenoux, H. Dao, A. De Bono, U. Deichmann, G. Giuliani, C. Herold, B. Kalsnes, S. Kluser, F. Løvholt, B. Lyon, A. Maskrey, F. Mouton, F. Nadim, and H. Smebye. 2009. The Global Risk Analysis for the 2009 Global Assessment Report on Disaster Risk Reduction. Universite de Geneve Publication. http://www-fourier.ujf-grenoble.fr/~mouton/Publis_HDR_applis/Peduzzi-The_Global_Risk_Analysis_for_the_2009_GAR-149.pdf

Petiteville, Ivan, Philippe Bally, and Guy Seguin. 2012. Satellite Earth Observation for Risk Management. In: *The Earth Observation Handbook*, edited by S. Ward. European Space Agency. www.eohandbook.com.

Prochaska, J. O., J. C. Norcross, and C. C. DiClemente. 1994 Changing for Good: The Revolutionary Program that Explains the Six Stages of Changes and Teaches You How to Free Yourself from Bad Habits. New York: W. Morrow.

RMSI. 2011. Malawi: Economic Vulnerability and Disaster Risk Assessment. www.masdap.mw/documents/145/download.

Robinson, D., Dhu, T. and Schneider, J. 2006. Practical Probabilistic Seismic Risk Analysis: A Demonstration of Capability. *Seismological Research Letters* 77(4): 453–59.

Rodda, H. J. E. 2005. The Development and Application of a Flood Risk Model for the Czech Republic. *Natural Hazards* 36(1-2): 207–20.

Rojas, R., L. Feyen, and P. Watkiss. 2013. Climate Change and River Floods in the European Union: Socio-Economic Consequences and the Costs and Benefits of Adaptation. *Global Environmental Change* 23: 1737–51. doi:10.1016/j.gloenvcha.2013.08.006.

Rokneddin, Keivan, Jayadipta Ghosh, Leonardo Dueñas–Osorio, and Jamie E. Padgett. 2013. Seismic Reliability Assessment of Aging Highway Bridge Networks with Field Instrumentation Data and Correlated Failures. II: Application. *Earthquake Spectra.* doi:http://dx.doi.org/10.1193/040612EQS160M.

SAARC Disaster Management Centre. 2008. Climate Change Adaptations to Reduce Disaster Risks—The Maldives. http://saarc-sdmc.nic.in/pdf/workshops/kathmandu/pres7.pdf.

Satake, K., and B. F. Atwater. 2007. Long-Term Perspectives on Giant Earthquakes and Tsunamis at Subduction Zones. *Annual Review of Earth and Planetary Sciences* 35: 349–74.

Schneider, A, M. Friedl, and D. Potere, D. 2009. A New Map of Global Urban Extent from MODIS Satellite Data. *Environmental Research Letters* 4(4): 044003. doi:10.1088/1748-9326/4/4/044003.

Scolobig, A., C. Vichon, N. Komendantova, M. Bengoubou-Valerius, and A. Patt. 2013. Social and Institutional Barriers to Effective Multi-hazard and Multi-risk Decision-making Governance. Technical Report D6.3, MATRIX project.

Sengara, W., M. Suarjana, D. Beetham, N. Corby, M. Edwards, M. Griffith, M. Wehner, and R. Weller. 2010. The 30th September 2009 West Sumatra Earthquake: Padang Region Damage Survey. Record 2010/44. Geoscience Australia. Canberra, Australia.

Sengara, W., M. Suarjana, M. Edwards, H. Ryu, W. Rahmanusyairi, I. Adiputra, I. I. Wahdiny, A. Utami, A. Mariany, M. A. Yulman, and B. Novianto. 2013. *Research on Earthquake Damage Models for Buildings in Indonesia*. Bandung: Research Centre of Disaster Mitigation, Bandung Institute of Technology.

Setiadi, N. J. 2014. Assessing People´s Early Warning Response Capability to Inform Urban Planning Interventions to Reduce Vulnerability to Tsunamis: Case Study of Padang City, Indonesia. Dissertation. Rheinische Friedrich-Wilhelms-Universität zu Bonn.

Setiadi, N., H. Taubenböck, S. Raupp, and J. Birkmann. 2010. Integrating Socio-Economic Data in Spatial Analysis: An Exposure Analysis Method for Planning Urban Risk Mitigation. Paper presented at REAL CORP 2010, Vienna, May 18–20. http://programm.corp.at/cdrom2010/papers2010/CORP2010_80.pdf.

