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UNDERSTANDING RISK

Review of Open Source and Open Access
Software Packages Available to Quantify Risk
from Natural Hazards

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ABBREVIATIONS

<i>AAL</i>	annual average loss	<i>IRD</i>	Institut de recherche pour le développement
<i>AIFDR</i>	Australia-Indonesia Facility for Disaster Reduction	<i>IST-SUPSI</i>	Instituto scienze della Terra–Scuola universitaria professionale della Svizzera italiana
<i>ANU</i>	Australian National University	<i>ITB</i>	Bandung Institute of Technology
<i>API</i>	application programming interfaces	<i>KIT</i>	Karlsruhe Institute of Technology
<i>BCR</i>	benefit-cost ratio	<i>LNEC</i>	Laboratório Nacional de Engenharia Civil
<i>CEDIM</i>	Center for Disaster Management and Risk Reduction Technology	<i>MDR</i>	mean damage ratio
<i>DEM</i>	digital elevation model	<i>METU</i>	Middle East Technical University
<i>DRM</i>	disaster risk management	<i>MEOW</i>	maximum envelope of water
<i>EPA</i>	Environmental Protection Agency	<i>MMI</i>	Modified Mercalli Intensity
<i>EU</i>	European Union	<i>MOM</i>	maximum of maximums
<i>FEM</i>	finite element method	<i>NCEP</i>	National Centers for Environmental Prediction
<i>FEMA</i>	Federal Emergency Management Agency	<i>NCREE</i>	National Center for Research on Earthquake Engineering
<i>GA</i>	Geoscience Australia	<i>NOAA</i>	National Oceanic and Atmospheric Administration
<i>GEM</i>	Global Earthquake Model	<i>NTU</i>	National Technical University (Athens)
<i>GFDRR</i>	Global Facility for Disaster Reduction and Recovery	<i>OGC</i>	Open Geospatial Consortium
<i>GIS</i>	geographic information system	<i>OS</i>	operating system
<i>GM</i>	ground motion	<i>OSSN</i>	Italian National Seismic Survey
<i>GMPE</i>	ground motion prediction equation	<i>PGA</i>	peak ground acceleration
<i>GUI</i>	graphical user interface	<i>PHIVOLCS</i>	Philippine Institute of Volcanology and Seismology
<i>IAHR</i>	International Association for Hydro-Environment Engineering and Research	<i>PML</i>	probable maximum loss
		<i>PRACE</i>	Partnership for Advanced Computing in Europe
		<i>PSHA</i>	probabilistic seismic hazard analysis
		<i>S_a</i>	spectral acceleration
		<i>SKM</i>	Sinclair Knight Merz
		<i>UNEP</i>	United Nations Environment Programme
		<i>USGS</i>	U.S. Geological Survey
		<i>USU</i>	Utah State University

EXECUTIVE SUMMARY

The World Bank's disaster risk management (DRM) activities utilize a range of open access and open source computational modelling tools to quantify the risk posed by natural hazards. An important goal of these activities is to build capacity among national and local governments and international development professionals working in disaster risk management. A key decision in these activities is the choice of modelling tool that will be used to address the hazard, exposure, and/or risk question under consideration. This document presents an objective analysis of freely available hazard and risk modelling software in order to facilitate selection of appropriate tools for various DRM activities. There have been previous evaluations of freely available modelling tools across various natural hazards, but this is the first multi-hazard systematic review using a set of consistent criteria. The analysis covers hazard risk models for cyclone (wind), storm surge and tsunami, earthquake, and flood.

Over 80 open access software packages—excluding commercial software packages—were considered in the evaluation. A preliminary analysis was used to determine whether the models were currently supported and if they were open access. Based on the results, a subset of 31 models was selected for more detailed analysis; these included 8 earthquake models, 4 cyclone models, 11 flood models, and 8 storm surge/tsunami models. The detailed analysis evaluated the models on the basis of over 100 criteria and provided a synopsis of available open access natural hazard risk modelling tools.

The quality and availability of open access/open source software has grown significantly over the past few years. For example, private entities such as Deltares now have an open source policy

regarding some flood models. In addition, leaders in developing risk models in the public sector, such as Geoscience Australia (EQRM, TCRM, TsuDAT, ANUGA) and CAPRA (ERN-Flood, Hurricane, CRISIS2007), are launching and/or helping many other initiatives. As we achieve greater interoperability between modelling tools, we will also achieve a future in which open source and open access modelling tools are connected and adapted to unified multi-risk model platforms and highly customized solutions.

Introduction: Purpose and Use of This Document

The demand for risk assessment data and modelling tools in the disaster risk management (DRM) community is high, and many open access software packages for natural hazards have been created over the last few decades. However, it is often difficult to assess the advantages and disadvantages of the different tools, given the wide range of contexts, purposes, and users' technical expertise.

This review is a technical document intended for a technical audience. It aims to highlight modelling tools' strengths (for example, sophisticated graphical user interfaces [GUIs], straightforward installation, frequent updates, and capacity for customization). It also highlights some of the challenges that a user of a modelling tool might

face (for example, complicated installation or poor documentation), though as modelling tools are updated, they may address the challenges identified here.

This review provides initial guidance to users on the appropriateness of the various modelling tools for specific purposes, and offers an introduction to the connectivity that is possible between models. We emphasize here, however, that the final decision about which tool to use must also be based on downloading and testing of a variety of possible tools. Finally, the document highlights where collaborative efforts between modelling tool developers could substantially improve our current understanding of risk.

1.0 – Background

This systematic assessment of software packages that simulate natural hazards and quantify risk was motivated by the interest of the World Bank and the Global Facility for Disaster Reduction and Recovery (GFDRR) in supporting DRM efforts. They envisaged an objective assessment of the functionality, quality, and usability of risk model software packages that would help potential users identify the optimal model(s) for addressing the hazard and risk question(s) of concern. They also saw the review as a way to address issues related to the development and use of open data and open source models, which they strongly support.

This assessment focused on open access and open source software packages only; thus no commercial models were considered. The 82 software packages examined in this report simulate a number of different perils. In addition to models designed for a single peril, the assessment also evaluated multi-risk software packages. The perils modelled with the packages were divided into the following four groups on the basis of peril characteristics: (a) earthquakes and their secondary effects such as liquefaction, fire, landslides, etc.; (b) inland flooding; (c) winds from either tropical or extra-tropical storms; and (d) coastal flooding due to tsunamis and/or storm surge. Each peril in the multi-risk software packages was assessed separately (though such packages may be particularly valuable, given their ability to solve multiple problems).

Risk assessments are produced in order to estimate possible economic, infrastructure, and social impacts arising from a particular hazard or multiple hazards. Three components are usually considered when assessing risk and probable loss: exposure, hazard, and vulnerability. Exposure represents the stock of property and infrastructure exposed to a hazard, and it can include socioeconomic factors. Hazard is defined as the probability of experiencing

a certain intensity of hazard at a location and is usually determined by an historical or user-defined scenario, probabilistic hazard assessment, or other methods. Some hazard modules can include secondary perils (such as soil liquefaction or fires caused by earthquakes, or storm surge associated with a tropical cyclone or extra-tropical cyclone). Vulnerability accounts for the susceptibility to damage of the assets exposed to the forces generated by the hazard. Fragility and vulnerability functions estimate the damage ratio and consequent mean loss respectively, and/or the social cost (e.g., number of injured, homeless, and dead) generated by a hazard, given the specified exposure.

The wide range of available loss estimation packages means there are multiple ways to simulate each component. Users may choose from software packages that are proprietary, open access, or open source, and that have varying degrees of complexity and usability. However, other considerations may also be important for users choosing a software package. For example, the most appropriate model may vary by region and hazard, because data availability and specificity also vary. Alternatively, a user may wish to modify the software to generate more loss outputs or derive a particular type of loss metric. Also, the technical skills of users can vary greatly. Thus a simple model driven by a GUI may be appropriate in some cases, but a more complex, command-line controlled model may provide additional flexibility for an advanced modeller. In other ways, the knowledge of the user may control the suitability of the model; an advanced user may desire control over definition of technical content, whereas an entry-level user may want a hardwired quick version. Thus a range of criteria should be considered when selecting a software package for a risk assessment.

For this assessment, the criteria were grouped into 11 modules. A summary of the modules, and the number of criteria and descriptors associated with each, is provided in table 1-1. Details on the criteria and descriptors for each module are given in appendix C. The assessment methodology and criteria follow the OPAL methodology as developed by Daniell (2009) in order to rank and evaluate software using a scorecard/multi-criteria decision analysis approach. The criteria and descriptors used for the assessment were modified in response to discussions with experts from GFDRR and the World Bank, who suggested adding useful criteria such as number of users in the community for a particular software package, as well as the package's particular GNU license.

It is important to note at this stage the difference between open source and open access and to articulate some of the key reasons why open source provides a more transparent framework than open access software packages. Open source, as the name suggests, refers to a software package model whose source code (programming language) is available for access and viewing. There are various formats for open source, with some software code being directly editable, some viewable but not directly editable, and some requiring registration before viewing. Open access, on the other hand, means that the

software package is directly downloadable, but that the source code is not editable or viewable. There are also different forms of open access, including full open access, partial open access (i.e., certain components are open), and partial source code.

“Open” also refers to the fact that payment is not required for using a software package, though for the technical and research community, open source provides a transparent, user-community-driven solution beyond the free price. In addition to making access to the software code available free of charge, open source software packages have the following advantages:

- The models and calculations are transparent (not a black box), so the science and assumptions behind the models can be checked and sensitivity analyses undertaken.
- The software allows users to detect and correct errors and to make direct improvements.
- Collaborative development of some packages means that many experts work on improving, and solving problems within, the same models.
- All their processes can be easily replicated and checked, which is critical for validation of the outputs.

Table 01-1
Description of
Modules and
Number of Criteria
Used for Ranking
Software Packages

Note: See appendix C for details on the descriptors.

Module	Abbreviation	Criteria	Descriptors
Software accessibility	SA	20	81
GUI	GU	3	7
Software details	SW	22	65
Technology	TE	5	15
Exposure	EX	17	53
Vulnerability	VL	18	56
Risk	RK	14	46
Post-event	PS	9	25
Forecasting	FC	3	9
Output	OU	6	17
Hazard-Flood	HF	29	81
Hazard-Hurricane/Wind	HS	21	59
Hazard-Earthquake	HE	27	81
Hazard-Wave	HT	18	57

2.0 – METHODOLOGY

An initial analysis of 82 open access software packages was used to select a subset for detailed assessment. The initial analysis looked for packages that met three criteria: they had to be (a) open access or open source; (b) active (currently supported); and (c) available. To be considered open access, the software package had to be downloadable and testable; this limitation reduced the number of packages to 60. Twenty-two packages provided manuals, papers, and/or methodologies but did not provide access to the software itself. If a package was inactive or unavailable, then it could not be tested in a rigorous manner. The initial analysis identified a total of 48 software packages for the four hazard groups that met these simple criteria. An additional subjective ranking based on output, hazard, risk, and available user support further reduced the number of modelling tools for detailed testing to 31. A description of the initial analyses is provided in appendix D.

All software was tested on a machine with a 2.5GHz Intel Core i5 with 4GB of RAM, running Windows 7 in the Windows operating system (OS), and Ubuntu 12.04 under Linux. To verify that software packages advertised as compatible with Mac OS actually ran under Mac OS, we relied on user reports.

The detailed assessment of the software packages involved the following steps:

1. The packages were installed and tested using their accompanying tutorials, along with various data sets and examples, in order to create outputs. The advantages and disadvantages of these software packages were compiled using a set of 117 criteria under 10 key classification modules common to all hazard groups and an additional 18 to 29 criteria associated with each specific hazard module (table 1-1).
2. The written descriptors for each module were converted to a numeric system using a point score having between two and five levels for each criterion. An example of the descriptors and the numerical values assigned to word descriptions is given in table 2-1. It should be noted that some of the criteria are subjective, although every effort has been made to define objective criteria. The relative importance of different factors can be adjusted by assigning weights to the various criteria. This allows users to rank the software packages according to what is important for them. A *supplementary spreadsheet to be available online* shows how each software package performed against each criterion.

Supplementary Spreadsheet

<https://www.gfdrr.org/RASoftwareReview>

Criterion code	Point score	Word criterion	Descriptor no.
SA-002	4	Fast, easy download without registration"	SA-0024
SA-002	3	Fast, easy download with registration	SA-0023
SA-002	2	Moderate download with registration	SA-0022
SA-002	1	Slow download with registration	SA-0021
SA-002	0	Registration did not work	SA-0020

Table 02-1

Sample Criterion for Assessing Software Packages (with five descriptors)

Note: The criterion shown in the table concerns software accessibility.

The criteria associated with the 11 modules listed in table 1-1 are discussed below, with an emphasis on which criteria should be considered most desirable.

1. *Software accessibility*. The 20 criteria associated with the software accessibility module cover a variety of software-related issues, such as licensing, availability, ease of use, and the user community. Reflecting the criteria for the initial analysis, all the packages analyzed in detail are open access, and most are open source (note earlier definitions).

Open source can mean many things. The diversity of open source license structures reflects the variety of interpretations of open source. Examples of open source software licenses include GNU GPL (or just GPL), Apache, and Creative Commons. Each of these has different reuse options, and usually software must be released with the same license if source code is reused.

Many factors influence the software package's ease of use, including the operating system, the language used for coding, the sophistication of the developer and user communities, and the inclusion of additional libraries and documentation that facilitate the use of the software package. Linux is currently the most common operating system for supercomputers; however, most basic users have no experience of Linux. This review therefore considered only software packages that can run on Windows operating systems.

In terms of coding languages, an open source coding language such as Fortran or Python is broadly considered best practice. Java is also a very good language that allows for fast analysis styles. Other common languages include C++ and Octave, both of which are open source. As long

as the software is well designed and extensible, and the developer(s) can be contacted via email, website wiki, and/or in open discussion, then any coding language can be used. Contact details were available for all software packages analyzed.

Additionally, the code should have a version code, a bugtracker, and some indication of release dates, as well as patches and a free non-login access virtual community to aid knowledge exchange. The coding and software should also be user-oriented, with separate documentation available for those wishing to modify or extend the tools and leverage any available APIs (application programming interfaces), and with tutorials, sample data, and expected results available for training and testing model installation.

The software package should include all required software and ideally be open source if coding changes are required; otherwise open access is sufficient. An example of open-closed software is freely available Hazus-MH, which requires a commercial geographic information system (GIS) package, ArcGIS, to run the model. Another important software accessibility component is related to data access. If the software package requires particular data to run the model, then these data should be available to all users, preferably as open data—i.e., as a library of generalized vulnerability functions.

2. *Graphical user interface*. The GUI module is an extremely important factor in the assessment because it determines the usability of a software package. Few users have the technical skills that allow them to execute models using command lines alone. For non-experts, grappling with risk assessment concepts is usually quite difficult; attempting to come to grips with what is being

modelled using a new software package makes things even harder. Thus, simple software that allows a user to point, click, and then understand is best for a non-expert. Two examples of software packages that achieve this level of simplicity are InaSAFE and TCRM. Both have help commands and simple descriptions that the user can easily understand. MAEviz/mHARP is another package that provides an easy-to-use GUI as well as hazard, exposure, and vulnerability analysis, so that users have more control over their analysis.

3. *Software details.* The software details module captures a variety of factors that influence the usability of the software. A wiki-type system for updating code and leaving ideas, as well as a direct system for handling bugs, is desirable. In cases where software has been derived from other models or other software, this relationship should be clear. The package should be integrated with the Internet and allow updating with recent open edits to the code. The ability to update the codes is important for facilitating adaption to current conditions, for ensuring that the software is not a black box, and for enhancing the community's ability to debug code.

Most software can be run on a standard PC and has been optimized by the software developers to execute efficiently; however, it is useful to have the option to change bin sizes and the capacity to fully optimize the code for the user's particular computer. This could mean allowing for parallel computing, or limiting the backup systems in place. Learning and tutorials are extremely important, and contribute to the software's potential ease of use. A full run-through with a test data set showing all the features of the software is very useful, as is the ability to produce graphics and user-defined plots.

4. *Technology.* The code should be written to maximize accuracy with minimal computational effort. Hence, the software package review takes various hardware and software requirements into account. All the software packages can be run on a standard PC (2.5GHz with 4GB of RAM and a 500GB hard drive); however, computationally expensive algorithms and GIS-based systems may require more computing power. Ideally, users determine whether the software algorithms are reasonable for their computational purposes. The actual physical computation is generally not computationally demanding, but where memory is insufficient, the large volumes of data (exposure or hazard event sets) can cause problems. For deterministic use in post-disaster studies, all of the software packages can be run in a reasonable time (assuming the region is not extremely large and the data are available). Rapid response data can be problematic, however, if data sets are not publicly available for reuse. In contrast, computing power plays a much more central role in stochastic or probabilistic modelling—i.e., in the simulation of 10,000+ years of hazard events analyzed against exposure data sets of varying sizes.

GIS analysis software licensing can be prohibitively expensive for many users; ideally, therefore, open source models should be able to run without the need for a separate GIS license and platform, and ideally all programs should be freeware. It is also ideal for the GIS to be integrated within the software, and for the data output to be in OGC (Open Geospatial Consortium) standardized format, or for the software to be a plugin for GIS. QGIS (www.qgis.org) provides a very robust freely open source software package or plugin. This approach also allows technological updates to be directly applied to the software package as it evolves, rather than relying on the GIS package version (as is the case, for example, with Hazus-MH).

5. *Exposure*. A critical factor for any risk assessment is exposure data. Thus for the software packages, the critical factors are the tools for managing exposure data. These include the ability to handle and utilize common construction and occupancy information, and the ability to handle site-specific as well as aggregate data—particularly given that some packages were developed with a regional focus. To aid in the collection of exposure data, pictures and examples (such as the World Housing Encyclopedia) should be used to illustrate the various exposure classification criteria.

Depending upon the vulnerability functions, exposure information can be restricted to structural features, or it can be extended to nonstructural features such as building contents and to infrastructure such as lifelines and emergency response facilities. Most software packages classify the various exposure elements using construction and occupancy information associated with location information. It may also be possible to account for temporal changes in various elements. Needless to say, this information should be compatible with the vulnerability functions provided by the software package. Flexible, open source software allows advanced users to provide additional building and classification types, temporal variability in population and demographics, new risk indicators, and supplemental socioeconomic parameters once relevant checks have been made to the applicability of the vulnerability, hazard, and loss modules.

Awareness of any restrictions the software package might impose on the spatial resolution of the analysis is critical. Ideally, the exposure, vulnerability, hazard, and socioeconomic damage and loss calculations can be completed at multiple levels, including global, continental, national, regional, city, and district/suburban.

6. *Vulnerability*. One of the fundamental factors influencing a risk assessment is vulnerability of the exposed assets. The availability of data for input, calibration, and validation governs the quality of the vulnerability module, and ideally the software package should be able to handle all types of vulnerability functions. The software package should use empirical methods (historical trending of data) or analytical methods (mathematical or mechanical approach) to calculate vulnerability (the susceptibility to damage or loss). The vulnerability functions should be computationally simple to allow for rapid response as well as consistent with observations of historical damage. InaSAFE is an example of a software package that provides excellent documentation with very good explanations of the algorithms used, and that offers a transparent framework for the determination of damage from hazard.

The number of damage states included in an analysis often determines the level at which the analysis is useful. With too few damage states, the analysis cannot be used for detailed loss analysis. With numerous damage states, a function can be characterized as continuous. Open source software allows the addition, alteration, or improved resolution of damage distributions as data become available.

The software package's vulnerability functions must be consistent with the spatial resolution of the exposure. Some software packages have site-specific vulnerability functions that are developed for modelling buildings (in some cases only residential buildings). Other packages have only generalized vulnerability functions that are designed for aggregate data. Both site-specific and aggregate vulnerability functions might accept additional exposure types such as bridges, roads, lifelines (utility systems), and critical emergency service and response facilities.

Many software packages simulate only physical vulnerability, but functionality to include socioeconomic vulnerability is very useful. InaSAFE, for example, allows for the calculation of impact and needs, including gender and age disaggregation; RiskScape provides socioeconomic disruption modelling.

7. *Hazards*. Whether packages include single-peril capabilities or multi-peril capabilities (with multiple primary perils and/or secondary perils associated with the primary hazard), the quality of the hazard module is a fundamental consideration for evaluating software packages. This assessment considered four groups of hazards: inland flood, earthquake, coastal flooding from storm surge and tsunamis, and wind hazard from tropical and extra-tropical storms. Many of the criteria listed in appendix C are hazard dependent; however, there are many similarities among the hazards and some criteria are applicable to all. The hazard module is used to rank the perils on the basis of their representation of the primary hazard, the availability of secondary perils (liquefaction, landslide, tsunami, and fire for earthquake; landslide, soil erosion/land degradation, sedimentation, salinity, and fire for floods), spatial resolution, and the availability of historical events (the historical event catalogue is just as relevant for floods versus earthquakes as is the spatial resolution).
8. *Risk components*. Risk can be quantified in a variety of ways. Losses may be calculated via a damage-loss conversion that—because loss data are absent—is often the least researched part of the entire process. The economic losses generally account for direct loss; estimates of indirect loss are less common. Most software packages simply use the mean damage ratio (repair to replacement cost) and variability from a vulnerability function to derive an economic loss.

Particularly when using aggregate exposure and aggregate vulnerability functions, it is common to use the mean damage ratio or coarse data sets (such as gross national product or gross domestic product) as a basis for loss. In addition, using a model for land-use planning and/or cost-benefit analysis may be relevant (such as in Kalypso for flood decisions, or MAEviz for earthquake), but this capability is highly dependent on the resolution of the model.

9. *Post-event scenarios*. Speed and simplicity of use are critical assets for post-event scenarios, which require quick access to information. Thus the different software packages were rated on their ability to generate products that would complement post-event response, recovery, and reconstruction efforts. Among these products are maps, which after a disaster facilitate collaboration among the users of the software. GIS capabilities can also be important for post-event analysis; but even where this capability is not built to an optimal level, a GIS-compatible output can often provide post-event viewing speed. Many software packages for earthquake and for flood, as well as the four multi-risk packages, provide GIS output compatibility for quick viewing. The ability to analyze consecutive events such as earthquake aftershocks or combined flood peaks was also considered in this module.
10. *Forecasting*. Because some emergency preparedness measures are taken in response to forecasts, a module that accounts for several criteria related to forecasting was included. Forecasting depends on the speed of analysis in much the same way that post-event analysis does. In cases where a disaster resembles an historical or modelled event scenario, forecasting also depends on the ability to quickly apply a database of tested scenarios.

11. *Outputs*. Model results are the most important output of the risk analysis and were therefore one of the modules included in the assessment. Software should make it easy to view outputs in GIS (such as OGC standard formats) in terms of hazard, exposure, and vulnerability. A one-page summary is also important, since it allows the key losses and products of the software to be simply and quickly viewed. Loss statistics should be available in a way that enables analysis and comparison of statistics and that makes possible production of loss exceedance curves, event loss tables, and return period analysis. Ideally, the models should take into account all uncertainties

for probabilistic analysis. Both sensitivity analysis and the ability to view uncertainties in deterministic scenario runs are also important. The uncertainty parameters in the criteria should be weighted by users, given that they will ultimately know what the desired uses of the software outputs are. In addition, it should be possible to rerun the analysis through either a saved file or automatic repeat function. Finally, model outputs such as a benefit-cost metric (offered by OPENRISK, a package not reviewed directly in this study), are also valuable.

3.0 - Results

A one-page summary of each of the 31 software packages assessed in detail is presented here, ordered by peril.

Earthquake Loss Estimation

16	CAPRA Earthquake
17	EQRM
18	Hazus-MH Earthquake Module
19	InaSafe -Earthquake
20	MAEviz/mHARP
21	OpenQuake
22	RiskScape-Earthquake
23	SELENA

Wind/Hurricane/ Storm Estimation

24	CAPRA-Hurricane
25	Hazus-MH Hurricane Model
26	RiskScape-Storm/Wind
27	TCRM

Flood Loss Estimation

28	BASEMENT
29	CAPRA-Flood Model
30	Delft-3D-FLOW
31	Hazus-MH Flood Module
32	HEC-RAS/HEC-HMS/HEC-FDA/HEC-FIA HEC Suite
33	InaSAFE Flood
34	Kalypso
35	NoFDP IDSS
36	RiskScape-Flood
37	Sobek Suite 1D/2D with HIS-SSM
38	TELEMAC-MASCARET

Tsunami/Storm Surge /Wave Loss Estimation

39	CAPRA-Tsunami and Storm Surge
40	Delft-3D-WAVE [SWAN]
41	InsaSAFE-Tsunami
42	OsGEO Tsunami [R.Tsunami]
43	RiskScape-Tsunami
44	SLOSH
45	TOMAWAC Wave
46	TsuDAT using ANUGA

CAPRA EARTHQUAKE

Software Name	Peril	License	Current Version	Open Source	Operating Systems
CAPRA	Earthquake	Apache 2.0, CC3BY	V2.0.0	Yes	Windows, Mac, Linux

Preferred Specific Information

Coding Language	Software Modules	Manual	GUI	Help
Visual Basic .NET	CRISIS-2007 (Hazard), Vulnerabilidad [Vuln.], CAPRA-GIS, WWJ Mapviewer	N	Y	Y

Goal and Summary of the Software

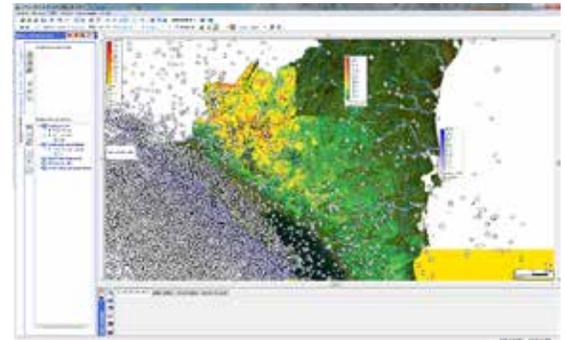
The software calculates deterministic and event set probabilistic risk for buildings using continuous fragility functions. CRISIS2007 is the hazard module that can create an event set using 3D source geometries of a particular annual frequency. Different ground motion (GM) parameters can be used, but spectral acceleration (Sa) is the most common. Once there is output, the vulnerability module [ERN-Vulnerabilidad] allows computation of fragility functions that are essentially user driven. Uncertainty is user driven with a simple variance. CAPRA-GIS is used for the quantification of the loss based on the input hazard set, for a particular exposure.

File Types Used

Hazard	Vulnerability	Exposure	Key Hazard Metrics
*.ame [main], *.txt, *.atn	*.fvu, *.dat/*.xml	*.shp	Spectral ordinates are used in terms of peak ground acceleration (PGA) and Sa. Calculations use ground motion prediction equations (GMPEs) and source-site distance, source geometry, and seismicity resulting from the CRISIS analysis.

Description of Software Risk Outputs

Human losses can be calculated directly from a vulnerability function. In addition, economic losses are output in a *.res format file. For the list of earthquakes, the exposure value as well as EP (expected loss), VarP (variance of the loss), and the beta distribution (a, b) are output. Annual average loss [AAL] over a set of buildings or one building, probable maximum loss (PML), and exceedance curves for loss are output. Losses are displayed per building in the CAPRA-GIS window, providing an easy view of loss. Liquefaction analysis can also be undertaken and a map produced (for landslide and tsunami also).



*CAPRA does not have a formal manual currently and instead uses support and tutorials.

Advantages and Disadvantages

- ✓ Hazard is not hardwired, and can be input from any other program as long as the file is in the right format.
- ✓ The log files are very good, and the individual file production means the rerun capabilities are very good.
- ✓ The process of going through the hazard, vulnerability, and exposure, and then building the functions, helps the basic user to understand the problem. Variability and uncertainty are handled well.
- ✓ Inbuilt GIS related directly to the loss calculations is very useful; GIS is modular and extendable.
- ✗ The fatality functions and economic functions lack a lot of diversity, with only a direct relationship available.
- ✗ The damage distribution is not calculated directly and only an MDR (mean damage ratio) is available.
- ✗ CRISIS2007 has a strange way of assigning fault regimes to faults: assignment can be done only through the GMPE, not directly.
- ✗ No formal manual is provided, and with its mix of Spanish and English, the entire GUI is quite difficult to maneuver.

Recommended Improvements for Greater Utility

The software would benefit from the input of fragility/casualty/economic functions from other projects. It could benefit from synergy with EQRM or MAEvis to add more functionality.

EQRM

Software Name	Peril	License	Current Version	Open Source	Operating Systems
EQRM	Earthquake	GPL	2.2svn1183	Yes	Windows, Mac, Linux

Preferred Specific Information

Coding Language	Software Modules	Manual	GUI	Help
Python, Matlab, C	EQRM Python	Y	N	Y

Goal and Summary of the Software

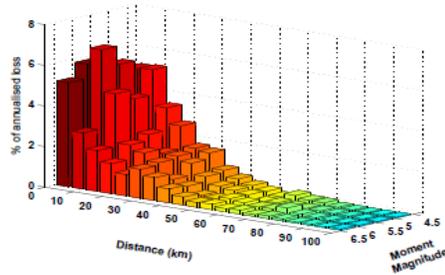
Earthquake Risk Model (EQRM) is a model for regional earthquake risk assessment that has been developed by Geoscience Australia (GA) for application to Australian cities. The model is utilized in the form of a Python or Matlab-based program founded on the Hazus model. It has been adapted to Australian conditions with the building/bridge types and other changes, especially the geological conditions within the hazard section. It also includes a regional seismicity model, attenuation model, regolith site response model, elements at risk [social demographics, building inventory], vulnerability of those elements at risk [building vulnerability model [capacity]], casualty model, injury model, and economic loss model.

File Types Used

Hazard	Vulnerability	Exposure	Key Hazard Metrics
*.xml, *.csv	*.csv	*.csv, *.par	Spectral ordinates are used in terms of a continuous S_a spectrum. Calculations use GMPEs and source-site distance, source geometry and seismicity, and return period. MMI (Modified Mercalli Intensity scale) is also possible.

Description of Software Risk Outputs

Structural, nonstructural, and contents damage based on lognormal fragility curves with standard deviation calculated in terms of spectral displacement (per the Hazus methodology) via performance point are used to create damage state probability. Total economic loss split into components (structural, contents, etc.) is calculated by usage, damage state, floor area, and cost per m^2 . Fatalities and injuries are also calculated. Both Australian values and those for Hazus are inbuilt. Outputs include aggregated annualized loss, annual loss, risk exceedance curves (PML), exceedance curves, and disaggregated losses by a number of options, such as distance, magnitude, construction type, and spatial unit in *.csv form. Various plots are available.



Screenshot of the disaggregated loss for Newcastle (Robinson, Fulford, and Dhu 2006).

Advantages and Disadvantages

- ✓ The software offers a large number of visualization options for hazard (uniform hazard spectra, hazard exceedance, and probabilistic seismic hazard analysis [PSHA]) and for risk (AAL, PML, disaggregation), including for a large number of building typologies.
- ✓ This software was the first to calculate event-based PSHA with this level of detail and analysis; it still leads for physical risk output options in terms of annualized losses and risks.
- ✓ It is completely open source and extendable, which allows for easy modification of parts of the code.
- ✗ Integration with GIS is lacking; this could be changed in future editions.
- ✗ There is no GUI, which makes it difficult for basic users. The software simply needs to be combined with MAEviz!

Recommended Improvements for Greater Utility

Socioeconomic indicators should be added, and there should be greater depth in GUI and GIS (as in MAEviz). EQRM would also combine well with CAPRA, given its event-based nature, despite the difference in vulnerability. EQRM needs a GUI for non-experienced users in order to become mainstream and could combine well with other software from GA (TCRM, TsuDAT) as well as flood software from Deltares, although rewriting would be necessary.

Hazus-MH Earthquake Module

Software Name	Peril	License	Current Version	Open Source	Operating Systems
Hazus-MH	Earthquake	Single User l	V2.1 (MR5)	No	Windows, Mac, Linux

Preferred Specific Information

Coding Language	Software Modules	Manual	GUI	Help
VB6, C++	Hazus-MH, ArcGIS Desktop, AEBM, CDMS, SQL Server	Y	Y	Y

Goal and Summary of the Software

The software calculates earthquake damage to infrastructure and populations over a census tract, county, or state in the United States. The hazard is based on an input of a set of earthquakes, or a scenario quake using NGA (next generation attenuation) relations. The vulnerability method is based on the capacity spectrum method—finding the performance point between demand and capacity. This allows for the calculation of losses to buildings, infrastructure, and lifelines, as well as social loss.

File Types Used

Hazard	Vulnerability	Exposure	Key Hazard Metrics
Inbuilt	Inbuilt	*.csv, *.xls, *.res, *.dbf	Spectral ordinates are used in terms of PGA and Sa [0.1, 0.3, 1.0, 3.0 sec]. Calculations use GMPEs as well as source-site distance and source geometry.

Description of Software Risk Outputs

Losses are based on buildings, essential facilities, transportation, and utilities. Damage states are calculated based on a lognormal pdf versus hazard metric. The output is in the form of an ArcGIS display of hazard and the relative losses to buildings and population. Shelter, deaths, injuries, and other social loss functions are calculated through calibration with historical losses and building damage. In addition, direct and indirect economic losses are taken into account with downtime and business interruption functions. These are calibrated for U.S. conditions. Many other earthquake loss estimation procedures have been based on this Hazus method.



Screenshot of Hazus Earthquake damage states.

Advantages and Disadvantages

- ✓ The software includes a detailed technical and user manual with full disclosure as to all data and assumptions related to fragility, hazard, and loss functions. Benefit-cost ratio (BCR) calculators and mitigation aspects are also part of the decision module.
- ✓ The software includes many groupings of buildings and loss estimates based on U.S. building typologies and expert judgment.
- ✓ GUI and system of analysis for earthquakes work well and even allow ShakeMap input.
- ✗ The package is heavily calibrated to U.S. conditions. Many loss functions have never been fully calibrated, given the lack of large loss events in the U.S. since 1994 (Northridge).
- ✗ Although free, the package cannot operate without commercial software (ArcGIS). A problem arose because .NET had not been installed, creating a conflict with the SQL server.

Recommended Improvements for Greater Utility

Hazus has already been adapted and has influenced EQRM, SELENA, MAEviz, etc. In terms of its functionality, it could become more global (adapting fragility functions to locations outside the United States) and open source (allowing changes in code, and changing GIS). As it develops, it should be monitored and its functions included in other software packages. The fire-following-earthquake, liquefaction, and input-output models can be applied to most other software packages.

InaSAFE-Earthquake

Software Name	Peril	License	Current Version	Open Source	Operating Systems
InaSAFE	Earthquake	GPLV3	V1.0.1	YES	Windows, Mac, Linux

Preferred Specific Information

Coding Language	Software Modules	Manual	GUI	Help
Python	InaSAFE, InaSAFE QGIS Plugin	Y	Y	Y

Goal and Summary of the Software

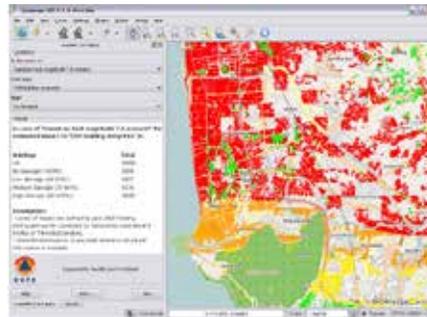
This software is a link between the science community and those in the planning and policy community seeking to understand an earthquake scenario. Created as a project of the Australia-Indonesia Facility for Disaster Reduction (AIFDR), World Bank, and GFDRR, it is a plugin that takes exposure inputs (population, buildings) and hazard inputs (MMI, intensity raster over the scenario area) from any model, then uses simple vulnerability functions to calculate an output through a simple-to-use GUI in a QGIS plugin form.

File Types Used

Hazard	Vulnerability	Exposure	Key Hazard Metrics
*.shp	n.a.	*.shpf	MMI is used via the input hazard file. Hazard is calculated outside the program and is then switched inside the program to create the impact functions.

Description of Software Risk Outputs

InaSAFE is currently in production; it currently outputs building loss (as a function of MMI) and damage state, and can also calculate economic losses based on floor area and contents/building value. It calculates fatalities using a PAGER function or an ITB (Bandung Institute of Technology) function. Displaced people are also calculated via population density. It has a great tool for measuring shelter needs, even calculating the amount of rice, drinking water, family kits, and toilets needed. The losses, shown in the form of a GIS file within QGIS, are easy to view. The sidebar also provides an easy-to-view loss summary.



Screenshot of the Padang 2009 earthquake (inasafe.org 2013).

Advantages and Disadvantages

- ✓ This is a wonderful tool that allows the “plug and play” addition of hazard and exposure layers into the system.
- ✓ It explains concepts clearly so that novice users are able to understand them.
- ✓ It is supported by a very good developer community and a very good manual system.
- ✓ It is easy to adjust functions and to read the code.
- ✗ It uses an ITB fatality function based on four earthquakes in which the MMI was only simulated and did not match the actual event (though the beauty of InaSAFE is that it can be changed and is extendable).
- ✗ It is still in the test phase, and still needs additional functionality.

Recommended Improvements for Greater Utility

This software would fit well both with ShakeMap utilities for rapid loss and with detailed scenario hazard estimates. It would benefit from the following: synergy with MAEviz to explore possible end modules to be coded; synergy with an additional hazard module (possibly MAEviz or EQRM); and some form of additional socioeconomic analysis with respect to indicators.

MAEviz/mHARP

Software Name	Peril	License	Current Version	Open Source	Operating Systems
MAEviz	Earthquake	Single User	V3.1.1 Build12	YES	Windows, Mac, Linux

Preferred Specific Information

Coding Language	Software Modules	Manual	GUI	Help
Java using Eclipse RCP	Many risk modules–NCSA GIS, MAEviz, EQvis+	Y	Y	Y

Goal and Summary of the Software

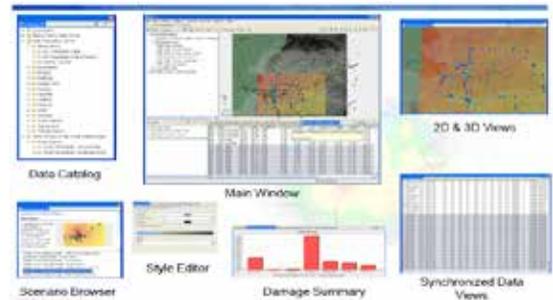
Another Hazus-based application, MAEviz (Mid-America Earthquakes Visualization) was developed to perform seismic risk assessment in the middle U.S. states. At first glance, it seems specialized; however, its huge potential can be seen in the flowchart of analysis procedures (48 and counting) and its complete Hazus system, including detailed algorithms. The visually driven system 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 users to add their own hazard data. It is easily extendable; the European Union [EU] project SYNER-G, for example, has added 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. Calculations use GMPES and source-site distance, source geometry, and seismicity.

Description of Software Risk Outputs

Damage estimates include options for multiple mitigation strategies, testing of scientific and engineering principles, and estimation of the earthquake hazard impact on lifelines and 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. Many modules (50+) have been produced for applications (like disruption analysis etc.). Simple reports and data views are given. The software creates all scenario outputs (disaggregated and not).



An overview of the MAEviz options [McLaren et al. 2008].

Advantages and Disadvantages

- ✓ The software is completely open source and features inbuilt GIS; it is well formatted with the GIS user interfaces.
- ✓ It 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.
- ✓ There is a developer community, and the function codes are easy to read and improve.
- ✓ Basic users find it easy to use; it offers a large array of infrastructure types for analysis.
- ✓ Combining detailed hazard, detailed vulnerability, and management and risk modelling, the software is easily extendable.
- ✗ It is currently tuned only for deterministic analysis.

Recommended 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 for probabilistic modelling would be useful. An InaSAFE-style command system could simplify the software even further for the most basic users, but it is currently fairly user-friendly.

OpenQuake

Software Name	Peril	License	Current Version	Open Source	Operating Systems
OpenQuake	Earthquake	Affero GPL (Apr 2013)	V0.4.6	YES	Windows, Mac, Linux

Preferred Specific Information

Coding Language	Software Modules	Manual	GUI	Help
Python	Separated Modules for Risk and Hazard	Y	N	Y

Goal and Summary of the Software

Currently in the production phase, the software is being designed to calculate earthquake risk transparently for any location on the globe at various levels (country, regional, local). The release date was moved from 2013 to 2014. In the demonstration of the software, hazard can be calculated using multiple PSHA methods (classical and event based) as well as deterministic scenarios analyzed via the NRML XML files [Natural Markup Language]. Vulnerability is then input in the form of fragility functions via xml to create a variety of risk outputs.

File Types Used

Hazard	Vulnerability	Exposure	Key Hazard Metrics
*.xml	.xml	*.xml	Software uses PGA, spectral acceleration at various periods via a wide range of source geometries with a large number of GMPEs. It uses various site effects methods, including Vs30. It will include many recurrence relation methods for probabilistic analysis, and will also include MMI.

Description of Software Risk Outputs

Risk outputs will include losses for nonstructural, structural, contents, and occupancy for residential buildings. The software creates loss curves, aggregated loss curves, loss maps (currently output in xml), fractional loss ratios, benefit-cost ratios, damage distribution and various aggregated loss ratios, and event loss tables for a particular taxonomy, or scenario losses and damage. Handling of fatalities and social losses is still being developed but will likely use PAGER-type loss functions associated with structural loss, or the empirical functions.



A view of the NRML .xml for vulnerability functions.

**v1 was originally due for release in April 2013; however, it was not available at the time of publication. The software should be retested once a full version is released.*

Advantages and Disadvantages

- ✓ Software includes a wide range of hazard and risk analysis tools, with a very good hazard section allowing for all types of sources, as well as fault and strain rate analysis.
- ✓ The source code and test case are promising for Messina 1908.
- ✓ It currently offers the most in-depth probabilistic analysis of any of the reviewed software packages for earthquake, accounting for classical PSHA as well as event-based PSHA.
- ✓ It provides a consensus from some earthquake experts globally through a stakeholder process for some parts of the software.
- ✗ It looks only at residential buildings.
- ✗ It is not known whether all data are freely available and open, or whether the all components of the software are open source.
- ✗ No GUI is currently available; the installation procedure through OATS had many difficulties, and the software will likely be difficult for non-engineers to use.

Recommended Improvements for Greater Utility

For the software to be useful externally, a stand-alone GUI with data is required. The installation procedure needs to be improved [note that software is still in the test, preproduction phase]. Before the software's release, it is hard to propose possible synergies, but given that the Python-coded EQRM joins well with the Global Earthquake Model (GEM), there is a natural synergy between OpenQuake and these two software packages. friendly.

RiskScape-Earthquake

Software Name	Peril	License	Current Version	Open Source	Operating Systems
RiskScape	Earthquake	Licensed [2-month]	V0.2.82	No	Windows, Mac, Linux

Preferred Specific Information						
Coding Language	Software Modules			Manual	GUI	Help
Java	RiskScape, Asset, Aggregation, Hazard, Fragility, Mitigation Builder			Y	Y	Y

Goal and Summary of the Software

The software creates deterministic and (in the future) probabilistic direct and indirect socioeconomic loss estimates for earthquakes for all types of assets, networks, and population, and includes all secondary hazards. It uses a wide array of builders, combining assets (input of buildings, infrastructure, etc.), aggregation (method to combine assets), hazard (defining the hazard model to be used), fragility (to create fragility curves), and mitigation (to perform analysis of changes in infrastructure quality).