Seto, K. C., B. Güneralp, and L. R. Hutyra. 2012. Global Forecasts of Urban Expansion to 2030 and Direct Impacts on Biodiversity and Carbon Pools. *Proceedings of the National Academy of Sciences* 109: 16083–16088. doi:10.1073/pnas.1211658109.

Shela, Osborne, Gaye Thompson, Paul Jere, and George Annandale. 2008. *Analysis of Lower Shire Floods & a Flood Risk Reduction and Recovery Programme Proposal for the Lower Shire Valley*. Government of Malawi, Department of Disaster Management Affairs, Office of the President and Cabinet.

Sieh, K., D. H. Natawidjaja, A. J. Meltzner, C. C. Shen, H. Cheng, K. Li, B. W. Suwargadi, J. Galetzka, B. Philibosian, and R. L. Edwards. 2008. Earthquake Supercycles Inferred from Sea-Level Changes Recorded in the Corals of West Sumatra. *Science* 322(5908): 1674–78.

Simpson, A. L., and T. Dhu. 2009. Enhancing Natural Hazard Risk Assessment Capacity in the CSCAND Agencies in the Philippines: An Options Paper. Geoscience Australia Professional Opinion 2009/004. Canberra, Australia.

Soden, R., N. Budhathoki, and L. Palen. 2014. Resilience Building and the Crisis Informatics Agenda: Lessons Learned from Open Cities Kathmnadu. *Proceedings of Information Systems for Crisis Response and Management Conference*, State College, PA, U.S.

Soil Conservation Service. 1986. Urban Hydrology for Small Watersheds. Technical Release TR-55. USDA, Soil Conservation Service, Hydrology Unit.

Sørensen, M., A. Babeyko, S. Wiemer, and G. Grünthal. 2012. Probabilistic Tsunami Hazard in the Mediterranean Sea. *Journal of Geophysical Research: Solid Earth* 117(B1): 2156–2202.

State Chancellery of Saxony (Staatskanzlei Freistaat Sachsen). 2003. Schadensausgleich und Wiederaufbau im Freistaat Sachsen: Bericht der Leitstelle Wiederaufbau. Dresden, Germany.

Stein, S., and E. Okal. 2007. Ultralong Period Seismic Study of the December 2004 Indian Ocean Earthquake and Implications for Regional Tectonics and the Subduction Process. *Bulletin of the Seismological Society of America* 97(1A): 279–95.

Stürck, J., A. Poortinga, and P. H. Verburg. 2014. Mapping Ecosystem Services: The Supply and Demand of Flood Regulation Services in Europe. *Ecological Indicators* 38: 198a–211. doi:10.1016/j.ecolind.2013.11.010

Takeuchi, K., T. Ao, and H. Ishidaira. 1999. Introduction of Block-wise Use of TOPMODEL and Muskingum-Cunge Method for the Hydro-environmental Simulation of a Large Ungauged Basin. *Hydrological Sciences Journal* 44(4): 633–46.

Taubenböck, H., J. Post, A. Roth, G. Strunz, R. Kief, S. Dech, and F. Ismail. 2008. Multi-scale Assessment of Population Distribution Utilizing Remotely Sensed Data: The Case Study Padang, West Sumatra, Indonesia. Paper presented at International Conference on Tsunami Warning, Bali, Indonesia, November 12-14.

Taylor, K. E., R. J. Stouffer, and G. A. Meehl. 2012. An Overview of CMIP5 and the Experiment Design. *Bulletin of the American Meteorological Society* 93**:** 485–98.

Thio, H. K., P. Somerville, and J. Polet. 2010. Probabilistic Tsunami Hazard in California. PEER Report 2010/108. Pacific Earthquake Engineering Research Center, University of California, Berkeley, CA, US.

Thomas, C., and D. Burbidge. 2009. *A Probabilistic Assessment of Tsunami Hazard of Southwest Pacific Nations*. Geoscience Australia Professional Opinion 2009/02. Canberra, Australia.

Tsunami Pilot Study Working Group. 2006. Seaside, Oregon Tsunami Pilot Study—Modernization of FEMA Flood Hazard Maps. NOAA OAR Special Report. NOAA/OAR/PMEL, Seattle, WA, U.S.