File Types Used

Hazard	Vulnerability	Exposure	Key Hazard Metrics
*.rksh	*.rksh	*.rksa	Ground motion is measured in MMI or other metrics and is calculated using intensity prediction equations and source-site distance, source geometry (point, fault, or historical earthquake), and soil effects.

Description of Software Risk Outputs

An empirical method is used to create loss using MDRs for different infrastructure types from the intensity with a continuous function to 1.0. Casualties are calculated in much the same way from a mean collapse rate.

Damage states, monetary losses via replacement, contents, nonstructural costs, a number of socioeconomic interruption parameters, fatalities, injuries, homeless, and uninhabitable buildings are all calculated over the *.shp aggregation selected.

*.kml outputs are in Google Earth in 3D.

*.shp outputs can be viewed in any GIS program.

*.pdf summary shows the key aspects and maps desired from the starting panel.

*.xls gives an Excel readout of the various losses.

RiskScape was very easy to run, with all models tested inside a few minute. The user interface is great.



Screenshot of the latest RiskScape v. 0.2.82 front page.

Advantages and Disadvantages

- ✓ Graphical user interface and tool builders are very easy to understand and a pleasure to use.
- ✓ Output of the analysis can be done in many forms (pdf, xls, in software, kml, shp).
- ✓ Historical earthquakes and the various builders are very easy to use. This is one of the most user-friendly packages!
- ✗ There is not a transparent explanation of how the different functions are calculated.
- ✗ The software is not itself open source, and the code is unavailable.
- ✗ The software itself is quite simplistic in terms of the features to calculate—e.g., simple curves.

Recommended Improvements for Greater Utility

The integration of an EQR-style analysis would be useful. Essentially, the RiskScape model is dominated by the hazard layer, which is limited to MMI in New Zealand. The probabilistic model will provide an additional boost to the software. Other software packages should understand the benefits of working with RiskScape, given the large effort that has gone into making the software user-friendly. The software should be open source.

SELENA

Software Name	Peril	License	Current Version	Open Source	Operating Systems
SELENA	Earthquake	GPLv2	V6.0	Yes	Windows, Mac, Linux

Preferred Specific Information

Coding Language	Software Modules	Manual	GUI	Help
Octave, C	SELENA v6.0	Y	Y	Y

Goal and Summary of the Software

SELENA [Seismic Loss Estimation using a logic tree Approach] has been produced by NORSAR with support from the International Centre for Geohazards, Norway, and essentially uses the Hazus damage probability methodology in a stand-alone Octave format, which has been calibrated to Oslo conditions. SELENA uses a logic tree approach based on the weighting of the input parameters in order to consider epistemic uncertainty. Hazard analysis is probabilistic, real-time, or deterministic; the capacity spectrum method is used to find the performance point and damage.

File Types Used

Hazard	Vulnerability	Exposure	Key Hazard Metrics
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*.txt *.txt *.txt

Software uses PGA and Sa [0.3, 1.0s]. It also uses NEHRP/EC8 soil classes and spectral shapes from IBC, EC8, or IS1893. Real-time data can also be input. Many GMPEs are used. Sources are modelled as finite faults.

Description of Software Risk Outputs

The software produces text files of five damage states in terms of built area, number of buildings, and probability per building type. The cost of repair is simply calculated by repair/replacement per m², giving a total direct economic loss value on a geounit basis. Uninhabitable units and debris computation are also included on a geounit level.

Social losses are calculated in terms of deaths and injuries (three levels), based on occupancy ratio, the structural damage, and a user input casualty rate.

Occupancy patterns are taken into account using the Hazus methodology [night, day, to/from work], and the text files give the results for these three times.

Plotting can occur in RiSe [a Google Earth display facility as part of SELENA] as an aggregated or disaggregated file with 16 percent, 84 percent, and logic tree options.



RiSe output from SELENA and the GUI interface.

Advantages and Disadvantages

- ✓ The software has an easy-to-use GUI, and the Hazus methodology is easy to use once the text files are prepared.
- ✓ It allows all types of disaggregation and logic trees in order to calculate loss.
- ✓ It uses Octave, an easy programming language, and also has a nice viewer [RiSe].
- ✗ Outputs are quite difficult to manipulate compared to other software packages.
- ✗ The number of text files that need to be input makes it complicated to run without errors; headers need to be in the right spot, and the use of many geounits and building types and occupancy contributes to the difficulty.

Recommended Improvements for Greater Utility

The original text file system should be reformatted, and the GUI interface should be integrated with this system. Currently, there is no intensity measurement, though one would be a useful addition for low-moderate seismicity countries with a lack of ground motion records. The logic tree component lends itself to being adapted into other software packages.

CAPRA-Hurricane

Software Name	Peril	License	Current Version	Open Source	Operating Systems
CAPRA-Hurricane	Storm/Wind	Apache2.0, CC3BY	V1.0.0.0	Yes	Windows, Mac, Linux

Preferred Specific Information					
Coding Language	Software Modules	Manual	GUI	Help	
Visual Basic .NET	CAPRA-Hurricane, CAPRA-RainNH, CAPRA-Flood - CAPRAVuIn, CAPRA-GIS	N*	Y	Y	

Goal and Summary of the Software

The software calculates deterministic and event set probabilistic risk for buildings using continuous fragility functions. CAPRA-Hurricane is the hazard module that can create a set of events for hurricane paths. CAPRA NHRain and CAPRA-Flood are combined for creating water column depth. Once there is output, the vulnerability module [CAPRA-Vulnerabilidad] allows computation of fragility functions that are essentially user driven and based on flood height and wind speed. Uncertainty is user driven with a simple variance. CAPRA-GIS is used for the quantification of the loss.

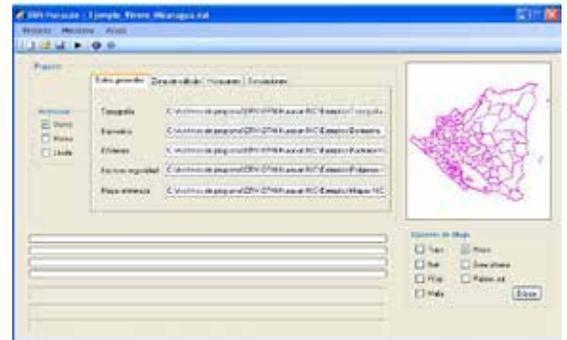
File Types Used			
Hazard	Vulnerability	Exposure	Key Hazard Metrics

.pcf,.atl (path) - *.ame	*.fvu, *.dat	*.shp, *.grn, *.dat (topo)	
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Metrics include maximum wind speed [3 second gust] influenced by topography and roughness; flood depth via spatial distribution of rainfall; and storm surge flood depth via bathymetry and hurricane path.

Description of Software Risk Outputs

Human losses can be calculated directly from a vulnerability function. In addition, economic losses are output in a *.res format file. From a hurricane event list, the exposure value as well as EP (expected loss), VarP (variance of the loss), and the beta distribution (a, b) are output. AAL over a set of buildings or one building, PML, and exceedance curves for loss are output. Losses are displayed per building in the CAPRA-GIS window, providing an easy view of loss. Landslides can also be calculated in relation to losses, as rainfall often causes problems.



Screenshot of the Nicaragua hurricane example.

Advantages and Disadvantages

- ✓ Hazard is not hardwired, and could be input from any other program as long as the file is in the right format.
- ✓ The log files are very good, and the individual file production means the rerun capabilities are very good.
- ✓ The CAPRA-Hurricane package works well, CAPRA-Vuln and CAPRA-GIS combine well to allow users to understand the loss.
- ✓ Inbuilt GIS related directly to the loss calculations is very useful. GIS is modular and extendable.
- ✗ The fatality functions and economic functions lack diversity, with only a direct relationship available, the damage distribution is not calculated directly, and only an MDR is available.
- ✗ No formal manual is provided, and with its mix of Spanish and English, the entire GUI is quite difficult to maneuver – with novice users, it will be difficult due to lack of help options.

Recommended Improvements for Greater Utility

The wind speed measurement should be calculated using pressure and other parameters available. Software could learn from TCRM about the hazard module. Some Hazus functions should be applied, and hazard file converters should be more functional. The methodology would work well in a MAEvis environment.

Hazus-MH Hurricane Model

Software Name	Peril	License	Current Version	Open Source	Operating Systems
Hazus-MH	Hurricane	Single User ©	V2.1 (MR5)	No	Windows, Mac, Linux

Preferred Specific Information

Coding Language	Software Modules	Manual	GUI	Help
VB6, C++	Hazus-MH, ArcGIS	Y	Y	Y

Goal and Summary of the Software

The software calculates hurricane damage to infrastructure and populations over a U.S. census tract, county, or state. The exposure module has around 5,000 unique building types, based on roof types, etc. There are many functions for each building type. The hazard module is based on user-defined or historical hurricanes, which can be converted for probabilistic analyses or analyzed individually. The vulnerability method is based on the peak gust speed versus a damage probability using empirical curves. This approach allows for the calculation of losses to buildings and essential facilities (other types not supported as yet).

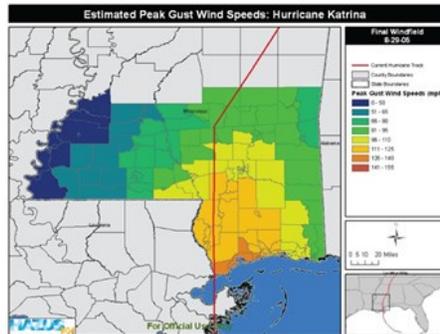
File Types Used

Hazard	Vulnerability	Exposure	Key Hazard Metrics
Inbuilt	Inbuilt	*.csv, *.xls, *.res, *.dbf, *.grd	Pressure and hurricane category versus return period is calculated for landfall versus non-landfall. Peak gust wind speed is generally the hazard parameter influenced by roughness, land cover. Rainfall is also used.

Description of Software Risk Outputs

Losses are based on buildings and essential facilities (loss of use and damage state). Software calculates the damage states based on a lognormal pdf versus the hazard metric. Debris is calculated along with tree blowdown.

The output is in the form of an ArcGIS display of hazard and the relative losses to buildings and population. Tables and reports are also created. Shelter, temporary housing, and displaced households are calculated through calibration with historical losses and building damage. In addition, direct (structural, nonstructural, contents, inventory) and indirect economic losses are taken into account with downtime and business interruption functions. These are calibrated for U.S. conditions.



Screenshot of Hazus Hurricane in action.

Advantages and Disadvantages

- ✓ There is a detailed technical and user manual with full disclosure concerning data and assumptions for fragility, hazard, and loss functions. BCR calculators and mitigation aspects are also part of the decision module.
- ✓ The package worked well combined with earthquake and flood.
- ✓ It includes many groupings of buildings and loss estimates that are based on U.S. building typologies and expert judgment.
- ✓ The GUI and system of analysis for hurricanes works well, allowing inclusion of new storm tracks.
- ✗ The software is heavily calibrated to U.S. conditions and difficult to apply to other locations.
- ✗ Although free, the package cannot operate without commercial software (ArcGIS).
- ✗ No fatality modelling is currently undertaken.

Recommended Improvements for Greater Utility

Hazus is not currently open source, and there are no hurricane loss analyses apart from the CAPRA and RiskScape software packages. The addition of transportation and power outages would be useful. Hazus could be integrated into the MAEvis methodology.

RiskScape-Storm/Wind

Software Name	Peril	License	Current Version	Open Source	Operating Systems
RiskScape	Wind	Licensed [2-month]	V0.2.82	No	Windows, Mac, Linux

Preferred Specific Information

Coding Language	Software Modules	Manual	GUI	Help
Java	RiskScape, Asset, Aggregation, Hazard, Mitigation Builder	Y	Y	Y

Goal and Summary of the Software

The software creates deterministic and (in the future) probabilistic direct and indirect socioeconomic loss estimates for wind gusts for all types of assets, networks, and population, and includes all secondary hazards. It uses a wide array of builders, combining assets (input of buildings, infrastructure, etc.), aggregation (method to combine assets), hazard (defining the hazard model to be used), fragility (to create fragility curves), and mitigation (to perform analysis of changes in infrastructure quality). For wind, a few test cases have been undertaken using the BLASIUS, RAMS, and GERRIS modelling of wind fields for locations in New Zealand.

File Types Used

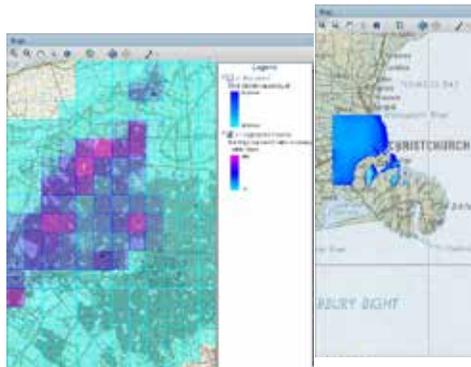
Hazard	Vulnerability	Exposure	Key Hazard Metrics
*.rksh	*.rksf	*.rksa	Terrain and roughness are influencing factors. Gust wind velocity, however, is the only modelled parameter (in m/s) solved via flow equations [i.e., Navier-Stokes]

Description of Software Risk Outputs

An empirical method is used to create loss using MDRs for different infrastructure types from the intensity with a continuous function to 1.0. Casualties are calculated in much the same way from a mean collapse rate.

Damage states, monetary losses via replacement, contents, nonstructural costs, a number of socioeconomic interruption parameters, fatalities, injuries, homeless, and uninhabitable buildings are all calculated over the *.shp aggregation selected. Currently not all functions are available for wind.

- *.kml outputs are in Google Earth in 3D.
- *.shp outputs can be viewed in any GIS program.
- *.pdf summary shows the key aspects and maps desired from the starting panel.
- *.xls gives an Excel readout of the various losses.



Screenshot of Hazus Hurricane in action.

Advantages and Disadvantages

- ✓ The GUI and tool builders are very easy to understand.
- ✓ Output of the analysis can be done in many forms (pdf, xls, in software, kml, shp).
- ✓ The various builders are very easy to use.
- ✗ There is not a transparent explanation of how wind speed is calculated (individual model equations are available for the three methods so far used in manuals, but not for the application in RiskScape).
- ✗ The software is not open source as such, and the code is unavailable online.
- ✗ The software itself is quite simplistic in terms of the features to calculate—e.g., simple curves.

Recommended Improvements for Greater Utility

The integration of a TCRM-style analysis would be useful. Essentially, the model is dominated by the hazard layer, and the vulnerability functions are not transparent. Much more study related to wind storm modelling is needed. Currently, RiskScape cannot really be integrated with other software packages.

TCRM

Software Name	Peril	License	Current Version	Open Source	Operating Systems
TCRM	Tropical Cyclone	GPLv3, CC3.0BY	V1.0.2	Yes	Windows, Mac, Linux

Preferred Specific Information

Coding Language	Software Modules	Manual	GUI	Help
Python and C	TCRM	Y	Y	Y

Goal and Summary of the Software

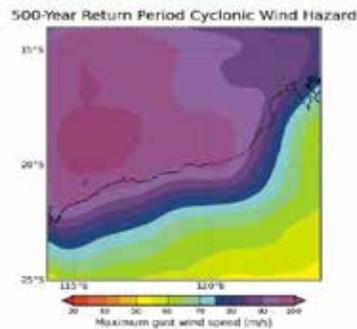
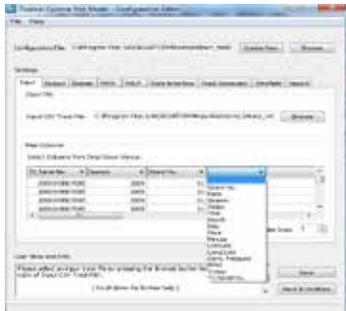
TCRM (Tropical Cyclone Risk Model) is a stochastic event simulator for tropical cyclone hazard. It uses wind field modelling distributions, which can be mathematically and statistically derived from a variety of methods, to simulate a user-input number of years of activity and create either a probabilistic view of wind speeds or just a single scenario. Having so many distributions available allows the user to see the sensitivities associated with stochastic modelling. Although created in Australia, this software could potentially be used anywhere. Lists of historical events can be input from the IBTrACS data set using tropical cyclone serial numbers and locations, and then defining radius of maximum wind, mean sea level pressure, and distribution to fit the wind field profile and boundary layer method. Different return periods are then input for the wind hazard calculation

File Types Used

Hazard	Vulnerability	Exposure	Key Hazard Metrics
*.nc, *.txt, *.csv	None	None	Cyclonic wind speed (maximum gust in m/s) is created for each return period at each grid point, including confidence intervals. Wind field, pressure, location, beta parameter, and bearing are used in terms of pdf.

Description of Software Risk Outputs

The hazard outputs are in the form of tracks, which can then be used in risk analysis



Example of Port Headland–Tutorial (TCRM 2011).

Advantages and Disadvantages

- ✓ The software package is easy to use—and widely used—for creating tropical cyclone tracks with many different wind field profiles and distributions.
- ✓ The data set supplied has all the data needed to run the model and is provided freely.
- ✓ The GUI is fantastic—the format is easy to use and help files are included.
- ✗ The advconfigeditor.exe should be renamed in order to prevent confusion.
- ✗ As with EQRM, installing MinGW, SciPy, and NumPy can be problematic depending on the version of Windows being used. There are fewer problems with Linux.

Recommended Improvements for Greater Utility

This software would work well with nearly every model, given the diversity and ease of coding. It currently addresses only hazard, so it cannot be compared with risk models.

BASEMENT

Software Name	Peril	License	Current Version	Open Source	Operating Systems
BASEMENT	Flood	Single user	V2.1.1	No	Windows, Mac, Linux

Preferred Specific Information

Coding Language	Software Modules	Manual	GUI	Help
Visual Basic .NET	BASEMENT, BASEchain, BASEplane, BASEMesh	Y	Y	Y

Goal and Summary of the Software

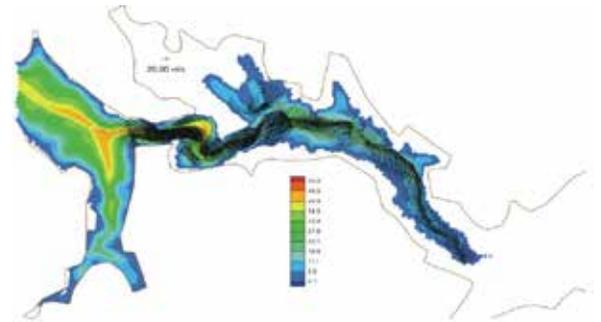
Basement is a numerical simulation software for computation of environmental flow and natural hazard events. It was programmed by ETH Zurich to determine the impact of river corrections. The whole program is developed for hydraulic purposes to analyze river flow and flood potentials. It offers many modelling possibilities including sediment transport, erosion and both steady and unsteady modes. It also includes many algorithms and calculation methods [optimisation techniques]. Basechain is a 1D numerical tool for river reach simulation. BASEplane is a 2D numerical tool for river reach simulation. Both of them are primarily hazard based.

File Types Used

Hazard	Vulnerability	Exposure	Key Hazard Metrics
*.bmc, ascii, *.txt	n.a.	*.shp	Flow depth and flow velocity can be calculated, as well as 1D and 2D options related to steady and unsteady flow limited by friction, sediment transport, and topography.

Description of Software Risk Outputs

There are essentially no risk outputs, as there are no modules for vulnerability or exposure analysis included. The hazard model is the output of the software and produces a detailed inundation map. 1D Saint-Venant, 2D shallow water, and 3D Navier-Stokes equations are solved in all domains, as well as the output of depth and velocity. The software also explores geography of channels. Some nice visualizations are possible through the BASEviz module.



Dam break scenario in BASEMENT.

Advantages and Disadvantages

- ✓ The manual explains the process well and also explains the parallel performance available in the code.
- ✓ There are good topographic input and grid components, as well as a large range of numerical models.
- ✓ The hazard model is sound and provides nice solutions to channel transport and flow.
- ✗ The software needs a lot of time to run (slow calculation speed).
- ✗ It is not easy to use and takes longer to learn than other flood software.
- ✗ There is no vulnerability or risk module.

Recommended Improvements for Greater Utility

This software would benefit from an associated risk module. It is not currently open source, meaning that changing many of the functions is not possible. The software itself provides a good format, being coded with links to Python; thus it could be used in some existing pursuits such as InaSAFE.

CAPRA-Flood Model

Software Name	Peril	License	Current Version	Open Source	Operating Systems
CAPRA-Flood	Flood	Apache2.0, CC3BY	V2.1	Yes	Windows, Mac, Linux

Preferred Specific Information

Coding Language	Software Modules	Manual	GUI	Help
Visual Basic .NET	CAPRA-Flood, HEC-RAS v2.1 linked., CAPRA-Vuln., CAPRA-GIS	N*	Y	Y

Goal and Summary of the Software

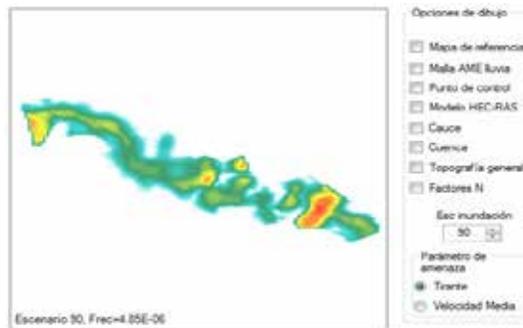
CAPRA-Flood is a simple tool for determining flood hazard. It uses rainfall data produced by the module, CAPRA-Lluvia, and hydraulic calculations, which are performed by a link to HEC-RAS. It takes multiple factors into account, such as mean velocity, depth, and rainfall, and also includes uncertainties. Its use of the HEC-RAS calculation engine makes it a fast and rather simple tool for evaluating risk and return periods based on precipitation data. For basin analysis, it calculates rainfall data based on geographical data (provided by simple shp files) and PADF (precipitation, area, duration and frequency) curves, which should be provided as txt files. A short manual is also included, which explains the theoretical background and the functionality of the program. Once there is output, the vulnerability module (CAPRA-Vulnerabilidad) allows computation of modifiable inundation depth fragility functions. CAPRA-GIS is used for the quantification of the loss based on the input hazard set for a particular exposure. The software is in both Spanish and English.