UNDP (United Nations Development Programme and RMSI. 2006. Developing a Disaster Risk Profile for Maldives.

http://www.preventionweb.net/files/11145_MaldivesDisasterRiskProfileFinalRep.pdf.

UNDP (United Nations Development Programme). 2004. *Reducing Disaster Risk: A Challenge for Development*. New York, U.S.: United Nations.

UN-HABITAT. 2010. Estado de Las Ciudades de America Latina y El Caribe. Regional Office for Latin America and the Caribbean, United Nations Human Settlement Programme. Rio de Janeiro, Brazil.

UNISDR (United Nations Office for Disaster Risk Reduction). 2005a. 10 Preliminary Lessons Learned from the Indian Ocean Tsunami of 26 December 2004. http://www.unisdr.org/files/5605_ISDR10lessonslearned.pdf.

———. 2005b. 2005 Hyogo Framework for Action 2005–2015: Building the Resilience of Nations and Communities to Disasters. Geneva, Switzerland. UNISDR. www.unisdr.org/wcdr.

———. 2009. Global Assessment Report on Disaster Risk Reduction: Risk and Poverty in a Changing Climate. Geneva, Switzerland: UNISDR. http://www.preventionweb.net/gar.

———. 2011. Global Assessment Report on Disaster Risk Reduction 2011: Revealing Risk, Redefining Development. Geneva, Switzerland: UNISDR. http://www.preventionweb.net/gar.

———. 2013a. Global Assessment Report 2013 Annex 1. Geneva, Switzerland: UNISDR. http://www.preventionweb.net/gar.

———. 2013b. Global Assessment Report on Disaster Risk Reduction 2013: From Shared Risk to Shared Value. Geneva, Switzerland: UNISDR. http://www.preventionweb.net/gar.

United Nations. 2007. World Urbanization Prospects. http://www.un.org/esa/population/publications/wup2007/2007WUP_Highlights_web.pdf.

Walsh, K. J. E., and J. I. Syktus. 2003: Simulations of Observed Interannual Variability of Tropical Cyclone Formation East of Australia. *Atmospheric Science Letters* 4: 28–40.

WAPMERR (World Agency for Planetary Monitoring and Earthquake Risk Reduction). 2013. Approximate Model for Worldwide Building Stock in Three Size Categories of Settlements. Background Paper prepared for the 2013 Global Assessment Report on Disaster Risk Reduction. UNISDR. Geneva, Switzerland. www.preventionweb.net/gar.

Ward, P. J., W. Beets, L. M. Bouwer, J. C. J. H. Aerts, and H. Renssen. 2010. Sensitivity of River Discharge to ENSO. *Geophysical Research Letters* 37: L12402. doi:10.1029/2010GL043215.

Ward, P. J., M. Dettinger, B. Jongman, M. Kummu, F. Sperna Weiland, and H. Winsemius. 2013b. Flood Risk Assessment at the Global Scale—The Role of Climate Variability. Paper presented at EGU General Assembly, Vienna, Austria. April 7-12.

Ward, P.J., S. Eisner, M. Flörke, M. D. Dettinger, and M. Kummu. 2014. Annual Flood Sensitivities to El Niño Southern Oscillation at the Global Scale. *Hydrology and Earth System Sciences* 18: 47–66. doi:10.5194/hess-18-47-2014.

Ward, P.J., B. Jongman, F. Sperna Weiland, A. Bouwman, R. Van Beek, M. Bierkens, W. Ligtvoet, and H. Winsemius. 2013a. Assessing Flood Risk at the Global Scale: Model Setup, Results, and Sensitivity. *Environmental Research Letters* 8: 044019. doi:10.1088/1748-9326/8/4/044019.

Winsemius, H. C., R. Van Beek, B. Jongman, P. J. Ward, and A. Bouwman. 2013. A Framework for Global River Flood Risk Assessments. *Hydrology and Earth System Sciences* 17(5): 1871–92. doi:10.5194/hess-17-1871-2013.

Wisner, B., P. Blaikie, T. Cannon, and I. Davis. 2004. *At Risk: Natural Hazards, People's Vulnerability and Disasters.* 2nd ed. New York, U.S.: Routledge.

World Bank. 2010a. *Emerging Stronger from the Crisis.* Vol. 1 of *World Bank East Asia and Pacific Update 2010.* https://openknowledge.worldbank.org/handle/10986/2455.

———. 2010b. *Natural Hazards, UnNatural Disasters*. Washington, DC, U.S.: World Bank.

———. 2012a. *Bangladesh: Towards Accelerated, Inclusive, and Sustainable Growth—Opportunities and Challenges.* Vol. 2. Washington, DC, U.S.: Poverty Reduction and Economic Management Sector Unit, South Asia Region, World Bank.

——— . 2012b. Consultancy for Prioritization of High Seismic Risk Provinces and Public Buildings in Turkey by Proto Engineering.

———. 2013. Risk Assessment Report, Morocco Natural Hazards Probabilistic Risk Assessment and National Strategy Development, Final Report. Prepared by RMSI Ltd. for the International Bank for Reconstruction and Development, Washington, DC, U.S.

Yamin, Luis Eduardo, Francis Ghesquiere, Omar Darío Cardona, and Mario Gustavo Ordaz. 2013.
Probabilistic Modeling for Disaster Risk Management: The Case of Bogota, Colombia (in

Spanish). Washington, DC, U.S.: International Bank for Reconstruction and Development and World Bank.

IV. Recommendations

This publication has highlighted the remarkable progress made in understanding, quantifying, and communicating risk since 2005, when the Hyogo Framework for Action was endorsed. The array of projects and experiences described here for some 25 countries demonstrates that no single approach to risk assessment is right in every case, and that the best risk assessments are those tailored to the context and identified need. At the same time, the recurrence of certain themes across the various projects makes it possible to start framing best practices and suggests some concrete recommendations for the next 10 years of risk assessment practice.

Drawing on discussions with developers and end-users of risk information as well as on submissions to this publication, we offer recommendations for two groups: those investing in and using risk information, and those producing it. Recommendations for the first group—disaster risk management (DRM) practitioners, government officials, donors, and nongovernmental organizations—are designed to ensure a successful investment that promotes more-resilient development and communities. Recommendations for the second group are designed to promote greater transparency and accountability in the risk assessment process. In our experience, the value of the best technical risk assessment in the world is zero if it does not motivate readers, users, or decision makers to reduce, mitigate, or manage their risk. Thus, we offer recommendations on education, collaboration, and ownership before moving on to the technical aspects of risk analytics.

Recommendations for those commissioning and using risk information:

1. Clearly define the purpose of the risk assessment before analysis starts.
Too many risk assessments are implemented precipitously. These risk assessments—initiated without first defining a question to be answered and a specific end-user—often become scientific and engineering exercises that upon completion must find a use case and a purpose. Properly targeted assessments, on the other hand, suit their intended purpose and are not over-engineered or over-resourced. If a community seeks to understand the hazards it faces and to develop plans for evacuation, then mapping of exposure and natural hazards is a valid approach, but a different approach would be needed for financial planning or retrofitting design. Similarly, collecting detailed site-level construction information on selected buildings may be appropriate for the design of retrofitting measures, but this approach is not practical for a national-level risk assessment.

Where risk assessments have been commissioned in response to a clear and specific request for information, they have tended to be effective in reducing fiscal or physical risk. Among the well-targeted risk assessments described in this publication, we note here the following:

- *The Pacific Catastrophic Risk Assessment and Risk Financing Initiative (PCRAFI).* PCRAFI was designed to inform risk financing and insurance options, and ultimately to transfer risk to the international financial market. Given this purpose, the analysis had to conform to standards acceptable to the financial market. The first payout of the Pacific Catastrophe Pool in 2014 in Tonga is testament to the success of this project. An additional benefit of the project is that the data and analysis generated have been made available to all stakeholders to use for other purposes (for example, to determine how cyclone risk will change as climate change effects are increasingly felt).

- *The assessment of seismic risk to Costa Rican Water and Sanitation systems.* Costa Rican water and sanitation officials seeking to ensure continuation of services following an earthquake created the demand for this project. The development of the objectives, collection of data, and presentation of results were all aimed toward a very specific goal, and as a consequence resources and ultimately results were used efficiently.
- *Urban seismic risk mapping to inform DRM plans in Aqaba, Jordan.* This project was initiated to manage the urban development expected in response to Aqaba's being declared a special economic zone. The project supplied the evidence for an earthquake risk management master plan and served as the basis for an operational framework for earthquake risk reduction.