File Types Used

Hazard	Vulnerability	Exposure	Key Hazard Metrics
*.ame(main), *.txt, *.grn	*.fvu, *.dat	*.shp	Rainfall intensity [mm/24h], storms/simulations, and PADF (precipitation, area, duration, frequency) curves are produced for rainfall. For floods, rainfall runoff is calculated to give a flood depth. Unit velocity can also be calculated, and various hydrograph methods can be used.

Description of Software Risk Outputs

Human losses can be calculated directly from a vulnerability function. In addition, economic losses are output in a *.res format file. For flood events, the exposure value, as well as EP (expected loss), VarP (variance of the loss) and the beta distribution (a, b), are outputs from the input list. AAL over a set of buildings or one building, PML, and exceedance curves for loss are output. Losses are displayed per building in the CAPRA-GIS window, providing an easy view of loss.



Screenshot of an inundation scenario in CAPRA-Flood,

Advantages and Disadvantages

- ✓ The log files are very good, and the individual file production means the rerun capabilities are very good.
- ✓ The process of going through the hazard, vulnerability, and exposure, and then building the functions, helps the basic user to understand the problem. Variability and uncertainty are handled well.
- ✓ Inbuilt GIS related directly to the loss calculations is very useful; GIS is modular and extendable.
- ✗ The fatality functions and economic functions lack diversity, with only a direct relationship available.
- ✗ The damage distribution is not calculated directly and is based only on inundation depth, not flow.
- ✗ No formal manual is provided, and with its mix of Spanish and English, the entire GUI is quite difficult to maneuver.

Recommended Improvements for Greater Utility

Capra-Flood could be combined with Kalypso or Deltares for flood hazard; specifically, some end functions from these software could be added to CAPRA-Flood.

Delft-3D-FLOW

Software Name	Peril	License	Current Version	Open Source	Operating Systems
Delft-3D-FLOW	Flood	GPLv3	V4.01.00rc3	Yes	Windows

Preferred Specific Information

Coding Language	Software Modules	Manual	GUI	Help
C++, DeltaShell	Delft-3D-FLOW	Y	Y	Y

Goal and Summary of the Software

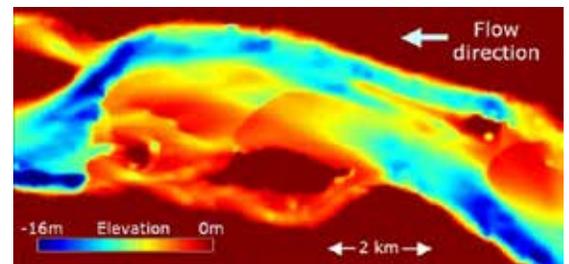
Delft-3D-Flow calculates solutions for unsteady flow using meteorological and tidal forcing upon a curvilinear (or rectangular) grid. The software can therefore model all tidal flow regimes, tsunamis, and river flow simulations. The software is compatible with all other modules in Delft3D. It allows for 3D flow modeling within and around engineering structures, making it a useful tool for locations or projects that may consider flood control structures.

File Types Used

Hazard	Vulnerability	Exposure	Key Hazard Metrics
Ascii - .mdf	n.a.	Too many (river details)	On a curvilinear or rectangular grid, the flow, direction, etc. can be modelled on a number of points. Cross sections as well as atmospheric, tidal, harmonic, wind, and temperature conditions are also looked at, including all stresses and conservation.

Description of Software Risk Outputs

The inundation depth, flow, and other hydrodynamic characteristics, as well as turbulence quantities, are output to a file after processing. All forms of 2D/3D equations are solved from Navier-Stokes incompressible free surface flow. Boundary conditions and other details such as wind, control structures, and cross sections are also output to files. This approach makes rerun very easy. Coupled with HIS-SSM, there are certain opportunities and possibilities to change the calculated hazard values into risk values. These changes have not been implemented in open source as yet. The software could potentially use the flood layers calculated as part of a 3D-FLOW scenario.



Just one application of Flow (geography.exeter.ac.uk 2013).

*HIS-SSM is currently not combined in the software, but can be requested free of charge.

Advantages and Disadvantages

- ✓ The software is well suited to modelling 3D flow; it takes all boundary phenomena and details into account.
- ✓ It offers many application possibilities (rivers, storm, tide, tsunami) and is coupled with all other Deltares software.
- ✓ Large-scale analysis is possible (limited only by computing power).
- ✓ The user can choose from many inbuilt functions for each part of the calculation—e.g., fitting coefficients.
- ✗ For risk assessment, the computation is quite difficult to use, with many inputs needed (3D modelling).
- ✗ To review results, the software needs external tools such as Delft3D-WAVE.

Recommended Improvements for Greater Utility

This software package is state-of-the-art. Further development of risk products on the end of the software is potentially a collaboration point. Combining with MAEviz, TCRM, or CAPRA would also be a natural progression to improve the software's risk output capability.

Hazus-MH Flood Module

Software Name	Peril	License	Current Version	Open Source	Operating Systems
Hazus-MH Flood Module	Flood	Single User ©	V2.1 (MRS)	No	Windows

Preferred Specific Information

Coding Language	Software Modules	Manual	GUI	Help
VB6, C++	Hazus-MH, ArcGIS	Y	Y	Y

Goal and Summary of the Software

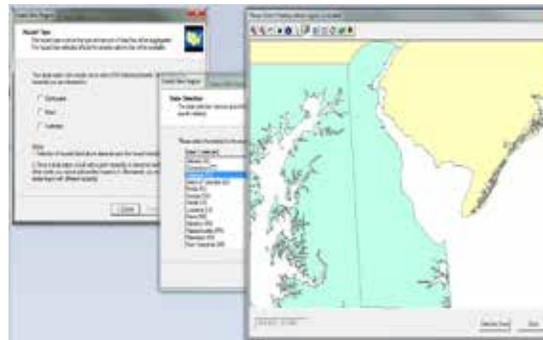
The software calculates flood damage to infrastructure and populations over a U.S. census tract, county, or state. The hazard is based on an input of a set of floods, or a scenario flood using depth-discharge frequency. A combination of hydraulic and hydrologic modelling is added to a digital elevation model (DEM). Hydrologic modelling is done via stream gauge data and a regression equation for discharge frequency for each reach. Hydraulic modelling is done in 2D, using cross sections, Manning's n, and all flow regimes. The estimates are confined to within the floodplain. The relationship to inundation depth is generally used within the flood vulnerability module.

File Types Used

Hazard	Vulnerability	Exposure	Key Hazard Metrics
Inbuilt or .flt	Inbuilt	*.csv, *.xls, *.res, *.dbf, *.grd	Inundation depth is used in the analysis. A combination of hydraulics and hydrology is used in combination with DEM and roughness data, as well as various regressions upon return periods.

Description of Software Risk Outputs

Losses are based on buildings, essential facilities, transportation, and utilities. The software calculates the damage based on occupancy and count. A lognormal pdf versus inundation depth is used. The output is in the form of an ArcGIS display of hazard and the relative losses to infrastructure and population. Social losses are calculated via a simple function, whereas shelter needs are analyzed in depth. In addition, direct [cost of repair, income loss, and agricultural damage] and indirect economic losses are taken into account with downtime and business interruption functions. These are calibrated for U.S. conditions.



The Hazus front screens

Advantages and Disadvantages

- ✓ The software includes a detailed technical and user manual with full disclosure as to all data and assumptions used with respect to fragility, hazard, and loss functions. BCR calculators and mitigation aspects are also part of the decision module.
- ✓ The software includes many groupings of buildings and loss estimates based on U.S. building typologies and expert judgment.
- ✓ The GUI and system of analysis for floods are good. The analysis is very sound, using 1D/2D and hydraulic and hydrological modelling.
- ✗ The software is heavily calibrated to U.S. conditions; the depth-damage functions are from the U.S. Army Corps of Engineers and are applicable to U.S. building types.
- ✗ Although free, the package cannot operate without commercial software (ArcGIS).

Recommended Improvements for Greater Utility

Hazus is not itself open source, but it can be considered a learning tool for other open source software packages. It provides a useful estimate of flood risk for anywhere in the United States. It allows for transference (or testing of the transference) of flood loss curves which could be used for other software packages like CAPRA or in other locations [as long as the US damage functions and assumptions hold].

HEC-RAS/HEC-HMS/HEC-FDA/HEC-FIA-HEC Suite

Software Name	Peril	License	Current Version	Open Source	Operating Systems
HEC	Flood	User License	V4.10	No	Windows

Preferred Specific Information

Coding Language	Software Modules	Manual	GUI	Help
HEC-2 - Fortran	HEC-RAS, HEC-HMS, RASMapper, HEC-1 links, etc., HEC-FIA	Y	Y	Y

Goal and Summary of the Software

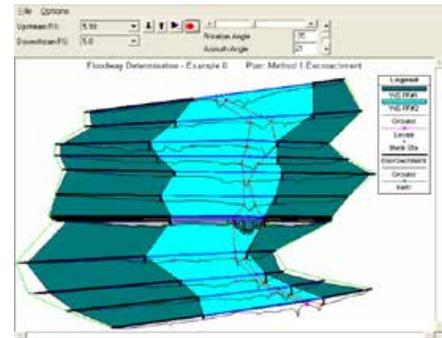
The HEC Suite allows the modelling of flood risk in its entirety—from hazard through to loss and then decision support in an easy-to-use Windows environment. It was designed by the U.S. Army Corps of Engineers for U.S. flood modelling. HEC-RAS undertakes 1D flow measurements to model hydraulic flow of rivers. It is probably the best known flood hazard software in the world. It can also model flood structures and sediment transport. HEC-HMS is the rainfall-runoff model; it includes urban and rural overland modelling, watershed runoff, and other water supply processes. These are combined with other tools for flood frequency statistics calculation (HEC-SSP) and geospatial modelling [HEC-GeoRas]. The risk components are then modelled in HEC-FDA and HEC-FIA.

File Types Used

Hazard	Vulnerability	Exposure	Key Hazard Metrics
*g01, *dss	HEC-FDA formats	*.shp, *.tif, *.cad *MrSID	Inundation depth and flow are modelled within the HEC Suite, including the temporal aspects through hydrographs.

Description of Software Risk Outputs

HEC-FIA uses hydraulic inputs in the form of depth grids and duration grids or hydrograph data to calculate risks for single events using an entire hydrograph. Economic losses are then calculated using location data input from Hazus, parcel data, or existing point data. Life loss calculations can be undertaken in a module called LifeSim, which is the most advanced fatality system among software packages that use indicator systems to model potential fatalities. Agricultural losses can be calculated using crop and harvest details. HEC-FDA is a probabilistic or deterministic methodology using the peak of the hydrographs. It looks at contents loss analysis, too. Annualized loss, annual damage, annual exceedance probabilities, and other conditional data are calculated, and uncertainty analysis is carried out as well. Risk analysis and visualization are also created.



Floodway determination: Perspective plot in HEC-RAS.

Advantages and Disadvantages

- ✓ HEC Suite provides an impressive array of software, given the full flood risk approach. There are around 15 tools that make up the suite, all of them freeware, and they have been developed over many years.
- ✓ Life loss and economic losses are calculated easily from the outputs of FDA and FIA.
- ✓ Tutorials with freely available data are offered, and there are very good manuals and data sets.
- ✓ The GUIs are very easy to use, and for first-time users make a lot of sense.
- ✗ The major drawback is the absence of source code, meaning that the software is not open source

Recommended Improvements for Greater Utility

If the source code could be obtained, then this software would be the best for flood. HEC-RAS will also change to 2D modelling soon. For now, the best that can be done is to look at and learn from the methodology, and then apply it to a software such as Kalypso or Deltares Sobek.

InaSAFE-Flood

Software Name	Peril	License	Current Version	Open Source	Operating Systems
InaSAFE	Flood	GPLv3	V1.0.1	Yes	Windows, Linux

Preferred Specific Information

Coding Language	Software Modules	Manual	GUI	Help
Python	InaSAFE, InaSAFE QGIS Plugin	Y	Y	Y

Goal and Summary of the Software

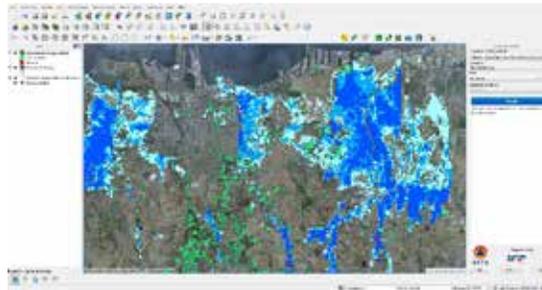
This software links the science community to those in the planning and policy community seeking to understand a flood impact scenario. Created as a project of the AIFDR, World Bank, and GFDRR, it is a plugin that takes exposure inputs (population, buildings from OpenStreetMap, or other shapefiles) and hazard inputs (inundation depth raster over the scenario area, from any open software), and then uses simple vulnerability functions to calculate an output through a simple-to-use GUI in a QGIS plugin form.

File Types Used

Hazard	Vulnerability	Exposure	Key Hazard Metrics
*.shp	n.a.	*.shp	Inundation depth is used via the input hazard file. Hazard is calculated outside the program.

Description of Software Risk Outputs

InaSAFE is currently in production; however, it currently outputs building loss (as a function of inundation depth) in terms of a 1 or 0 function. This could be adapted by the user. Displaced people are also calculated using population density and the buildings impacted by the flood raster. The software looks not only at the number of displaced, but also at the resources needed to support them. InaSAFE has a great tool for measuring various shelter needs, even calculating the amount of rice, drinking water, family kits, and toilets needed. The losses are shown in the form of a GIS file within QGIS that is easy to view.



Screenshot of a Jakarta flood example.

Advantages and Disadvantages

- ✓ This is a wonderful tool that allows the “plug and play” addition of hazard and exposure layers to the system.
- ✓ It explains concepts clearly so that novice users are able to understand them.
- ✓ The developer community makes it possible for researchers to adapt functions and easily contribute.
- ✓ OpenStreetMap and QGIS connectivity are very easy to use.
- ✗ The software is still in the test phase, and needs additional functionality.
- ✗ There is no numerical model for flood or water depth inside the software, though this is not necessarily a negative.

Recommended Improvements for Greater Utility

This software would fit well with many decision support modules of Kalypso and SOBEK for rapid loss, as well as any detailed scenario hazard estimates. It would benefit from some synergy with MAEvis to explore possible end modules to be coded. The software would also benefit from synergy with an additional hazard module, possibly a simple form such as NoFDP IDSS. Some form of additional socioeconomic analysis with respect to indicators would also improve it.

Kalypso

Software Name	Peril	License	Current Version	Open Source	Operating Systems
Kalypso	Flood	LGPLv2 (very good)	V12.11.1	Yes	Windows

Preferred Specific Information

Coding Language	Software Modules	Manual	GUI	Help
Java	Kalypso Hydrology 1D/2D, WSPM, Risk, Flood, BASE, Evacuation	Y	Y	Y

Goal and Summary of the Software

Kalypso is a multi-module program for calculations about hydrology (rainfall-runoff), water-level analysis, 1D/2D analysis, flood calculation, and risk determination. All these modules are linked together. The main focus is on deterministic hydrological calculations of river basins and floods. The user can start with hydrological analysis, which takes into account elements such as precipitation, rainfall, etc., and then continue to the risk calculation. It was originally built for German river locations. The risk calculation uses land-use data based on user input. The resolution of the calculations is quite nice, while the complexity of the modules decreases moving from the hazard to risk, meaning that the hydrological part is quite complex, while the modules for flood and risk are rather simple.

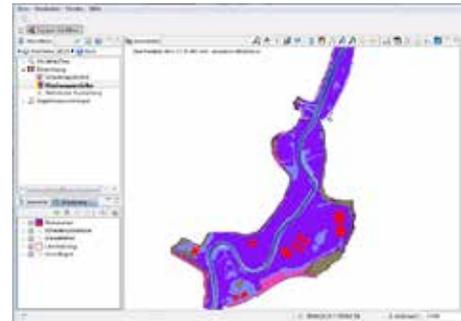
File Types Used

Hazard	Vulnerability	Exposure	Key Hazard Metrics
*.1d, *.2d	.xml / functions	*.shp, *.asc	Metrics include flow, inundation depth, and volume of water. 1D/2D rainfall modelling can take snow into account. Roughness is taken into account via land use.

Description of Software Risk Outputs

The risk outputs include entire hazard inundation maps for various return periods (between 2 and 100 years). Land use and other parameters can be input in order to give the risk. In Kalypso Risk, the parameters are combined as a damage function in an open format, using a function versus inundation depth or duration/frequency. This can have the form "x-" or a straight value, and it is then multiplied by the economic value to give loss.

This design allows the software to be easily manipulated, and fatalities could technically be calculated by manipulating the software. Kalypso Evacuation models an entire flooding scenario evacuation, including bus route changes and many other features.



Results for risk zones and damage potential.

Advantages and Disadvantages

- ✓ Multiple modules are included within the analysis, which allows for all-in-one loss analysis, and the system can easily be updated.
- ✓ The wiki-style system and manual for each component make the software easy to use. The results also have multiple export options.
- ✓ The GUI and GIS (through QGIS) are state-of-the-art and are easy to use, well-developed, and up-to-date.
- ✓ There are multiple options for optimization in terms of short-time and long-time modelling.
- ✗ As with most flood analyses, the risk and flood modules are too simple. The vulnerability analysis is essentially constructed with the hazard parameter overlaid on exposure.
- ✗ The software focuses mostly on German conditions, and the manuals are mostly in German.

Recommended Improvements for Greater Utility

This software should be combined with MAEvis, given the modular structure. It would benefit from the many modules on the end of it, as well as common language types in the structure. The shelter and evacuation modules are well suited for combining. The addition of fragility functions would help Kalypso. InaSAFE could learn from the simplicity of Kalypso's modules.

NoFDP IDSS

Software Name	Peril	License	Current Version	Open Source	Operating Systems
NoFDP IDSS	Flood	GPLv3, LGPL (source)	V1.0	Yes	Windows

Preferred Specific Information

Coding Language	Software Modules	Manual	GUI	Help
Java	NoFDP IDSS	Y	Y	Y

Goal and Summary of the Software

Produced as part of the INTERREG III project, NoFDP IDSS is an easy-to-use 1D program for developing, optimizing, and analyzing solutions for risk reduction. It contains the Deltares hydrological calculation tool SOBEK. IDSS is completely open source, as is SOBEK, so the two can now be combined. IDSS covers multiple modules for the import of geo-data and includes a simple GIS engine to edit the data. It also contains a link to ISAR, a calculation concept based on vegetation factors and renaturation. It is the precursor to Kalypso and has many links back to SOBEK.

File Types Used

Hazard	Vulnerability	Exposure	Key Hazard Metrics
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ASCII, *.csv	n.a.	*.shp, *.asc, *ZML/XML, tif	1D hydrodynamic modelling is undertaken using the modelling of SOBEK. The flow, inundation depth, duration, and frequency are modelled using input roughness, land use/land cover data, etc.
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Description of Software Risk Outputs

The program calculates the flooded areas due to different flood scenarios (return periods of 50 years, 100 years, etc.) and uses land-use information by CORINE to calculate economic damage (much as the Kalypso Risk module does). Multiple building and single building analysis are not covered within the calculation, but this information can be obtained by more detailed land-use data. A variety of flood structures can also be modelled.

The focus is on determining and calculating risk reduction variants and comparing them to each other by economic social parameter. This decision-support aspect is the most interesting part of NoFDP IDSS. The program also contains a number of collaboration tools, such as automatic report generator (based on Open Office), a screenshot database, and a link to Google Earth.



NoFDP IDSS scenario screen.

Advantages and Disadvantages

- ✓ The decision module is very easy to use for basic users, and allows for multivariate analysis.
- ✓ There is a risk reduction focus as well as collaboration tools.
- ✓ The open source outputs are useful, and the Google Earth screens are easy to understand and use.
- ✗ 1D analysis undertaken with SOBEK has not been updated since the end of INTERREG III in 2006.
- ✗ There is little information about the steps within the risk analysis.

Recommended Improvements for Greater Utility

Not all options that are in NoFDP IDSS have yet been added to Kalypso, though they will probably be added in the future. The software would be improved with a powerful model such as SOBEK 1D/2D.

RiskScape-Flood

Software Name	Peril	License	Current Version	Open Source	Operating Systems
RiskScape	Flood	Licensed [2-month]	V0.2.82	No	Windows, Mac, Linux

Preferred Specific Information

Coding Language	Software Modules	Manual	GUI	Help
Java	RiskScape, Asset, Aggregation, Hazard, Mitigation Builder	Y	Y	Y

Goal and Summary of the Software

The software creates deterministic and (in the future) probabilistic direct and indirect socioeconomic loss estimates for floods (riverine and coastal) for all types of assets, networks, and population, and includes all secondary hazards. It uses a wide array of builders, combining assets (input of buildings, infrastructure, etc.), aggregation (method to combine assets), hazard (defining the hazard model to be used), fragility (to create fragility curves), and mitigation (to perform analysis of changes in infrastructure quality).

File Types Used: *.rskm = aggregation

Hazard	Vulnerability	Exposure	Key Hazard Metrics
*.rksh	*.rksf	*.rksa	Metrics include inundation velocity, inundation depth, and ponding, as well as inundation duration on each level.