2. Promote and enable ownership of the risk assessment process and efforts to mitigate risk.

A sense of ownership is critical to ensuring that knowledge created through a risk assessment is promulgated and acted upon. Countries, communities, and individuals must feel they have a stake in and connection to risk information if that information is to be used, especially by government. In many countries, if risk information is not seen as authoritative—if it is not understood to originate from government-mandated agencies—it will not be used in decision making.

Risk information can be generated anywhere. Risk assessment specialists in London, for example can generate risk information on flood in Pakistan. But extensive experience suggests that unless the Pakistan authorities have been actively engaged in the assessment process, the information produced, no matter how accurate or sophisticated, will have limited or no uptake and use. Engagement with official government stakeholders and local specialists—at the start of a risk assessment, through its implementation, and finally to its conclusion—is critical for the success of a DRM effort.

Fortunately, as many of the projects described in part III make clear, the importance of ownership is increasingly being recognized:

- In Jordan, local scientific and government groups partnered with international and other development agencies to integrate seismic risk reduction considerations into Aqaba's economic development.
- In Malawi, the government partnered with the World Bank and Global Facility for Disaster Reduction and Recovery to assess flood risk in the Shire River Valley as part of an effort to reduce entrenched poverty and make the valley a national economic hub.
- In Peru, Technical Assistance Projects fostered a hands-on approach to generating, understanding, managing, and using risk information, and thus promoted ownership of the process and the results of the assessment.

The crucial role of ownership is also evident in the increasing part played by volunteers in collecting fundamental data used in risk assessments (such as through volunteered geospatial information, or crowdsourcing). This shift toward community participation reflects communities' sense that they can contribute to understanding and mitigating the risk they face. Experience shows that governments and decision makers increasingly recognize the value and the potential of this approach, but consider it critical that the data are certified (for accuracy). In many cases governments would also like to harness volunteer efforts toward particular needs—for example, may wish to direct volunteers toward collecting information about buildings' attributes (such as use, number of floors, vintage, and structural materials) rather than focusing on buildings' location and footprint. Universities have shown themselves to be excellent partners in this type of volunteer data collection, and their participation assists with ownership and helps to ensure data's scientific validity.

Partnerships designed to both produce risk information and build capacity—such as those between the government of Australia and various scientific/technical agencies in Asia and the Pacific, and between the World Bank and countries in Latin America and the Caribbean—have also been an important means of promoting ownership. A number of elements go into assuring the success of these partnerships: high levels of trust developed over long periods of time; a focus on work that builds on existing capabilities and interests; and the involvement of credible, capable, and committed experts who understand the partner country's systems and cultures, including its language.

3. Cultivate and promote the generation and use of open data.
All the case studies featured in this publication make clear that the creation and use of open data should be encouraged.

A risk assessment that yields only a paper or PDF report is of limited use. Its relevance and appropriateness are of short duration, and few decision makers are likely to engage with it. A much greater impact can be expected of a risk assessment that shares the data it has collected and improved with stakeholders. The effort required to collect exposure information is substantial, but fortunately, the data sets produced have relevance and use for a range of DRM purposes as well as for urban and local planning. If all the input data sets and final results are made technically open, the broader community is able to engage through improvements in data and development of new applications and information for community awareness; and the private sector is able access data that can improve its resiliency. Data sharing can also redound to the advantage of those who undertook the original assessment, because it allows new data to be exploited when they become available; this means that additional or new analysis is less of a drain on resources and takes less time than it otherwise would.

With respect to creation of new open data, our short experience is only beginning to speak to the immense potential of structured and unstructured volunteered geospatial information, better access to remote sensing data over wider areas, and better ways of exploiting and integrating new exposure data sets and models, as well as the release of *technically* open data sets by governments, the private sector, and nongovernmental organizations.

It is clear from case studies and research that greater effort is needed to open up and improve damage and loss data collections to make them meaningful and useful for understanding and quantifying risk. An encouraging sign is a pilot being undertaken by the Insurance Bureau of Canada that will give cities access to flood insurance claims data, alongside municipal infrastructure data and current and future climate data on flood[75]—a significant step toward better understanding and managing urban flood risk.