Description of Software Risk Outputs

An empirical method is used to create loss utilizing MDRs for different infrastructure types from the intensity with a continuous function to 1.0. Casualties are calculated in much the same way from a mean collapse rate.

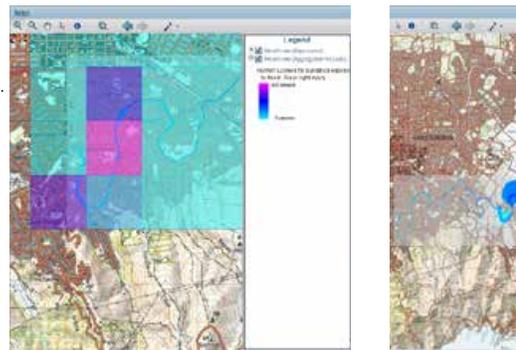
Damage states, monetary losses via replacement, contents, nonstructural costs, a number of socioeconomic interruption parameters, fatalities, injuries, homeless, and uninhabitable buildings are all calculated over the *.shp aggregation selected.

*.kml outputs are in Google Earth in 3D.

*.shp outputs can be viewed in any GIS program.

*.pdf summary shows the key aspects and maps desired from the starting panel.

*.xls gives an Excel readout of the various losses.



NoFDP IDSS scenario screen.

Advantages and Disadvantages

- ✓ The GUI and tool builders are very easy to understand and a pleasure to use.
- ✓ Output of the analysis can be done in many forms [pdf, xls, in software, kml, shp.]
- ✓ Historical floods examined within the software and the various builders are very easy to use. This allows for a fast view of the possible analysis that can be undertaken.
- ✗ There is not a transparent explanation of how the different functions are calculated.
- ✗ The software is not itself open source, and the code is unavailable.
- ✗ The software itself is quite simplistic in terms of the features to calculate—e.g., simple curves.

Recommended Improvements for Greater Utility

The way RiskScape portrays the loss information with outputs and shows the need for detailed DEMs is impressive and could be combined with a probabilistic engine or a Deltares-type software.

Sobek Suite 1D/2D with HIS-SSM

Software Name	Peril	License	Current Version	Open Source	Operating Systems
Sobek 1D/2D	Flood	GPLv3	V2.13.002	Yes	Windows

Preferred Specific Information

Coding Language	Software Modules	Manual	GUI	Help
C++, DeltaShell	SOBEK1D (Pipe, Overland), SOBEK2D (Rural, Urban, River), HIS-SSM (Risk outputs)	Y	Y	Y

Goal and Summary of the Software

SOBEK undertakes all types of 1D/2D hydrodynamic modelling by solving flow equations on both 1D network systems and 2D horizontal grids. This approach can be used for river flood forecasting and modelling, overland flooding, drainage system modelling, and engineering structure testing (dam breaks, breaches, rural and urban flooding). It is computationally efficient and allows for all flow regimes. SOBEK 1D can be run through two modules—pipes and examining overland flow. It can also be coupled with D-Rainfall Runoff Open Water, which creates event sets or separate events. SOBEK 2D gives three options for downloading, including rural, urban, and river modelling, which consists of an overland flow module in 2D and a rainfall-runoff model.

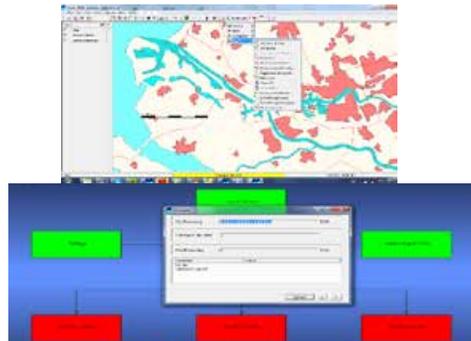
File Types Used

Hazard	Vulnerability	Exposure	Key Hazard Metrics
Many	n.a.	Many	Flow and inundation depth are the key metrics. They can also be plotted as a time series. The modelling includes wetting and drying processes and physical phenomena, and looks at all flow types, roughness, and mass conservation.

Description of Software Risk Outputs

The main output is the inundation depth at different time periods on the spatial scale defined, along with the flow velocities. In both 1D and 2D, the hydrograph methods are changeable, and the complete set of Saint-Venant equations is solved. The rainfall-runoff model can be either distributed or lumped; it allows analysis of many catchments and input of historical rainfall or production of rainfall patterns. Note, however, that there are essentially only hazard outputs. They can be viewed in a GIS platform along with all 1D network and 2D grid structures.

HIS-SSM could be connected to Sobek in order to calculate casualties and damage associated with representative scenarios of the outputs from the SOBEK suite.



Screenshots of SOBEK in action.

**HIS-SSM is currently not combined in the software, but can be included free of charge upon request.*

Advantages and Disadvantages

- ✓ The software provides all solutions for 1D and 2D flood modelling, with pipes, overland, rural, urban, and river modules.
- ✓ It is simple to install and very easy to use. The end products are easily viewable.
- ✓ It is compatible with OpenMI (along with other Delft products), which allows for user adaption.
- ✓ The programming is designed to be very fast, with efficient computation structures.
- ✗ Unless the software is combined with HIS-SSM, only hazard outputs are produced.
- ✗ Not currently fully open source at time of review.*

Recommended Improvements for Greater Utility

This software offers a fantastic basis for flood hazard modelling, and the software structure works very well. SOBEK (and all the Deltares products) would combine well with CAPRA, TSUDAT, InaSAFE, or MAEviz.

** Sobek 1D/2D is currently being released under <https://publicwiki.deltares.nl/display/nghs/Development>. The 1D components are open source, and there is currently a partial source code available; there will be components released in 2014 and a full release in 2015.*

TELEMAC-MASCARET

Software Name	Peril	License	Current Version	Open Source	Operating Systems
TELEMAC	Flood	GPLv3 and LGPL	V6.2	Yes	Windows, Unix Linux

Preferred Specific Information

Coding Language	Software Modules	Manual	GUI	Help
Fortran, Python, Perl	TELEMAC2D-3D, MASCARET, ARTEMIS, SISYPHE, SEDI-3D, STBTTEL	Y	Y	Y

Goal and Summary of the Software

The software is a set of mathematical solvers for various equations related to free surface flow. Many of these can be used for floods and waves. It has been very well tested, with over 200 applications worldwide to date. A finite element method (FEM) grid is set up and discretized into triangles, with the numerical modelling then being undertaken to solve 1D/2D/3D equations. The various module parts are ARTEMIS (wave modelling in harbors), MASCARET (1D surface), TELEMAC-2D (2D Saint-Venant), TELEMAC-3D (3D Navier-Stokes), SISYPHE (2D sediment transport), and SEDI-3D (3D sediment transport). STBTTEL is used to build the grid interface. The GUI is provided through BlueKenue or a software called FUDAA, which allows the grid to be generated. POSTEL-3D also allows creation of 2D sections from 3D simulations. It consists of a series of Fortran subroutines and functions that are easily adapted.

File Types Used

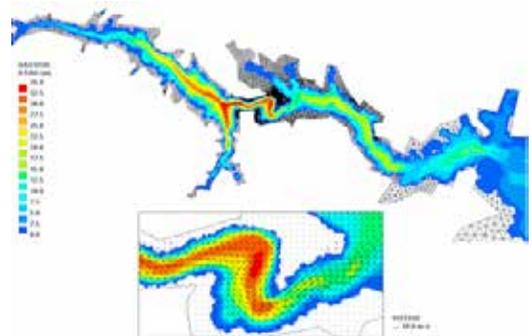
Hazard	Vulnerability	Exposure	Key Hazard Metrics
Many	n.a.	ASCII, SELAFIN	Amplitude (inundation depth) and flow are calculated through the various equations.

Description of Software Risk Outputs

Some risk outputs of TELEMAC include the inundation modelling based on dam breaks, embankment failures, and other structural breaks. Risk as such is not calculated; however, a few applications have used TELEMAC-MASCARET for risk production.

Though often overlooked, TELEMAC is a very powerful solver suite; in the 1D it can solve all flow regimes [subcritical, supercritical], as well as steady and unsteady flows. TELEMAC-2D has been well set up for supercomputing and is currently part of the PRACE (Partnership for Advanced Computing in Europe) project that models flooding of the Rhine.

There is the potential to include an open source risk output package on the end of each of these modules.



Malpasset dam break (opentelemac.org 2013).

Advantages and Disadvantages

- ✓ Validation is a key parameter checking the output; the software has been ratified by the International Association for Hydro-Environment Engineering and Research (IAHR), and there is documentation of these validation cases.
- ✓ The software provides all the tools necessary for wave and inundation modelling via solving equations.
- ✓ The code is in Fortran and easily downloadable for use in any application.
- ✓ There is quite a large user community for these tools.
- ✗ The software is not for basic users, and using it for applications requires considerable manipulation.
- ✗ There is no risk calculation within the software.

Recommended Improvements for Greater Utility

This software should be examined in greater depth; however, it definitely offers a very useful set of libraries and tools to integrate into flood and wave modelling. It has natural synergies with any of the risk modules, including HEC-FIA, Kalypso, Sobek HIS-SSM, CAPRA, or NoFDP IDSS.

CAPRA-Tsunami and Storm Surge

Software Name	Peril	License	Current Version	Open Source	Operating Systems
CAPRA	Tsunami/Storm Surge	Apache2.0, CC3BY	V2.0.0	Yes	Windows,Mac, Linux

Preferred Specific Information

Coding Language	Software Modules	Manual	GUI	Help
Visual Basic .NET	CRISIS-2007 (Hazard), CAPRA-Hurricane, Vulnerabilidad (Vulnerability), CAPRA-GIS, WWJ MarbleBlue	N*	Y	Y

Goal and Summary of the Software

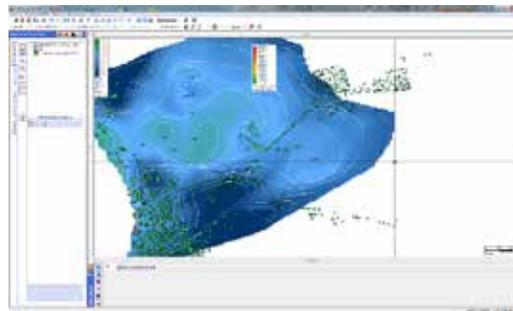
The software calculates deterministic and event set probabilistic risk for tsunamis, using continuous fragility functions. CRISIS2007 is the hazard module that can create an event set using source geometries of a particular annual frequency for tsunami generation. Inundation depths are then produced from topography and bathymetry. Once output, the vulnerability module, CAPRA-Vulnerabilidad, allows computation of fragility functions, which are essentially user driven. Uncertainty is user driven with a simple variance. CAPRA-GIS is used for quantifying the loss based on the input hazard set for a particular exposure, and then Map Viewer CAPRA-WWJ, a visualization tool using the NASA WorldWind Java SDK engine, is used. Storm surge is handled as part of CAPRA-Hurricane.

File Types Used

Hazard	Vulnerability	Exposure	Key Hazard Metrics
*.ame[main], *.tsu, *.pcf	*.fvu, *.dat	*.shp, *.grn, *.dat	Inundation depth is the modelled parameter, using either storm surge from hurricane tracks or tsunami (wave height). Both need the bathymetry and topography data.

Description of Software Risk Outputs

Human losses can be calculated directly from a vulnerability function. In addition, economic losses are output in a *.res format file. For the list of tsunamis and/or storm surge events, the exposure value as well as EP (expected loss), VarP (variance of the loss), and the beta distribution [a, b] are output. AAL over a set of buildings or one building, PML, and exceedance curves for loss are output. Losses are displayed per building in the CAPRA-GIS window, providing an easy view of loss.



Screenshot of the San Juan tsunami.

Advantages and Disadvantages

- ✓ Hazard is not hardwired, and could be input from any other program as long as the file is in the right format.
- ✓ The software provides both tsunami and storm surge options.
- ✓ The log files are very good, and the individual file production means the rerun capabilities are very good.
- ✓ The tutorials help a basic user to understand the problem.
- ✓ Inbuilt GIS related directly to the loss calculations is very useful; GIS is modular and extendable.
- ✗ The fatality functions and economic functions lack diversity, with only a direct relationship available.
- ✗ The damage distribution is not calculated directly and is based only on inundation depth, not velocity; the model is a simple one. It is unclear where roughness is used in terms of assumptions.
- ✗ No formal manual is provided, and with its mix of Spanish and English, the GUI is quite difficult to maneuver.

Recommended Improvements for Greater Utility

CAPRA would benefit from a more formal tsunami methodology, such as that of TsuDAT. An inbuilt historical tsunami database would also help users to create the event set. There should be additional calibration of loss functions, though there are fewer functions available in other software tools.

Delft-3D-WAVE (SWAN)

Software Name	Peril	License	Current Version	Open Source	Operating Systems
Delft-3D	Wave	GPLv3	4.01.00rc.03 [40.91]	Yes	Windows, Mac, Linux

Preferred Specific Information

Coding Language	Software Modules	Manual	GUI	Help
Fortran77/90, C/C++, DeltaShell	Delft3D	Y	Y	Y

Goal and Summary of the Software

Delft-3D-Wave is a GUI-based application using the SWAN model and the HISWA model, both of which are strong calculation engines for hydraulic flow and waves. The software can look at wind-generated waves in coastal waters, examining all depths of water, and can model wave generation, propagation, and breaking problems of short-crested random waves. It needs a lot of advanced-user input, but is one of the most powerful numerical tools for calculating large-scale wave propagation and storm surges. It is usable for estuaries, tidal inlets, lakes, barrier islands, channels, and coastal regions. It is coupled to Delft3D-FLOW.

File Types Used

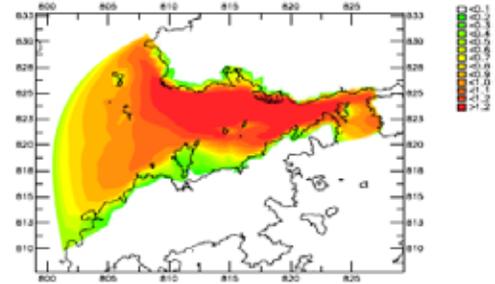
Hazard	Vulnerability	Exposure	Key Hazard Metrics
Ascii - .mdw	n.a.	.dep, .grd, .enc, .wnd, .bnd, .pol, .loc, .obs, .pol	On a curvilinear grid, wave height, direction, etc. can be modelled on a number of points. All types of roughness, topography, bathymetry, wind, etc. are taken into account.

Description of Software Risk Outputs

This software offers only a hazard output; however, it creates the most detailed 3D wave models available. A binary file is output with the data in time series format as a 2D or 3D map.

The distance, depth, mean wave period/direction, directional spreading, dissipation rate, mean wave length, and current velocity are modelled on the grid and wind components. Also modelled are frequencies, densities, and spectral nautical directions in the spectra files.

There is no attached risk module.



A 2D plot [Delft3D-Wave 2013].

Advantages and Disadvantages

- ✓ The software is well developed for modelling 3D waves.
- ✓ It is very fast, using as it does the set of Fortran90 codes based on the third generation SWAN model—though it also allows use of the second generation model.
- ✓ There are many application possibilities (storm, tide, tsunami).
- ✓ Large-scale analysis is possible (limited only by computing power).
- ✗ For risk assessment, the computation is quite difficult to carry out, with many inputs needed (3D modelling).
- ✗ It needs external tools to review results.

Recommended Improvements for Greater Utility

Delft3D-Wave using SWAN achieves what it sets out to achieve. It could be combined as an option for detailed scenario modelling in complex regions and is a very useful tool combined with Delft3D-FLOW.

InaSAFE-Tsunami

Software Name	Peril	License	Current Version	Open Source	Operating Systems
InaSAFE	Tsunami	GPLv3	V1.0.1	Yes	Windows,Mac, Linux

Preferred Specific Information

Coding Language	Software Modules	Manual	GUI	Help
Python(+libraries), QGIS	InaSAFE, InaSAFE QGIS Plugin	Y	Y	Y

Goal and Summary of the Software

This software is a link between the science community and those in the planning and policy community seeking to understand a tsunami impact scenario. Created as a project of the AIFDR, the World Bank, and GFDRR, it is a plugin that takes exposure inputs (population, buildings) and hazard inputs (tsunami inundation depth) from any Openstreetmap data or software, then uses simple vulnerability functions to calculate an output through a simple-to-use GUI in a QGIS plugin form.

File Types Used

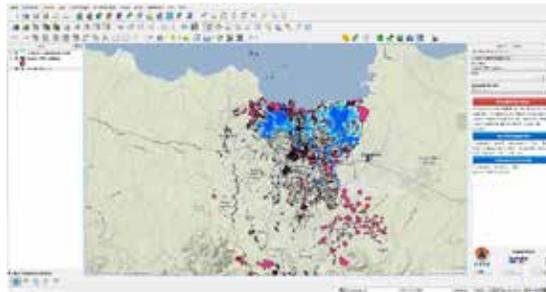
Hazard	Vulnerability	Exposure	Key Hazard Metrics
*.shp	n.a.	*.shp	Tsunami inundation depth is used via the input hazard file. Hazard is calculated outside the program and is then switched inside the program to create categories of inundated (1) or not inundated (0).

Description of Software Risk Outputs

InaSAFE is currently in production; however, it currently outputs buildings that are inundated as a result of a tsunami wave as well as damage state, and it can also calculate economic losses based on floor area and contents/building value.

Displaced people are also calculated via the population density. It has a great tool for measuring various shelter needs, as in the other InaSAFE modules.

The losses are shown in the form of a GIS file within QGIS and are easy to view.



Startup screen including the exposure data.

Advantages and Disadvantages

- ✓ This is a wonderful tool that allows the “plug and play” addition of hazard and exposure layers to the system.
- ✓ It explains concepts clearly so that novice users are able to understand them.
- ✓ Its functions and coding are easy for inexperienced users to understand.
- ✓ There is a good developer community that promotes interaction.
- ✗ The software is still in the test phase, and needs additional functionality.

Recommended Improvements for Greater Utility

This software would fit well with many functions for rapid loss and any detailed scenario hazard estimates. It would benefit from some synergy with MAEviz to explore possible end modules to be coded, and could use run-up heights from TsuDAT or CAPRA.

The software would also benefit from synergy with an additional vulnerability function builder for various tsunami impacts globally. Some form of additional socioeconomic analysis with respect to indicators would make the software more useful for decision makers.

OsGEO Tsunami (R.Tsunami)

Software Name	Peril	License	Current Version	Open Source	Operating Systems
OsGEO Tsunami	Tsunami	GPL	No vers.	Yes	Windows,Mac, Linux

Preferred Specific Information

Coding Language	Software Modules	Manual	GUI	Help
R, GRASS-GIS	GRASS-GIS, R.Hazard.Tsunami	Y	Y	Y

Goal and Summary of the Software

R.tsunami is a plugin for the open-source GIS tool GRASS-GIS. Within GRASS-GIS, it is a numerical model for calculating inundation depth, storm surges, and run-up for tsunami waves. It has been tested in two areas, the Ligurian coast and the Virgin Islands. R.tsunami calculates the hazard of tsunami events, but does not address exposure or vulnerability; therefore further plugins for GRASS-GIS are needed. Users can drag in exposure data and then use vulnerability functions based on U.S. Army Corps of Engineers functions for flood heights with building stocks of the respective countries. Exposed stock is simply intersected with the hazard layer to create statistics.

File Types Used

Hazard	Vulnerability	Exposure	Key Hazard Metrics
Evaluated directly	.shp (poly or point)	Multiple	Inundation depth and run-up are calculated using the plugin based on location, bathymetry, topography, and roughness.

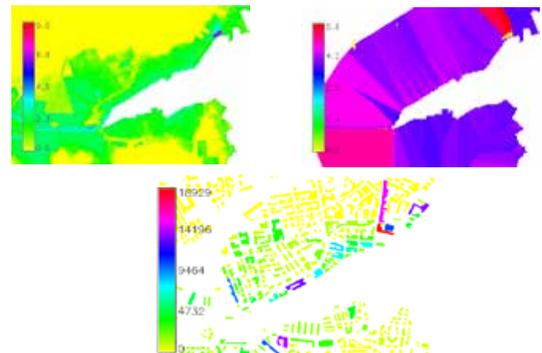
Description of Software Risk Outputs

The software needs a lot of data, including

- digital terrain model raster map
- roughness raster map
- height of the generated wave in the source point
- depth of the sea in the source point
- sea depth near the coast
- output flooded area map name
- output flood height map name
- coordinates of a point on the sea

It is tailored to EU conditions, using CORINE land use for roughness calculations.

Equations of economic loss for different return periods are characterized for a high event, medium event, and low event (as defined by the user) for residential and agricultural buildings per m².



Startup screen including the exposure data.

Advantages and Disadvantages

- ✓ This is a straightforward plugin for GRASS GIS that is easily understandable and open source.
- ✓ It attempts to calculate the economic impact of tsunamis and characterizes damage states.
- ✓ It uses roughness based on CORINE land cover, which provides a good basis for the rest of Europe.
- ✓ The damage-stage relations will usually be different for tsunami/storm surge than for flood—but in the absence of information they are perhaps reasonable.
- ✗ Much data needs to be input.
- ✗ Not many case studies have been tested around the world.
- ✗ No manuals or tutorials have been provided.

Recommended Improvements for Greater Utility

The GRASS-GIS plugin is very simple but could provide a useful additional testbed for applying InaSAFE and for converting the functions from R to Python.