Given the benefits it stands to gain, the global DRM community needs to be willing to press for greater access to fundamental data sets that quantify risk. Without access to higher-resolution digital elevation models, results for flood, tsunami, and storm surge inundation may be impossible to produce at the necessary resolution, or may be massively inaccurate. Similar gaps in fundamental data exist across all hazard areas, and these are hindering the development of robust and accurate information. In many cases the needed data already exist but are not accessible. If the DRM community comes together and advocates for these data to become technically open, access is likely to improve and data gaps to be closed.

4. Make better communication of risk information an urgent priority.
Clear communication throughout the risk assessment process, from initiation through delivery of the results and the development of plans in response, is critical for successfully mitigating disaster risk.

A case study featured in this publication is a must-read for all risk assessment practitioners and disaster risk managers who believe that exceptional communication of risk information is the key to preparedness and risk reduction. A massive "Build Back Better" campaign led by the government of Indonesia in the aftermath of the 2009 Padang earthquake demonstrates conclusively that well-targeted education and communication of risk information can increase awareness of natural hazards and their potential impacts. Analysis also shows, however, that progress from increased awareness to substantive action is very difficult to achieve, even in a community that has witnessed at first hand the devastation of an earthquake. The study finds overall that homeowners can be motivated to put risk knowledge into practice and build more resilient homes if the correct combination of timely information, technical training, community supervision, and financial and nonfinancial incentives and disincentives are offered.

Some of the improvements that can be made in communicating risk at the subnational and city level is can be seen in the InaSAFE project in Indonesia. Among the key partner in InaSAFE's development were Indonesian authorities, who realized the need for interactive risk communication tools that could robustly and simply answer the question "what if?" InaSAFE is demand driven, involved user participation in its development, uses open data and an open model, and offers extensive graphical displays (provided by a GIS system) and an extensive training program. Communication was frequent and wide-ranging throughout the development of InaSAFE and continued during the collection of data, the use of the

[75] Insurance Bureau of Canada, "Fighting Urban Flooding," 2014, http://www.ibc.ca/en/Natural_Disasters/Municipal_Risk_Assessment_Tool.asp.

model, and the formation of response plans. The software has won awards and is being used in other countries, including the Philippines and Sri Lanka.

To build on this progress in communicating risk, significant investment and innovation will be needed in coming years.

5. Foster multidisciplinary, multi-institutional, and multi-sectoral collaborations at all levels, from international to community.

Risk assessment is a multidisciplinary and multi-institutional effort that requires collaborations at many levels, from international, to national and subnational, down to the individual.

Generating a useable risk assessment product involves consultations among technical experts, decision makers, and disaster managers, who must reach agreement on the purpose and process of a risk assessment. Collaboration among technical disciplines, agencies, governments, NGOs, and virtual communities, as well as informal peer-to-peer exchanges and engagement with local communities, will help an effort succeed.

This publication draws attention to a variety of collaborations that aim to build better risk information:

- *The Global Earthquake Model* brings together public institutions, private sector institutions (most notably insurance and reinsurance agencies), nongovernmental entities, and the academic sector, all with the goal of improving access to tools, data sets, and knowledge related to seismic risk.
- *The Willis Research Network* initiative links more than 50 international research institutions to the expertise of the financial and insurance sector in order to support scientists' quantification of natural hazard risk.
- *The Understanding Risk* community of practice, made up of more than 3,000 practitioners from across all sectors in more than 125 countries, is creating new partnerships and catalyzing advances in understanding, quantifying, and communicating natural hazard risk.
- The *Bangladesh Urban Earthquake Resilience Project* is a platform for addressing urban risk that brings together officials in planning, governance, public service, and construction code development as well as scientists and engineers, and that fosters consensus on how to overcome institutional, legislative, policy, and behavioral barriers to a more earthquake-resilient city.

One key task of these and similar collaborations is reaching out to communities to build consensus, raise awareness, and promote action concerning the risks they face. Greater effort is needed to provide national- and subnational-level information on risk to community groups and nongovernmental organizations working at the community level. Too often, organizations working within communities to increase preparedness and reduce risk lack access to this relevant information on natural hazard risk. Significant gains could arise from merging work being produced at national or subnational level with communities' understanding of their risks and challenges—but this opportunity has as yet rarely been capitalized upon.

6. Consider multi-risk assessments instead of assessing single risk in isolation.

Rarely does a country, community, or citizen face potential risks from only one hazard, or even from natural hazards alone. Our environments and social structures are such that multiple or connected risks—from financial hazards, multiple or cascading natural hazards, and anthropogenic hazards—are the norm. A risk assessment that accounts for just one hazard may struggle with relevance and will not necessarily speak to a decision maker who is responsible for broader risk management. Moreover, failure to consider the full risk environment can result in maladaptation: heavy concrete structures, for example, can protect against cyclone wind but can be deadly in an earthquake.

Experience shows that the benefits of a multi-hazard risk approach include improvements in land-use planning, better response capacity, greater risk awareness, and increased ability to set priorities for mitigation actions. Such an approach also highlights the importance of partnerships generally and of multidisciplinary, multi-institutional, and multi-sectoral collaborations in particular. Examples of this approach showcased in this publication include projects in Morocco, Guadeloupe and Naples, and Maldives.

Decision makers need to exercise particular caution where risks in food security and the agricultural sector are concerned. Such risks should be considered at all times alongside flood and drought analysis. Food security–related risks such as animal and plant pests and diseases are important for many populations, yet they are not considered under the Hyogo Framework for Action.

7. Keep abreast of evolving risk.

Risk assessments must be dynamic because risks themselves are always evolving. Assessments that estimate evolving or future risk allow stakeholders to act now to avoid or mitigate the risk they will face in the future. Getting ahead of risk is particularly important in rapidly urbanizing areas or where climate change impacts will be felt the most.

The evolution of meteorological hazard arising from climate change will likely occur slowly. The same is true for changes in hazard due to sea-level rise (for example, with higher sea levels, inundation from storm surge and tsunami events may reach further inland). That said, it is possible today—with varying levels of uncertainty—to estimate how climate change may affect losses from meteorological hazards such as cyclone. One project described in this publication, for example, examines how tropical cyclone patterns, altered by climate change, can result in reduced or increased losses in 15 Pacific Island countries, assuming steady-state exposure.

Given the intensive data needs involved, there have been few efforts to look at changing exposure and vulnerability, along with the resulting change in risk, in urban environments. While the contribution of urbanization to greater exposure is widely recognized, studies rarely consider how changes in urban building practices are changing building vulnerability—often for the worse. The recent study of evolving seismic risk in Kathmandu offers an important example of this approach. The study shows that the incremental construction of houses in Kathmandu, where stories are added to buildings informally over time, has increased both exposure and vulnerability in the area. Using a single-scenario earthquake event, a reproduction of the 8.1 magnitude Bihar earthquake of 1934, the analysis finds that the potential number of buildings sustaining heavy damage or collapse in this event has increased from ~50,000 in 1990 to ~125,000 in 2010, and that it may be as high as 240,000 by 2020 if action is not taken.

Considering global changes in hazard and exposure for flood offers some sobering statistics for the future: "middle of the road" socioeconomic changes and climate change could increase riverine flood risk for between 100 million and 580 million people by 2050, depending on the climate scenario. At a city level, changes in exposure and flood hazard for Dhaka, Bangladesh, were found likely to increase the annual average loss by a factor of 20 to 40. Moreover, while both climate change and socioeconomic development were found to contribute importantly to this increase in risk, the individual contribution of socioeconomic development is greater than that of climate change.

Coastal regions are especially dynamic, and—in light of future sea-level rise driven by local subsidence, the thermal expansion of the oceans, and melting of continental ice—need special consideration. Changes in sea level can be particularly important for relatively flat low-lying islands and coastlines, since a small change in sea level can affect huge areas. Even small changes can become extremely important during flood and storm surge events.

Recommendations for those producing risk information:

8. Understand, quantify, and communicate the uncertainties and limitations of risk information.

Once risk information is produced, its users must be made aware of its limitations and uncertainties, which can arise from uncertainties in the exposure data, in knowledge of the hazard, and in knowledge of fragility and vulnerability functions. A failure to understand or consider these can lead to flawed decision making and a potential increase in disaster risk. A risk model can produce a very precise result—it may show, for example, that a 1-in-100-year flood will affect 388,123 people—but in reality the accuracy of the model and input data may provide only an order of magnitude estimate. Similarly, sharply delineated flood zones on a hazard map do not adequately reflect the uncertainty associated with the estimate and could lead to decisions such as locating critical facilities just outside the "flood line," where the true risk is the same as if the facility was located inside the flood zone.