RiskScape-Tsunami

Software Name	Peril	License	Current Version	Open Source	Operating Systems
RiskScape	Tsunami	Licensed [2-month]	V0.2.82	No	Windows ,Mac, Linux

Preferred Specific Information

Coding Language	Software Modules	Manual	GUI	Help
Java	RiskScape, Asset, Aggregation, Hazard, Mitigation Builder	Y	Y	Y

Goal and Summary of the Software

The software creates deterministic and (in the future) probabilistic direct and indirect socioeconomic loss estimates for tsunamis for all types of assets, networks, and population, and includes all secondary hazards. It uses a wide array of builders, combining assets (input of buildings, infrastructure, etc.), aggregation (method to combine assets), hazard (defining the hazard model to be used), fragility (to create fragility curve), and mitigation (to perform analysis of changes in infrastructure quality). The RiCOM model, which solves a Reynolds-averaged 3D wave equation, has been used so far in test cases. High-resolution topography and bathymetry are also used within the analysis.

File Types Used: *.rskm = aggregation

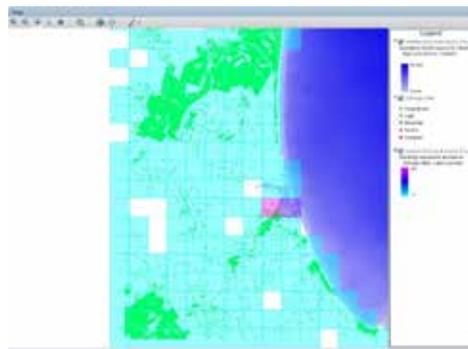
Hazard	Vulnerability	Exposure	Key Hazard Metrics
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*.rksh	*.rksf	*.rksa	Tsunamis are measured in terms of the same parameters as flood. Inundation depth (m), duration (hrs), velocity (m/s), and ponding are included.
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Description of Software Risk Outputs

An empirical method is used to create loss, using MDRs for different infrastructure types from the intensity with a continuous function to 1.0 using an empirical fragility function. RiskScape-Tsunami currently allows everything except human susceptibility to be calculated. Damage states, monetary losses via replacement, contents, nonstructural costs, a number of socioeconomic interruption parameters, fatalities, injuries, homeless, and uninhabitable buildings are all calculated over the *.shp aggregation selected. This is not available for all options in RiskScape.

- *.kml outputs are in Google Earth in 3D.
- *.shp outputs can be viewed in any GIS program.
- *.pdf summary shows the key aspects and maps desired from the starting panel.
- *.xls, *.csv give an Excel readout of the various losses.



Screenshot of the RiskScape loss output for Hawke's Bay tsunami.

Advantages and Disadvantages

- ✓ GUI and tool builders are very easy to understand and a pleasure to use.
- ✓ Output of the analysis can be done in many forms (pdf, xls, in software, kml, shp).
- ✓ Mitigation factors, tide levels, and predefined tsunamis can be calculated easily to see the process of tsunami risk assessment.
- ✗ There is not a transparent explanation of how the different functions are calculated.
- ✗ The software is not open source, and the code is unavailable.
- ✗ The software itself is quite simplistic in terms of the features to calculate—e.g., simple curves.

Recommended Improvements for Greater Utility

There is a natural link between the Delft3D models, TELEMAC3D models, and the high-resolution modelling attempted by RiskScape. These models within RiskScape attempt to calculate very in-depth hazard parameters, but there is no one model for hazard in RiskScape. TsuDAT and RiskScape also should collaborate, given the proximity of the development teams and given that RiskScape currently lacks probabilistic hazard calculations.

SLOSH

Software Name	Peril	License	Current Version	Open Source	Operating Systems
SLOSH	Storm Surge	Single User	V1.65i	Yes	Windows, Linux

Preferred Specific Information

Coding Language	Software Modules	Manual	GUI	Help
Python	SLOSH	Y	Y	Y

Goal and Summary of the Software

SLOSH is a simple hurricane storm surge calculator (using a 1D wave model). It uses an historical database and predefined modelling grids for common geographic basins, including coastal areas of North America (the Atlantic), parts of the Caribbean, and some Pacific coasts. SLOSH can also be run in a mode that works out different scenarios, changing landfall directions, Saffir-Simpson categories, forward speeds, and sea levels. It then creates a maximum envelope of water (MEOW).

File Types Used

Hazard	Vulnerability	Exposure	Key Hazard Metrics
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Many

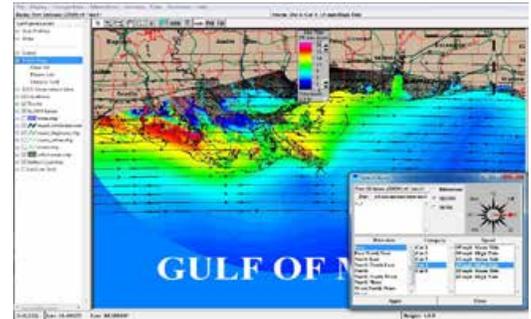
n.a.

n.a.

Surge heights are calculated based on a simple 1D wave equation solver combined with data on wind, topography, bathymetry, pressure, and forward direction.

Description of Software Risk Outputs

SLOSH is a hazard model that creates inundation depths over the coastal areas. It does, however, have two useful features that are essentially risk indicators: a MEOW and a MOM (maximum of the maximums), which is the maximum of all the singular MEOWs for a particular basin. Many basins have been modelled, and SLOSH includes five MOMs (Cat 1 MOM, Cat 2 MOM, etc.). These risk indicators are very useful for planning. Another program, PHISH/PSURGE, can be used for probabilistic analysis of storm surge heights.



2009 New Orleans hurricane model..

Advantages and Disadvantages

- ✓ The latest version dates to December 2012 and is still based on the engine of the 2003 version—which is simple to use and transparent.
- ✓ The software has a great historical database that is integrated into the software.
- ✓ It is very well suited for basic users: easy to install, easy to use, and very fast.
- ✗ It has only a few output/export options into .rex, .pcx, and .txt and these are not very useful.
- ✗ The software is technologically outdated, and it will be no longer developed.

Recommended Improvements for Greater Utility

This software has some great features, but was last updated 18 months ago and is no longer being developed. Some of the tools would be useful inputs into CAPRA and into the planning components of other software where the maximum characterization makes sense.

TOMAWAC Wave

Software Name	Peril	License	Current Version	Open Source	Operating Systems
TOMAWAC	Wave	GPLv3	V2.0.0	Yes	Windows, Mac, Linux

Preferred Specific Information

Coding Language	Software Modules	Manual	GUI	Help
Visual Basic .NET	TOMAWAC, TELEMAC 2D, TELEMAC 3D	Y	Y	Y

Goal and Summary of the Software

The software is part of the set of mathematical solvers for various equations related to free surface flow, a few of which can be used for floods and waves. In this case, the same FEM grid is set up and discretized into triangles, with the numerical modelling then being undertaken to solve 1D/2D/3D equations. The various module parts are TELEMAC-2D (2D Saint-Venant), for tsunamis with wavelengths in the shallow water domain (wavelength > 20 times the depth); TELEMAC-3D (3D Navier-Stokes), for shorter wavelengths; and TOMAWAC, for modelling wave propagation in coastal areas. TOMAWAC uses a solution of spectroangular density of wave action ($F = E/pg$). STBTTEL is also used to build the grid interface. POSTEL-3D also allows creation of 2D sections from 3D simulations. It consists of a series of Fortran subroutines and functions that is easily adapted and can be viewed in various programs such as BlueKenue.

File Types Used

Hazard	Vulnerability	Exposure	Key Hazard Metrics
--------	---------------	----------	--------------------

Many

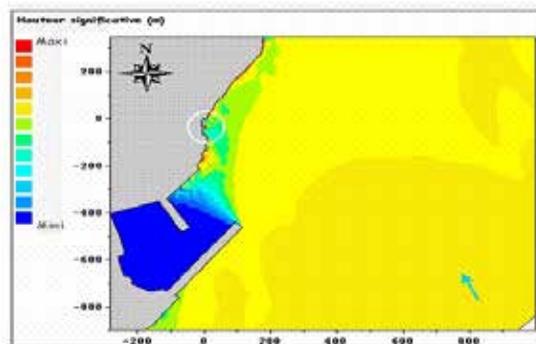
n.a.

ASCII, SELAFIN

Amplitude in terms of peak wave height is output. In addition, frequency and direction for mean and peak are output. Wave-induced currents are also calculated at each point of the mesh.

Description of Software Risk Outputs

This set of solvers unfortunately does not follow through to risk; however, the hazard calculation could be integrated directly into risk assessments. The currents, as well as frequency and duration outputs, are useful.



Tomawac output of waves.

Advantages and Disadvantages

- ✓ Validation is a key parameter checking the output. The software model has been ratified by IAHR, and there is documentation of these validation cases. It provides another useful solver.
- ✓ The software provides all the tools necessary for wave modelling via solving equations.
- ✓ The code is in Fortran and easily downloadable for use in any application.
- ✓ There is quite a large user community.
- ✗ This is not for basic users, and much manipulation is required in order to use the software for applications.
- ✗ There is no risk calculation within the software.

Recommended Improvements for Greater Utility

The tool needs to be examined in greater depth; however, it definitely offers a very useful set of libraries and tools to integrate into wave modelling. It has natural synergies with any of the risk modules for tsunami, such as Hazus and CAPRA.

TsuDAT using ANUGA

Software Name	Peril	License	Current Version	Open Source	Operating Systems
TsuDAT	Tsunami	GPL, CC by AU	V2.0	Yes	Linux, Windows (Client)

Preferred Specific Information

Coding Language	Software Modules	Manual	GUI	Help
Python	TsuDAT, GeoNode, TsuDAT Client	Y*	Y	Y

Goal and Summary of the Software

TsuDAT is a calculation software for tsunami inundation, based on the Probabilistic Tsunami Hazard Assessment by Geoscience Australia, which allows many individual scenarios to be created from 76,000 different modelled synthetic tsunamis. The hazard is calculated at a point of 100m depth offshore around Australia. The hazard can then be disaggregated for an event with a defined height and return period, giving a table of results. The scenario is then run using the hydrodynamic model, ANUGA, in order to solve the shallow water wave equations over the DEM topography and bathymetry data. Offshore time series and ANUGA scripts can be edited, meaning that any inundation code can be used. TsuDAT has a variable mesh resolution and friction that can be drawn as polygons by the user.

File Types Used

Hazard	Vulnerability	Exposure	Key Hazard Metrics
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*.csv into py

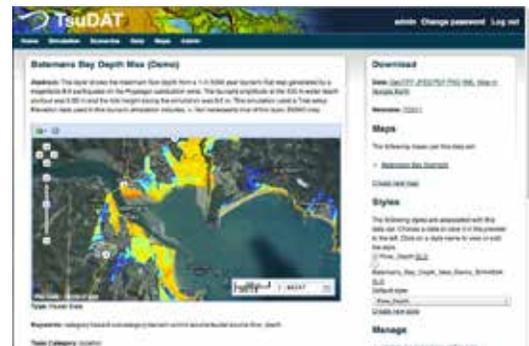
n.a.

*.shp, *.grd

Inundation depth, via wave height, is modelled through a finite volume method mesh, solving a 2D shallow water wave equation with respect to momentum, roughness, boundary, and forcing conditions.

Description of Software Risk Outputs

The software presents an inundation map of the location that the user uploads as a DEM. For an engineer or a decision-maker, it is a very good tool for creating a map. TsuDAT Client also allows the user to analyze the given scenario through the NCI (a cloud computing system in Canberra) and then receive the results back. Currently, no risk model is attached, though a couple of test cases have been undertaken internally; on the other hand, the software is extendable and the inundation map could be uploaded to InaSAFE or analyzed within another environment of flood inundation modelling, potentially NoFDP IDSS or Kalypso.



TsuDAT picture of Batemans Bay inundation (OpenGeo 2013).

It should be noted that testing TsuDAT fully was not possible, as it was being updated during this study.

Advantages and Disadvantages

- ✓ The software's tsunami hazard methodology is the best of all wave software packages reviewed.
- ✓ The methodology for disaggregating a suitable scenario is better than that of any other package.
- ✓ The ability to "plug and play" the code with any hydrodynamic model is useful.
- ✓ The use of GeoNode and fully open source systems is useful.
- ✗ The code can be looked at locally, but running TsuDAT requires a connection to the server at the NCI. Thus if Internet connections are not working, analysis cannot take place.

Recommended Improvements for Greater Utility

TsuDAT should be promoted as much as possible and seems the best candidate to be combined with other software. The system for scenario selection and disaggregation lends itself to a MAEvis system. It should be implemented in InaSAFE to allow risk outputs as well as in other modules for tsunami globally.

4.0 – Discussion and Conclusion

The information presented here is intended to guide users in selecting suitable software packages. Users can draw on additional information (*included in the supplementary spreadsheet to be available online*) to further align software selection with their specific requirements. But it is important for users to actually test software packages in order to make informed decisions about which is best for their purposes.

The findings of this review—some perhaps surprising—are as follows:

1. Open source software has a reputation for poor GUIs and difficult installation. But as the quality of open source software continues to improve, this reputation is proving unfounded. Many of the software packages (Deltares tools and RiskScape, for example) were first developed for commercial purposes and have advanced GUIs, and many are simple to install with a few clicks.
2. Deterministic analysis is the most common function among the software packages reviewed. However, probabilistic or stochastic event set modelling can be undertaken in many software packages, including OpenQuake, CAPRA, and EQRM.
3. Many software tools could be improved by enabling user-defined exposure and vulnerability. Without this capability, many tools can be used only regionally.
4. It is becoming increasingly easy to use multiple packages for a single region and/or hazard as a means of characterizing the uncertainty in the risk, or checking for the sensitivities in the analysis.

There is a potential for valuable synergy between existing software packages. A number of open source software packages could be combined to generate a multi-risk model with multiple views of a hazard. An example is a hypothetical “super package” that combined MAEviz, EQRM, Kalypso, Deltares, TCRM, and TsuDAT (but the options are limitless).

One goal of this review has been to provide a platform for dialogue between all open source and open access software package developers and users. Ideally, it will also inspire collaboration between developers, who have thus far done a great job with open access and open source packages.

Typically, risk model development and software development are two distinct activities. But this review suggests that the ideal situation is one in which scientists and engineers develop the risk model—inputs, outputs, calibration—and software developers work closely with this team to build efficient and user-friendly tools that are easily extended and adapted to suit a wide range of applications.

Supplementary Spreadsheet

<https://www.gfdrr.org/RASoftwareReview>



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- McLaren, T. 2008. "MAEVIZ." Presentation at EclipseCON, Santa Clara, CA, March 17-20.
- Robinson, D., G. Fulford, and T. Dhu. 2006. "EQRM: Geoscience Australia's Earthquake Risk Model: Technical Manual: Version 3.0.1." Record 2005/001. Geoscience Australia, Canberra.

Appendix A.

References and Other Information for Software Packages Initially Assessed

NAME OF SOFTWARE PACKAGE	DEVELOPING INSTITUTION	REGION DEVELOPED	DOWNLOAD LOCATION / LITERATURE
ADCIRC	University of North Carolina	U.S.	www.adcirc.org
ANUGA	Australian National University (ANU) and GA	Australia	http://sourceforge.net/projects/anuga/ .
ANUGA and TsuDAT	ANU and GA	Australia, Indonesia	https://github.com/AIFDR/tsudat2 .
ATHYS	Institut de recherche pour le développement (IRD)	France	http://www.athys-soft.org/v1/Index.html .
BASEMENT	ETH Zurich [ETH-Z]	Switzerland	http://www.basement.ethz.ch/services/download/box_feeder/BASEMENT_v2.2.1.zip .
CAPRA [ERN-Flood, ERN-Lluvia]	World Bank, United Nations Office for Disaster Risk Reduction, GFDRR	Central America	http://www.ecapra.org/sites/default/files/software/Setup_ERN-Inundaci%C3%B3n%20v2.1_100812.rar .
CAPRA [ERN-Hurricane]		Central America	http://www.ecapra.org/ERN-Hurricane .
CAPRA [Earthquake, ERN-Surge, ERN-Tsunami via CRISIS2007]		Central America	http://www.ecapra.org/crisis-2007 .
CATS	Federal Emergency Management Agency (FEMA), ESRI	U.S.	https://www.saic.com/products/security/cats/ .
Champ2.0	FEMA	U.S.	http://www.fema.gov/ .
ComMIT [MITgcm]	MIT	U.S.	http://nctr.pmel.noaa.gov/ComMIT/ .
COULWAVE	Cornell University, Texas A&M	U.S.	http://isec.nacse.org/models/coulwave_download.php .
CREST	Center for Disaster Management and Risk Reduction Technology [CEDIM]	Germany	Tyagunov, S. 2006. "CREST Software." Karlsruhe, Germany; Tyagunov, S., G. Grünthal, R. Wahlström, L. Stempniewski, and J. Zschau. 2006. "Seismic Risk mapping for Germany." <i>Natural Hazards Earth Systems Science</i> 6: 573–86.
DBELA	EU CENTRE	Italy	https://github.com/VSilva/DBELA .
Delft-3D-FLOW, -WAVE	Delft [Deltares]	Worldwide	http://oss.deltares.nl/web/delft3d/source-code;jsessionid=3A3C93DEEAE13D06A0FCAE8A7D39E5D6 .
DR3M	U.S. Geological Survey (USGS)	U.S.	http://water.usgs.gov/software/DR3M/ .
ELER	JRA-3, NORSAR, Imperial	Europe	http://www.koeri.boun.edu.tr/deprenmuh/eski/ELER/eler_dvd.rar .
EPEDAT	EQE International	California, U.S.	Eguchi, R. T., Goltz, J. D., Seligson, H. A., Flores, P. J. N., Blais, C., Heaton, T. H. and Bortugno, E. 1997. "Real-Time Loss Estimation as an Emergency Response Decision Support System: The Early Post-Earthquake Damage Assessment Tool [EPEDAT]." <i>Earthquake Spectra</i> 13 [4]: 815–32.

NAME OF SOFTWARE PACKAGE	DEVELOPING INSTITUTION	REGION DEVELOPED	DOWNLOAD LOCATION / LITERATURE
EQRMatlab	GA	Australia	Robinson, D., Fulford, G. and Dhu, T. 2006. "EQRM: Geoscience Australia's Earthquake Risk Model." Record 2005/01, Geoscience Australia, Canberra.
EQR Python	GA	Australia	http://sourceforge.net/projects/eqrm/files/ .
EQSIM	Karlsruhe Institute of Technology (KIT)	Germany	Markus, M., Fiedrich F., Leebmann, J., Schweier, C. & Steinle, E. 2004. "Concept for an Integrated Disaster Management Tool." Proceedings of the 13th World Conference on Earthquake Engineering, Vancouver.
Extremum	Extreme. Situations Research. Center. Ltd.	Russia	Frolova, N., Larionov V. & Bonnin, J. [2006]. "Multi-Hazard Risk Assessment at Different Levels with Extremum System Application", The Paper presented at Third International Conference on Early Warning, Bonn, Germany.
GSFLOW	USGS	USAU.S.	http://water.usgs.gov/nrp/gwsoftware/gsflo/gsflo.html .
HAZ-Taiwan (TELES)	National Center for Research on Earthquake Engineering (NCEE)	Taiwan	Yeh, C.H., Loh, C.H. & Tsai, K.C. [2006]. "Overview of Taiwan Earthquake Loss Estimation System", Natural Hazards, Vol. 37, No. 1-2, pp. 23-37.
HAZUS Flood, Earthquake, Hurricane	FEMA	U.S.	http://www.fema.gov/hazus .
HEC-RAS	USA Army Corps of Engineers	U.S.	http://www.hec.usace.army.mil/software/hec-ras/downloads.aspx .
HydroFOSS	Instituto scienze della Terra-Scuola universitaria professionale della Svizzera italiana (IST-SUPSI)	Worldwide	https://svn.osgeo.org/grass/grass-addons/grass6/HydroFOSS/ .
Hydrognomon	National Technical University (NTU) Athens	Greece	http://hydrognomon.org/download.html .
InaSAFE Earthquake, Flood, Tsunami	AIFDR	Indonesia	https://github.com/AIFDR/inasafe .
InLET	ImageCat, Inc.	California, U.S.	http://rescue-ibm.calit2.uci.edu:8888/inlet/inlet.php .
Kalypso	Hamburg University of Technology and Bjoernsen Consulting Engineers	Germany	http://sourceforge.net/projects/kalypso/ .
LESSLOSS/LNECLOSS	Laboratório Nacional de Engenharia Civil (LNEC), Consortium	Lisbon	Sousa, M. L., Campos Costa, A., Carvalho, A. & Coelho, E. [2004]. "An Automatic Seismic Scenario Loss Methodology Integrated on a Geographic Information System.", Proceedings of the 13th World Conference on Earthquake Engineering, Vancouver., Canada, Paper No. 2526.
MAEViz	University of Illinois	U.S.	http://earthquake.ncsa.illinois.edu:8080/release/3.1.1/maeviz-3.1.1.setup.exe .
mHARP (MAEViz and Eqvis combined)	University of Illinois, and collaborators	U.S.	http://mharp.ncsa.illinois.edu/?page_id=48 .