If risk information is to be useful in making communities more resilient and better able to manage risk, then the specialists who produce it must do more to clearly and simply communicate its uncertainties and limitations. Fortunately, some recent projects suggest that progress is being made in this regard:

- In Kathmandu, assessment of damage to buildings as risk evolves over times includes a range of uncertainty.
- In global risk models, the limitations for use in national and subnational risk reduction are clearly articulated.
- In Morocco, results of multi-hazard risk analysis are communicated using a range of different approaches.

9. Ensure that risk information is credible and transparent.
Risk information must be credible and transparent: scientifically and technically rigorous, open for review, and honest regarding its limitations and uncertainties.

A risk assessment must be perceived as credible for it to be worth acting upon. The best way to demonstrate credibility is to have transparent data, models, and results open for review by independent, technically competent individuals. Equally important is the clear articulation of the assessments' limitations. Several projects included in this publication found that data limitations and assumptions made in the modelling process could greatly change the end result:

- Multiple tsunami hazard maps were produced in Padang, Indonesia, by different institutions, each offering plausible information for decision makers, and each based on different approaches, assumptions, and data.
- Depending on the choice of elevation data in modelling tsunami hazard, inundation levels varied dramatically as a function of the digital elevation model used in the simulation.
- Different seismic hazard results for ground motion in Japan (**Error! Reference source not found.**) highlight the impact of the choice of attenuation function.

These examples make clear the need for credible, scientific, and transparent modelling of risk. Every risk analysis should be accompanied by modelling metadata that articulate the data sets and modelling parameters used so that anyone can recreate identical results. In other words, we need to achieve an "academic level" of transparency. The selection of modelling parameters also speaks to the need for credible scientific and engineering inputs throughout the modelling process; in theory, anyone can run a risk model, but in reality, the absence of necessary scientific and engineering training risks can produce results that are fundamentally inaccurate and misleading.

10. Encourage innovations in open source software.
It is clear that immense progress has been made in the last 5 to 10 years in creating new open source hazard and risk modelling software. More than 80 open source software packages are currently available for flood, tsunami, cyclone (wind and surge), and earthquake, with at least 30 of these in wide use. Moreover, significant progress has been made in improving open source geospatial tools, such as QGIS and GeoNode, which are lowering the financial barriers to understanding risks at national and subnational levels.

There is some tendency to assume that open source software may be less robust than commercial packages, may be less user-friendly, and may not offer technical support. But this assumption has little basis. Some of the most widely used packages, such as InaSAFE and TCRM, provide interactive help, and others, such as the Deltares-developed packages, have impressive graphical user interfaces that offer point-and-click capabilities. Available software packages range from those that meet the needs of entry-level users to those that are appropriate for advanced scientific and engineering analysis. Some tools offer single hazard and risk analysis—probabilistic and deterministic—and some, such as RiskScape and CAPRA, offer multi-hazard capabilities.

Increasing the uptake of open source modelling tools is an important challenge that will need to met in coming years. Among specific goals in this area are the following:

- Access to software with user-friendly interfaces, simple single-click installation, and tutorials on software use should be increased.
- Licensing restrictions on how software may be used or altered should be easier to understand.
- Access to model source code—through wiki-type systems—should be increased in order to provide improved transparency in how results are calculated, allow for customization and optimization of code, enable production of better code through multiple independent reviews, provide developers with an easy way to manage and update code, and offer users easy access to models.
- Standard model outputs and data (e.g., event loss tables) should be made viewable at every stage of the analysis without significant increases in processing.
- Tools should have the capability of using custom exposure data and hence of handling both static risk and dynamic risk.
- Software should host a greater range of vulnerability functions capable of calculating vulnerability (susceptibility to damage or loss) using either empirical methods (historical trending of data) or analytical methods (mathematical or mechanical approach). These should cover both physical and social vulnerability.
- Risk should be calculable not only for a building or building type, but also for a diverse portfolio of buildings and infrastructure, or in terms of the total economic loss for a city or region.

A great challenge for the next five years—one that has arisen rapidly along with innovative software models—involves "fitness-for-purpose" interoperability, transparency, and standards. This challenge needs to be overcome in a way that continues to catalyze innovation and yet also better supports risk model users. But it is an institutional challenge, and not a technical one, and it can be met if model developers agree on minimum standards and build partnerships across institutions and hazard types.