NAME OF SOFTWARE PACKAGE	DEVELOPING INSTITUTION	REGION DEVELOPED	DOWNLOAD LOCATION / LITERATURE
MIRISK	GFDRR Grant	Japan	http://siteresources.worldbank.org/EXTDISMGMT/Resources/MIRISKprofScawthorn.pdf .
noFDP IDSS with SOBEK-River (1D Hydraulic Model)	Darmstadt University. / Collaborators	Germany as part of INTERREG III	http://nofdpidss.sourceforge.net/ .
OpenQuake	GEM	Italy	https://github.com/gem/eq-engine/ .
OpenRISK	SpaRisk LLC	Worldwide	http://www.risk-agera.org/index.php/files/category/4-openrisk-software .
OsGEO Tsunami (R.tsunami)	IST-SUPSI	Italy	http://svn.osgeo.org/grass/grass-addons/ .
OSRE	Kyoto University	Japan	http://www.risk-agera.org/index.php/files/category/1-osre .
PAGER	USGS	U.S.	earthquake.usgs.gov/pager .
PIHM and GIS and QGIS plug in	Penn State	U.S.	http://www.pihm.psu.edu/pihm_downloads.html .
QLARM-WAPMERR	WAPMERR/Max Wyss	Switzerland	www.wapmerr.org .
Quick20	FEMA	U.S.	http://www.fema.gov/library/viewRecord.do?id=2316 .
R.Hazard.Flood	M. D. Leo, M.D.	Italy	http://grasswiki.osgeo.org/wiki/AddOns/GRASS_6#r.hazard.flood .
RADIUS	United Nations Environment Programme [UNEP]	India	http://worldbank.mrooms.net/course/view.php?id=483&pageid=3053 .
REDARS	MCEER, ImageCat, Inc.	California, U.S.	ftp://mceer.buffalo.edu/Stoyle/redars/ .
REDAS	PHIVOLCS	Philippines	www.phivolcs.dost.gov.ph/images/IEC/redas.pdf .
ReFH	Centre for Ecology & Hydrology [CEH], and Wallingford Solutions	United Kingdom	http://www.ceh.ac.uk/Feh2/FEHSoftware.html .
Risk.IITB	IIT Bombay	India	Sinha, Ravi, Aditya K. S. P. & Gupta A. 2008. "GIS-Based Urban Seismic Risk Assessment Using RISK.IITB." Journal of Earthquake Technology 45 [3-4]: 41-63.
RiskSCAPE Earthquake, Flood, Tsunami, Wind	National Institute of Water and Atmospheric Research [NIWA], and GNS Science	New Zealand	http://www.riskscape.org.nz/ .
RORB	Sinclair Knight Merz [SKM], Monash University	Australia	http://www.eng.monash.edu.au/civil/research/centres/water/rorb/ .
Runup v2	FEMA	U.S.	http://www.fema.gov/library/viewRecord.do?id=3392 .
SAFER	Multiple EU partners	Europe	Fast based SELENA – Zschau, J., Gasparini, P., Papadopoulos, G., & SAFER Consortium . [2007] "Status of the SAFER Project [Seismic eArly warning For EuRope].", Paper presented at American Geophysical Union [AGU] Fall Meeting, San Francisco.

NAME OF SOFTWARE PACKAGE	DEVELOPING INSTITUTION	REGION DEVELOPED	DOWNLOAD LOCATION / LITERATURE
SEISMOCARE	University of Patras, and Consortium	Greece	Anagnostopoulos, S., Providakis, C., Salvaneschi, P., Athanasopoulos, G. & Bonacina, G. [2008]. "SEISMOCARE: An Efficient GIS Tool for Scenario-type Investigations of Seismic Risk of Existing Cities." <i>Soil Dynamics and Earthquake Engineering</i> , 28 [2], 73-84.
SEISVARA	NORSAR	India	http://eqrisk.info/seis.php .
SELENA	NORSAR	Norway	http://sourceforge.net/projects/selena/files/ .
SES2002 and ESCENARIS	Director General for Dir. Of Civil Protection	Spain	Roca, A., Goula, X., Susagna, T., Chàvez J., González, M. J. & Reinoso, E. [2006]. "A Simplified Method for Vulnerability Assessment of Dwelling Buildings and Estimation of Damage Scenarios in Spain"; <i>Bulletin of Earthquake Engineering</i> , Vol. 4, No. 2, pp. 141-158.
SIGE	Italian National Seismic Survey (OSSN)	Italy	Di Pasquale, G., Ferlito, R., Orsini, G., Papa, F., Pizza, A. G., Van Dyck, J. & Veneziano D. [2004]. "Seismic Scenario Tools for Emergency Planning and Management."; Paper presented at the 29th XXIX General Assembly of the European Seismological Commission, Potsdam, Germany.
SLOSH	National Oceanic and Atmospheric Administration (NOAA)	U.S.	http://slosh.nws.noaa.gov/sloshPriv .
Sobek Suite – 1D, 2D	Deltares	Netherlands	http://www.deltares.nl/en/software/108282/sobek-suite .
SPBELA	EUCENTRE	Italy	Borzi, B., Crowley, H. & Pinho, R. [2008]. "Simplified Pushover-based Earthquake Loss Assessment (SP-BELA) Method for Masonry Buildings."; <i>International Journal of Architectural Heritage</i> , Vol. 2 [No. 4] pp. 353-376.
StrucLoss/KOERILoss	Middle East Technical University (METU)	Turkey	Kandilli Observatory and Earthquake Research Institute. 2002. "Earthquake Risk Assessment for Istanbul Metropolitan Area."; Kandilli Observatory and Earthquake Research Institute, Istanbul, available from URL: http://www.koeri.boun.edu.tr/deprenmmuh/EXEC_ENG.pdf .
SWAN	Delft (Deltares)	Netherlands	http://swanmodel.sourceforge.net/ .
SWMM	Environmental Protection Agency (EPA)	U.S.	http://www.epa.gov/nrmrl/wswrd/wq/models/swmm/ .
SYNER-G [Eqvis]	Consortium	Europe	http://www.vce.at/syner-g . Contact EU project consortium partners for Eqvis and OOFIMS (available on website).
TauDEM	Utah State University (USU)	U.S.	http://hydrology.usu.edu/taudem/taudem5.0/downloads.html .
TCRM	Geoscience Australia	Australia	http://code.google.com/p/tcrm/ .

NAME OF SOFTWARE PACKAGE	DEVELOPING INSTITUTION	REGION DEVELOPED	DOWNLOAD LOCATION / LITERATURE
TELEMAC-MASCARET	Collaboration between Germany, UK, France	France	http://www.opentelemac.org/index.php/download .
TOMAWAC and WAVE – TELEMAC	Collaboration between Germany, UK, France	France	http://www.opentelemac.org/index.php/download .
USGS Water Resources Applications Software [NSSv6, OWLS, PKFQ]	USGS	U.S.	http://water.usgs.gov/software/ .
WaSIM	ETH-Z	Switzerland	http://www.wasim.ch/products/model_r9-2-0.htm .
Wave Watch 3	National Centers for Environmental Prediction [NCEP]	U.S.	http://polar.ncep.noaa.gov/waves/wavewatch/wavewatch.shtml .

Appendix B.

Additional Software Packages and Links

Table B-1 lists—and includes links to—software packages that were not reviewed in their entirety but will be in the future. Some were discovered too late in the review process to be included; some solve only a very simple set of equations and may not be extensive in their application to risk assessment; others were known to be only hazard engines, and were not reviewed if enough risk software packages existed in their group (e.g., earthquake). The applicable packages will be reviewed over the coming months and years, and a dynamic list for the worldwide user community will be provided in order to keep the list of potential open source risk assessment software up-to-date.

Table B-1 Software Packages to Be Reviewed in the Future

SOFTWARE PACKAGE	LINK
A Java/C routine: for distributed rainfall-runoff	https://code.google.com/p/jgrass/ .
Atmospheric models from the MITGCM (which are also to be used in the COMMIT software)	http://mitgcm.org/ .
Clawpack/Diego Melgar/Geoclaw	https://github.com/dmelgarm https://github.com/clawpack/geoclaw .
DHSVM: Distributed hydrologic model	http://www.hydro.washington.edu/Lettenmaier/Models/DHSVM/documentation.shtml .
ECOMSED: 3D hydrodynamic and sediment transport computer code.	http://www.hydroqual.com/ehst_ecomsed.html .
FLDTA: 1D Flow	http://csdms.colorado.edu/viewvc/midas/ .
FVCOM: A set of solvers	http://fvcom.smast.umassd.edu/FVCOM .
Hydrotrend	http://csdms.colorado.edu/viewvc/hydrotrend/ .
LBRM: Large Basin Runoff [Distributed]	http://www.glerl.noaa.gov/wr/lbrmexamples.html .
MoCaHAZ: Wiemer – ETH-Z : – seismic hazard assessment [Wiemer – ETH-Z]	http://www.seismo.ethz.ch/static/stat_2010_website/stat-website-pre2010/www.earthquake.ethz.ch/research/Swiss_Hazard/downloads/software_downloads.html ; - contact authors.
NSHMP: U.S. seismic hazard mapping program	http://earthquake.usgs.gov/hazards/products/conterminous/2008/software/ .
OHAZ: Probabilistic hazard for BSHAP [Balkans]	www.wbbalkanmaps.org ; - contact authors.
OPENFOAM: A wide range of coastal solvers for fluid equations	http://www.openfoam.org/download/ .
OpenSHA: earthquake hazard, global use, probabilistic	http://www.opensha.org .
Parflow: Watershed model	http://inside.mines.edu/~rmaxwell/maxwell_software.shtml .
POM	http://www.aos.princeton.edu/WWWPUBLIC/htdocs/pom/ .
PREVAH: Distributed rainfall-runoff (login)	http://www.hydrologie.unibe.ch/PREVAH/ .
RORB v6.14	http://eng.monash.edu.au/civil/research/centres/water/rorb/ .
SEISRISKIII: A global earthquake hazard engine [probabilistic]	http://earthquake.usgs.gov/hazards/apps/seisrisk/seisrisk.zip .
Stvenant: 1D model from 1992 to 1994	http://csdms.colorado.edu/wiki/Model:STVENANT .
STWAVE: Nearshore wind-wave growth	http://chl.erd.usace.army.mil/chl.aspx?p=s&a=SOFTWARE;9 .
SWASH: Simulating near-surface waves	http://swash.sourceforge.net/ .
TOPKAPI: Advanced rainfall-runoff software	http://www.progea.net/prodotti.php?c=Acquista&p=Acquista_TOPKAPI .
Topoflow: A group of distributed hydrologic tools	http://csdms.colorado.edu/viewvc/topoflow/ .
TSUNAMOS	https://nees.org/warehouse/filebrowser/577 ,
TUNAMI	http://code.google.com/p/tunami/ .
WaSIM: Distributed rainfall-runoff model	http://www.wasim.ch/en/products/model_r9-2-0.htm .

Appendix C.

Software Criterion Used in Evaluation

Table C-1 provides a verbal description of the criteria for the modules used in the analysis of the 31 software packages. The criteria are not exhaustive and can be changed, added to, removed, and adjusted, to reflect the opinions of future users and software updates. The process and most of the criteria are derived from the OPAL procedure described in Daniell (2009), with additional criteria suggested during meetings with World Bank and GFDRR experts.

CRITERION CODE	MAIN CRITERION	DESCRIPTION OF CRITERION	TOTAL VALUE
<i>SOFTWARE ACCESSIBILITY</i>			
SA-001	Global availability	Internet based and normal software versions, current	4
SA-002	Ease of download	Not available just on Internet; downloadable, fast, usable	4
SA-003	Instructions for use	Manual updated every few months	4
SA-004	Documentation	Clear methodology, results, and updating with new versions	4
SA-005	Versions of software	Windows, Mac, or Linux based	4
SA-006	Ability to contact developer	Email/phone contact, updated website, and open discussion	4
SA-007	Ease of coding	Extensible, clear, public domain, all components	4
SA-008	Coding language used	Fortran, C++, web-based, Java, VB, XML, Excel, Python, Matlab, SOSEWIN, self-organizing systems	4
SA-009	Number of open source components	Which components of the system are open source and which closed source	4
SA-010	Licensing	GNU GPL licensing type—e.g., GPLv3, GPLv2; reuse features	4
SA-011	GIS license	No cost associated with GIS; no trial period; fully integrated into system	4
SA-012	Other software needed	Types of other software needed	4
SA-013	Mailing lists	Availability of mailing lists (user and developer)	4
SA-014	Popularity	Number of people registered to the mailing list, and extent to which the systems used	4
SA-015	Code versioning	Latest version of the code	4
SA-016	Bugtracker	Any form of bugtracker?	4
SA-017	Frequency of new releases and patches	How often has the software been updated?	4
SA-018	Data access	Does the user have access to all data?	4
SA-019	Virtual Communities	Setup of virtual communities such as Matlab Central; user-added code, and help.	4

Table C-1 Description and Score Levels for Module Criteria

CRITERION CODE	MAIN CRITERION	DESCRIPTION OF CRITERION	TOTAL VALUE
SA-020	Extensible architecture	Possible for any user, anywhere, for personal use; checked for public use; end-user oriented, with separate documentation available for those wishing to modify or extend the tools or leverage the APIs	4
<i>GRAPHICAL USER INTERFACE</i>			
GU-001	GUI presence	Does the software have a GUI?	4
GU-002	GUI quality	Quality of the GUI (subjective rating)	10
GU-003	GUI help	Help	4
<i>SOFTWARE DETAILS</i>			
SW-001	Integration with Internet	Online updates available when online; user community page also current	4
SW-002	Open editing (Wiki)	Wiki-style interface allows users to update code, leave ideas, and update list of and/or fix bugs in software	4
SW-003	Computation speed	Testing for the various optimization/minimization of coding	4
SW-004	Global language	English used for the analysis, translatable, simple architecture; globally available software language	4
SW-005	Hardwiring	Functions are hardwired in many cases into the coding—SELENA, etc.	4
SW-006	Adaptability (allow additions)	Not a wiki update but a direct system to handle bugs; email-associated with a user number	4
SW-007	Recent developments	Able to use new versions of flood hazard, vulnerability modules, etc.	4
SW-008	Update method (versions)	Update is not via DVD; email user list exists; updates downloadable	4
SW-009	Hybrid methods	Use of more than one method to adapt to different situations (multiple level systems of all risk components)	4
SW-010	Reliance on past methods	Collaboration, or previous models; inherent decision-making	4
SW-011	Current application	Relevance to current conditions and population/settlement data	4
SW-012	Development status	Inclusion of development status and updated list of bugs fixed	4
SW-013	Updated recently	How recently updated?	4
SW-014	Computing power required	Level of hardware required, GHz, GB, and method	4
SW-015	Licensing	Free access installation	4
SW-016	Global testing under all platforms	Windows, Linux, Unix, Mac, Vista, Windows95, and various service packs; no need to change hardware	4

CRITERION CODE	MAIN CRITERION	DESCRIPTION OF CRITERION	TOTAL VALUE
SW-017	Learning and tutorials	Learning and tutorials provided for user awareness	4
SW-018	Optimization	Software optimized with no slow parts and user warnings provided	4
SW-019	Data plotting	Integration with user-based data plotting; many options	4
SW-020	Backup systems during analysis	Backup systems in place for loss of data, more data sets, etc.	4
SW-021	Ease of use	User knowledge check, advanced and normal settings	4
SW-022	Tutorial-based loss analysis	Run-through explaining methodology, to the final results	4
TECHNOLOGICAL ASPECTS			
TE-001	GIS licensing	GIS closed or open source (open source does not always use open GIS)	4
TE-002	GIS production	Integrated GIS, or output in GIS format; use of GIS for exposure selection	4
TE-003	Dynamic improvement	Technology updated; updates applied to software package	4
TE-004	Remote sensing accuracy	% accuracy in terms of height, building type, GIS systems, and other methods; what methods used; how well have they been improved and checked?	4
TE-005	Rapid response/real data	Updating of systems in place to apply real data to software then rapid response	4
EXPOSURE COMPONENTS			
EX-001	Test locations used	Location of test sites	4
EX-002	Collection	Method of collection, collaboration, reliance on technology, etc.	4
EX-003	Global cover	% global population covered; building type, cost, age of building, demographics, etc.	4
EX-004	Portfolio analysis	Is portfolio analysis allowed; can groups of buildings be input?	4
EX-005	Inventory elements	What is the use of the elements and their importance?	4
EX-006	Critical + lifelines	Damage modelling and risk analysis possible for most important elements	4
EX-007	Format of collected material	Format of the collected data	4
EX-008	Ontology-taxonomy	Is there an existing taxonomy to be adhered to?	4

CRITERION CODE	MAIN CRITERION	DESCRIPTION OF CRITERION	TOTAL VALUE
EX-009	Temporal data	Temporal changes to the buildings recorded and satellite images; retrofitting history, seismic code (if any) adhered to	4
EX-010	Spatial data	Spatial changes able to be recorded and collected	4
EX-011	Location	Accuracy of the exposure calculation at the location being tested	4
EX-012	Accuracy of typology	Number of bins used and able to be used to maintain computational speed	4
EX-013	Allow addition of building types	Not set and hardwired; new building types able to be calculated	4
EX-014	Population assessment	Accuracy of the population at any time of day, demographics	4
EX-015	Risk indicators	Exposure data used to identify risk indicators	4
EX-016	Data management	Ease of data access, time taken to access, easy storage method	4
EX-017	Socioeconomic	Inclusion of costs or human components	4
<i>RISK COMPONENTS</i>			
RK-001	Economics (level of layers)	Direct, Indirect, analysis, GNP basis, repair, MDR	4
RK-002	Social (level of layers)	Deaths, levels of injuries, homeless, shelter needs, etc.	4
RK-003	Complexity	Complexity of calculations from damage-loss conversion	4
RK-004	Output accuracy	Calibration with real disasters	4
RK-005	Dynamic vulnerability	Extent to which dynamic changes of vulnerable regions are taken into account in equations	4
RK-006	Social vulnerability	Inclusion of age, demographics, community awareness programs included in the analysis and output	4
RK-007	Age of equations	Age and use of the equations for social and economic costing (new data, new accuracy)	4
RK-008	Uncertainty	Extent to which uncertainty is constrained; use of logic tree approaches	4
RK-009	Visualization	Visualization via GIS or graphs of comparative scenarios	4
RK-010	Decision possibilities	Logic tree approach employed or expert opinion setup	4
RK-011	Single or portfolio-risk insurance/financing	Consideration of single building and portfolio of buildings for insurance purposes	4

CRITERION CODE	MAIN CRITERION	DESCRIPTION OF CRITERION	TOTAL VALUE
RK-012	Disaggregation	Possibility of disaggregating economic data	4
RK-013	Cost-benefit analysis	Possibility of cost-benefit analysis	4
RK-014	Use for land planning and zoning	GIS layering and scenario overlaying to help governments	4
<i>VULNERABILITY COMPONENTS</i>			
VL-001	Empirical ability	Use of empirical methods in one level or more	4
VL-002	Fragility function parameters	Intensity/inundation depth or flow; sediment transport/speed of wind/ wave height	4
VL-003	Rapid response	Ease with which vulnerability damage is constrained exactly for rapid response	4
VL-004	Correlation with damage	Damage state correlation	4
VL-005	Analytical method used	Use of analytical methods	4
VL-006	Complexity of algorithm	Influence on knowledge and coding complexity	4
VL-007	Damage states	Specific damage states used; extent to which they are well defined	4
VL-008	Uncertainty	Extent to which uncertainty is well construed	4
VL-009	Location data	Level on which location data are analyzed	4
VL-010	Universal application for vulnerability functions	Can this be applied globally?	4
VL-011	Ability to detect indicators	Methods used to pick up vulnerability indicators	4
VL-012	Occupancy	Use and occupancy type and rate	4
VL-013	Structural	Basic structural features (materials used, irregularities in plan and elevation, building height and internal characteristics, complex failure mechanisms)	4
VL-014	Quality of stock	Age and number of age brackets, correlation to disaster codes, variability	4
VL-015	Material variability/building differences	Probabilistic techniques and distributions to quantify building variability	4
VL-016	Pictures/GIS	Presence of pictures and GIS of vulnerable houses via screening methods, etc.; panoramic/street view	4
VL-017	Additional non-structure-based damage elements	Nonstructural, contents, business interruption	4
VL-018	Aggregation of data	Data aggregated to create a result?	4

CRITERION CODE	MAIN CRITERION	DESCRIPTION OF CRITERION	TOTAL VALUE
<i>POST-EVENT ANALYSIS</i>			
PS-001	Maps	Maps produced or not? Collaboration with disaster managers and event loss analysts?	4
PS-002	Direct management	Use of lifeline data and the forecast to implement directly into management after an event	4
PS-003	Disaster management tools	Technological tools used before and after flood as part of the system	4
PS-004	Speed of calculation	Speed from source to an output loss estimate	4
PS-005	Accuracy	Comparison with previous disaster events in terms of loss	4
PS-006	Optimization of building choice	Use of screening methods, before and after; presence of disaster management at most at-risk areas	4
PS-007	Functionality/communications	Ease with which information is transferred to relevant people (army, government)	4
PS-008	Topography/GIS	Output of topography and GIS data for use on the ground	4
PS-009	Consecutive event modelling	In tune with the hazards looked at; warning system production	4
<i>FORECASTING</i>			
FC-001	Speed	Speed for a certain large-scale calculation	4
FC-002	Accuracy	Large-scale accuracy based on comparison with past floods	4
FC-003	Database of tested scenarios	Availability for use in post-disaster analysis (can apply quick previous estimates)	4
<i>OUTPUTS OF THE SOFTWARE</i>			
OU-001	GIS	Format easily visible within the GIS program in the package	4
OU-002	One-page summary	Similar to Onepager but with more features (optimization visualization, uncertainties)	4
OU-003	Ease of reading results/format	Simplicity and ease of application for use in Open Office Math; results already graphed	4
OU-004	Loss statistics	Event loss tables, year probabilities, annual rate of exceedance, etc.; primary and secondary uncertainties	4
OU-005	Statistics module	Presence of view and analysis for comparing statistics	4
OU-006	Rerun module	Ease of rerunning the analysis	4

CRITERION CODE	MAIN CRITERION	DESCRIPTION OF CRITERION	TOTAL VALUE
<i>HAZARD – FLOOD</i>			
HF-001	Station data	Possibility of using station data in the calculation	4
HF-002	Numerical model	Type of numerical modelling used	4
HF-003	1D/2D/3D modelling	Types of dimensional wave equations solved	4
HF-004	Empirical data (raster measured data)	Use of empirical data for analysis	4
HF-005	Theoretical data (modelled)	Use of theoretical data for analysis	4
HF-006	Ability to update hydrographs	Possibility of updating hydrographs	4
HF-007	Disaggregation	Ways in which data can be disaggregated	4
HF-008	Rainfall/riverine/coastal	Rainfall, riverine, and coastal hazards accounted for	4
HF-009	Link to storm surge	Storm surge accounted for	4
HF-010	Intensity-frequency-duration	Use of intensity-frequency-duration curves	4
HF-011	Zoning systems for flood inbuilt	Are zoning systems for flood inbuilt, and can flood control structures be accounted for?	4
HF-012	Stochastic catalog production	Possibility of producing stochastic catalogs	4
HF-013	Optimization techniques	Specific optimization/minimization techniques used	4
HF-014	Historical flood event databases	Possibility of using historical flood event databases	4
HF-015	Digital elevation model use/ topography use	Approach to accounting for topography	4
HF-016	On floodplain vs. off floodplain hazard	Calculation of hazard on floodplain only, or off floodplain as well	4
HF-017	Water speed analysis	Water speed (flow, velocity) taken into account	4
HF-018	Sediment transport	Possibility of accounting for sediment transport	4
HF-019	Model resolution	What is the model resolution?	4
HF-020	Rainfall model (resolution and type)	Types of rainfall models used	4
HF-021	Catchment (simple scaling and transposition OR rainfall-runoff)	Types of catchment that can be modelled	4
HF-022	Rainfall runoff (distributed or lumped)	Type of rainfall-runoff model: distributed (spatially variable) or lumped (spatially non-variable)	4
HF-023	River reach models (channel-flow routing models or hydrodynamic river models)	Type of river reach models that can be used	4
HF-024	Probabilistic and/or deterministic	Model's use of single studies vs. calculation of event return periods	4

CRITERION CODE	MAIN CRITERION	DESCRIPTION OF CRITERION	TOTAL VALUE
HF-025	Location specificity	Possibility of undertaking entire process in any location vs. necessity of undertaking process in fixed location	4
HF-026	Snow and other forms of precipitation	Possibility of taking snow, etc. into account	4
HF-027	Flood control input/secondary effects	Possibility of undertaking flood control input	4
HF-028	Type of hazard files	Types of hazard files used; ease of use	4
HF-029	Temperature/climate change	Possibility of accounting for climate change and temperature	4
<i>HAZARD - WIND / STORM / HURRICANE</i>			
HS-001	Station data	Possibility of using station data in the model	4
HS-002	Numerical model	Type of numerical modelling used	4
HS-003	1D/2D/3D modelling	Possibility of accounting for 1D, 2D, 3D modelling	4
HS-004	Empirical data [raster measured data from meteorology centers]	Possibility of using empirical data in the modelling	4
HS-005	Synthetic theoretical data [modelled]	Possibility of producing synthetic/theoretical storms	4
HS-006	Surge	Consideration of surge	4
HS-007	Hail	Possibility of modelling hail	4
HS-008	Tornado/lightning	Possibility of using tornados and lightning	4
HS-009	Pressure	Possibility of applying pressure	4
HS-010	Peak wind speed or multi-wind-speed-based	Use peak wind speed vs. multiple wind speeds	4
HS-011	Location and topographic data	Specific location and topographic data	4
HS-012	Radius of maximum winds	Model's use of radius of maximum winds	4
HS-013	Modelling details	Specific modelling details?	4
HS-014	Deterministic	Possibility of modelling deterministic storms	4
HS-015	Probabilistic	Possibility of accounting for probabilistic modelling	4
HS-016	Local effects or not	Types of local effects accounted for	4
HS-017	Spatial resolution of the wind model	Spatial resolution of the wind model	4
HS-018	Temporal resolution of the wind model	Temporal resolution of the wind model	4
HS-019	Use of historical events	Possibility of using historical events	4
HS-020	Use of severity Indices	Types of severity indices used	4
HS-021	Format of hazard file	Specific format of hazard file	4
<i>HAZARD - EARTHQUAKE AND ASSOCIATED EFFECTS</i>			
HE-001	Spectrum-based vs. intensity	Use of spectrum-based technique vs. intensity-based method vs. hybrid	4

CRITERION CODE	MAIN CRITERION	DESCRIPTION OF CRITERION	TOTAL VALUE
HE-002	User-defined earthquakes and events	Possibility of users defining earthquakes or GM	4
HE-003	Magnitude/location	Type of magnitude and location used	4
HE-004	Observed GMs	Use of past equations or real-time GMs to produce GMs	4
HE-005	Empirical GMs	GMPEs and their global application	4
HE-006	Theoretical GMs/basis	Theoretical modelling of GMs produced; level of theoretical modelling of source, path, and site effects	4
HE-007	Ability to update GMs	Possibility of user applying regional GMs and new GMs	4
HE-008	Seismic source types available	Types of seismic sources analyzed	4
HE-009	Probabilistic seismic hazard analysis (reliance)	Probabilistic techniques used; Poissonian or time dependent, multiple options	4
HE-010	Deterministic seismic hazard analysis (reliance)	Either observed or deterministic techniques used; possible logic tree applied to parameters	4
HE-011	Disaggregation	Possibility of disaggregating data into components (magnitude-distance-epsilon)	4
HE-012	Uncertainty in hazard parameters	Inclusion of uncertainty in hazard parameters	4
HE-013	Spatial or temporal correlation	Spatial and temporal correlation between GMs possible	4
HE-014	Stochastic catalogs	Application of stochastic catalogs for completeness	4
HE-015	Optimization techniques	Demand data and other optimization/minimization	4
HE-016	Historical earthquake catalogs	Extent to which historical catalogs are used	4
HE-017	Active fault database	Extensiveness of active fault database; fault history in terms of earthquakes	4
HE-018	Instrumental earthquake catalog	Possibility of using instrumental data and applications	4
HE-019	Soil database/site class	Extent of the site classification scheme used + conversion system used to final ordinates	4
HE-020	Geodetic data standards	Quality and accuracy, collection, code types and data, transfer and exporting, metadata, and accessibility for GPS and GIS	4
HE-021	Liquefaction	Liquefaction taken into account, intensity based, detailed or not	4

CRITERION CODE	MAIN CRITERION	DESCRIPTION OF CRITERION	TOTAL VALUE
HE-022	Fault rupture	Fault rupture taken into account, GIS based, detailed or not	4
HE-023	Landslide/slope stability	Landslides and slope stability taken into account, empirical vs. analytical, detailed or not	4
HE-024	Tsunami (linking into other software)	Tsunamis, links to other software, basis, details, etc.	4
HE-025	Fire	Fire analysis	4
HE-026	Other: aftershock + volcano + quake lakes	Aftershocks, volcanoes, quake lakes taken into account (basis and details)	4
HE-027	Format of hazard file	Ease of using format of hazard file	4
<i>HAZARD - TSUNAMI / STORM SURGE / WAVE</i>			
HT-001	Intensity metric used for tsunami or storm surge	Wave height, energy	4
HT-002	User defined earthquakes and events	Possibility of users defining earthquakes or GM	4
HT-003	Storm model	Storm model if model is only for storm surge	4
HT-004	Fault model	Type of block modelled	4
HT-005	Wave model	Model type (1D, 2D, or 3D), equation used	4
HT-006	Roughness coefficients	Roughness coefficients used; basis for coefficients	4
HT-007	Probabilistic tsunami hazard analysis (reliance)	Probabilistic techniques used	4
HT-008	Deterministic tsunami hazard analysis (reliance)	Deterministic techniques used	4
HT-009	Disaggregation	Possibility of disaggregating data into components (magnitude-distance-epsilon)	4
HT-010	Stochastic catalogs	Application of stochastic catalogs for completeness?	4
HT-011	Historical tsunami or storm surge catalogs	Extent to which historical tsunami catalogs are used	4
HT-012	Coastal resolution	Resolution defined for inundated coastline	4
HT-013	Bathymetry	Specific bathymetry data needed	4
HT-014	Active fault database	Extensiveness of the active fault; history on fault	4
HT-015	Instrumental earthquake catalog	Possibility of using instrumental data and applications	4
HT-016	Geodetic data standards	Quality and accuracy, collection, code types and data, transfer and exporting, metadata, and accessibility for GPS and GIS	4
HT-017	Other: aftershock + volcano + quake lakes	Aftershocks, volcanoes, quake lakes taken into account (basis and details)	4
HT-018	Format of hazard file	Computer format	4

Appendix D.

Summary of Software Packages in Initial Assessment

A list of all software packages used in the assessment and the results of the initial review are provided in table D-1. The table categorizes the packages by the four peril categories, indicates whether the software package was selected for more detailed analysis, and provides a quick synopsis of the package’s features. The name of each software package is hyperlinked to the software’s URL. (There are a number of other packages for flood and wave that were not included in this table; links for these are listed in appendix A.)

The software packages selected by the initial review are listed in table D-2. Further analysis of the packages used subjective criteria that accounted for the packages’ outputs, the hazard and risk they addressed, and their accessibility. Table D-2 highlights in green the packages selected for detailed review.

Although the inland flood model RORB is listed in Table D-1, it was not included in the assessment and should be looked at in the future. The source code is not available; however, it is state of the art in terms of rainfall-runoff simulations used to calculate flood hydrographs from rainfall. It allows for distributed, nonlinear modelling and can work in urban and rural catchments. Also, a new Australian rainfall and runoff model, AR&R, is coming out soon and should be examined in the future.

Table D-1

Summary by Hazard Group of Software Packages Included in the Analysis

TYPE OF SOFTWARE PACKAGE	CHOSEN	TYPE OF SOFTWARE	DOWNLOADABLE	OPEN ACCESS OR CLOSED ACCESS	ACTIVE	DOCUMENTATION	SOFTWARE CODE AVAILABLE?	PROGRAMMING LANGUAGE	INSTITUTION	LOCATION
CAPRA	Yes	Earthquake	YES	Open	YES	YES	YES	Visual Basic.NET	World Bank	Central America
CATS	No	Earthquake	NO	Closed	YES	YES	NO	ESRI ArcView	FEMA, ESRI	U.S.
CREST	No	Earthquake	YES	Closed	NO	YES	YES	ArcGIS, ArcObject, VBA	CEDIM	Germany
DBELA	No	Earthquake	YES	Open	YES	YES	YES	Matlab	EU CENTRE	Italy
ELER	Yes	Earthquake	YES	Open	YES	YES	NO	Matlab	JRA-3, NORSAR, Imperial	Europe
EPEDAT	No	Earthquake	NO	Closed	Half	YES	NO	Windows-based, Mapinfo	EQE International	California, U.S.
EQR Matlab	No	Earthquake	NO	Open	YES	YES	YES	Matlab	GA	Australia
EQR Python	Yes	Earthquake	YES	Open	YES	YES	YES	Python	GA	Australia
EQSIM	No	Earthquake	NO	Closed	NO	YES	NO	C++, xmf	KIT	Germany
Extremum	No	Earthquake	NO	Closed	YES	YES	NO	Windows-based, GIS	Extreme Situations Research Center Ltd.	Russia
HAZ-Taiwan (TELES)	No	Earthquake	NO	Closed	YES	YES	NO	Microsoft Visual C++ and MapInfo	NCREE	Taiwan

TYPE OF SOFTWARE PACKAGE	CHOSEN	TYPE OF SOFTWARE	DOWNLOADABLE	OPEN ACCESS OR CLOSED ACCESS	ACTIVE	DOCUMENTATION	SOFTWARE CODE AVAILABLE?	PROGRAMMING LANGUAGE	INSTITUTION	LOCATION
Hazus-MH	Yes	Earthquake	YES	Open	YES	YES	NO	VB6, C++, ArcGIS	USGS	U.S.
InaSAFE	Yes	Earthquake	YES	Open	YES	YES	YES	Java, QGIS plugin	AIFDR	Indonesia
InLET	No	Earthquake	NO	Closed	YES	YES	NO	js, Windows	ImageCat, Inc.	California, U.S.
LESSLOSS/ LNECLOSS	No	Earthquake	NO	Closed	NO	YES	NO	Fortran	LNEC, Consortium	Lisbon
MAEviz	Yes	Earthquake	YES	Open	YES	YES	YES	EclipseRichClient, Geotools	Uni. Illinois	U.S.
mHARP	Yes	Earthquake	YES	Open	YES	YES	YES	EclipseRichClient, Geotools	University of Illinois	U.S.
MIRISK	No	Earthquake	YES	Closed	NO	YES	NO	HTML, Java, PHP	Kyoto University	Japan
OpenQuake	Yes	Earthquake	YES	Open	YES	YES	NO	Python, Java	GEM	Italy
OpenRISK	No	Earthquake	YES	Open	YES	YES	YES	Object-oriented, Web, GUI	SpaRisk LLC	Worldwide
OSRE	No	Earthquake	YES	Open	NO	YES	YES	Windows-based GUI, Java	Kyoto University	Japan
PAGER	No	Earthquake	NO	Closed	YES	YES	NO	Matlab, unknown	USGS	U.S.
QLARM- WAPMERR	No	Earthquake	NO	Closed	YES	YES	NO	Internet-based, Java, PostgreSQL	ETHZ and WAPMERR	Switzerland
RADIUS	No	Earthquake	YES	Closed	NO	YES	NO	Excel	UNEP	India
REDARS	No	Earthquake	YES	Closed	YES	YES	NO	GUI Windows, Basic	MCEER, ImageCatInc	California, U.S.
REDAS	No	Earthquake	NO	Closed	YES	YES	NO	GUI Windows, Basic	PHIVOLCS	Philippines
Risk.IITB	No	Earthquake	YES	Closed	YES	YES	YES	ArcGIS, ArcObject, VBA	IIT Bombay	India
RiskScape	Yes	Earthquake	YES	Open	YES	YES	NO	Java-GIS not needed	NIWA and GNS	New Zealand
SAFER	No	Earthquake	NO	Closed	NO	YES	NO	Same as SELENA	Multiple EU	Europe
SEISMOCARE	No	Earthquake	NO	Closed	NO	YES	NO	GIS based, VBA	Multiple EU	Greece
SEISVARA	No	Earthquake	YES	Open	YES	YES	NO	Excel based	NORSAR	India
SELENA	Yes	Earthquake	YES	Open	YES	YES	YES	Matlab, C++ depending on version	NORSAR	Norway
SES2002 and ESCENARIS	No	Earthquake	NO	Closed	YES	YES	NO	Visual Basic, dll using MapObjects 2.1	Gen Dir. Of Civil Protection	Spain
SIGE	No	Earthquake	NO	Closed	YES	YES	NO	Visual Basic, dll using MapObjects 2.1	OSSN	Italy
SPBELA	No	Earthquake	NO	Closed	NO	YES	NO	n/a	EU CENTRE	Italy

TYPE OF SOFTWARE PACKAGE	CHOSEN	TYPE OF SOFTWARE	DOWNLOADABLE	OPEN ACCESS OR CLOSED ACCESS	ACTIVE	DOCUMENTATION	SOFTWARE CODE AVAILABLE?	PROGRAMMING LANGUAGE	INSTITUTION	LOCATION
SPBELA	No	Earthquake	NO	Closed	NO	YES	NO	n/a	EUCENTRE	Italy
SYNER-G [Eqvis]	No	Earthquake	YES	Closed	YES	YES	NO	Matlab	Consortium	Europe
StrucLoss/ KOERILoss	No	Earthquake	NO	Closed	YES	YES	NO	MapBasic and MapInfo	METU	Turkey
HEC-RAS	Yes	Flood	YES	Open	YES	YES	NO	Fortran originally	U.S. Army Corps of Engineers	U.S.
ANUGA	No	Flood	YES	Open	NO	YES	YES	Python and C	ANU and GA	Australia
ATHYS	No	Flood	YES	Open	YES	YES	NO	Fortran	IRD	France
BASEMENT	Yes	Flood	YES	Open	YES	YES	NO	Python code in some parts, unknown for some	ETH-Z	Switzerland
Champ2.0	No	Flood	YES	Open	YES	YES	NO	Windows- interfaced Visual Basic	FEMA	U.S.
DR3M	No	Flood	YES	Open	NO	YES	YES	Fortran 77	USGS	U.S.
GSFLOW	No	Flood	YES	Open	YES	YES	YES	Fortran 90 and C, with GUI	USGS	U.S.
InaSAFE	Yes	Flood	YES	Open	YES	YES	YES	Python	AIFDR	Indonesia
Kalypso	Yes	Flood	YES	Open	YES	YES	YES	Java	Hamburg University of Technology and Bjoernsen Consulting Engineers	Germany
USGS [NSSv6, OWLS, PKFQ]	No	Flood	YES	Open	Some	YES	YES	DOS-based	USGS	U.S.
Quick20	No	Flood	YES	Open	YES	YES	NO	DOS-based, Visual Basic, Binary	FEMA	U.S.
ReFH	No	Flood	YES and No	Closed	YES	YES	NO	Spreadsheet-OS; full software- closed	CEH and Wallingford Solutions	United Kingdom
RiskScape	Yes	Flood	YES	Open	YES	YES	NO	Java	GNS and NIWA	New Zealand
WaSIM	No	Flood	YES	Open	YES	YES	NO	C+	ETH-Z	Switzerland
HydroFOSS	No	Flood	YES	Open	NO	YES	YES	GrassGIS plugin	IST-SUPSI	Worldwide
Hydrognomon	No	Flood	YES	Open	YES	YES	NO	Linked to non-free libraries, unknown	NTU Athens	Greece
CAPRA [ERN- Flood, ERN- LLuvia]	Yes	Flood	YES	Open	YES	YES	YES	VB	World Bank	Central America
R.Haz.Flood	No	Flood	YES	Open	YES	YES	YES	GrassGIS plugin, R	M. D. Leo	Italy

TYPE OF SOFTWARE PACKAGE	CHOSEN	TYPE OF SOFTWARE	DOWNLOADABLE	OPEN ACCESS OR CLOSED ACCESS	ACTIVE	DOCUMENTATION	SOFTWARE CODE AVAILABLE?	PROGRAMMING LANGUAGE	INSTITUTION	LOCATION
TELEMAC-MASCARET	Yes	Flood	YES	Open	YES	YES	YES	Fortran	Collaboration between Germany, UK, France	France
Hazus Flood	Yes	Flood	YES	Open	YES	YES	NO	VB6, C++, ArcGIS	FEMA	U.S.
RORB	Yes	Flood	YES	Open	YES	YES	NO	Fortran	Monash University/SKM	Australia
Sobek Suite - 1D, 2D	Yes	Flood	YES	Open	YES	YES	YES	C++, GIS and other connecting languages	Deltares	Netherlands
noFDP IDSS with SOBEK-River [1D]	Yes	Flood	YES	Open	YES	YES	YES	Eclipse, Java	Darmstadt University	Germany as part of INTERREG III
TauDEM	No	Flood	YES	Open	YES	YES	YES	C++, VB	USU	U.S.
Delft-3D-FLOW	Yes	Flood	YES	Open	YES	YES	YES	C++, GIS and other connecting languages	Deltares	Worldwide
PIHM and GIS and QGIS plug in	No	Flood	YES	Open	YES	YES	YES	C, C++ and QGIS	Penn State	U.S.
SWMM	No	Flood/ stormwater	YES	Open	YES	YES	YES	Fortran up to v4, now C in v5 with rewrite	EPA	U.S.
ANUGA and TsuDAT	Yes	Tsunami/ storm surge	YES	Open	YES	YES	YES	Python	ANU and GA	Australia, Indonesia
CAPRA [ERN-Surge, ERN-Tsunami via CRISIS2007]	Yes	Tsunami/ storm surge	YES	Open	YES	YES	YES	VB	World Bank	Central America
RiskScape	Yes	Coastal surge/ tsunami	YES	Open	YES	YES	YES	Java	GNS and NIWA	New Zealand
ADCIRC	No	Storm surge	NO	Open	YES	YES	NO	Fortran 90	University of North Carolina	U.S.
COULWAVE	No	Storm surge	YES	Open	YES	YES	YES	Fortran 90	Cornell University, Texas A&M	U.S.
Delft-3D-WAVE [SWAN]	Yes	Storm surge	YES	Open	YES	YES	YES	C++	Delft [Deltares]	Netherlands
InaSAFE	Yes	Tsunami	YES	Open	YES	YES	YES	Python	AIFDR	Indonesia
OsGEO Tsunami [R.tsunami]	Yes	Tsunami	YES	Open	YES	YES	YES	GrassGIS plugin, R	IST-SUPSI	Italy

TYPE OF SOFTWARE PACKAGE	CHOSEN	TYPE OF SOFTWARE	DOWNLOADABLE	OPEN ACCESS OR CLOSED ACCESS	ACTIVE	DOCUMENTATION	SOFTWARE CODE AVAILABLE?	PROGRAMMING LANGUAGE	INSTITUTION	LOCATION
Runup v2	No	Tsunami/storm surge	YES	Open	YES	YES	YES	DOS-based	FEMA	U.S.
SLOSH	Yes	Storm surge	Yes	Open	YES	YES	YES	Python and C vers 3.94	NOAA	U.S.
TOMAWAC and WAVE - TELEMAC	Yes	Wave/storm surge	Yes	Open	YES	YES	YES	Fortran	Collaboration between Germany, UK, France	France
Wave Watch 3	No	Storm surge	YES	Open	YES	YES	YES	Fortran	NCEP	U.S.
SWAN	Yes	Storm surge	YES	Open	YES	YES	YES	Fortran	Delft University	Netherlands
ComMIT [MITgcm]	No	Tsunami	NO	Open	YES	YES	No	Java	MIT	U.S.
Hazus-MH	Yes	Hurricane	YES	Open	YES	YES	No	VB6, C++, ArcGIS	FEMA	U.S.
RiskScape	Yes	Windstorm	YES	Open	YES	YES	No	Java	GNS and NIWA	New Zealand
CAPRA Hurricane	Yes	Hurricane rainfall	YES	Open	YES	YES	YES	VB	World Bank	Central America
TCRM	Yes	Tropical cyclone modelling	YES	Open	YES	YES	YES	Python and some C	GA	Australia



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