# FloodRisk: a QGIS plugin for flood consequences estimation

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## Abstract

In times of increasing disaster losses, the reduction (or mitigation) of consequences of natural hazard needs to be effective and efficient. An in-depth understanding of the effects of disasters, is required in order to develop forms of sustainable risk management as well as risk mitigation and adaptation strategies (Directive 2007/60/CE; IPCC, 2012). This is especially true given the limited financial resources available.

In this context, we developed a prototype tool: FloodRisk, a QGIS plugin that provides the assessment of flood consequences, in terms of loss of life and direct economic damages.

The proposed cost assessment tool aims to be used for decision support systems and policy development of risk management.

## Keywords

Flood risk, risk map, open source software, desktop GIS, QGIS

## 1 Introduction

According to the IPCC (2012), one of the most important consequences of climate change will be the increase in the frequency and magnitude of extreme events such as floods.

Flood risk management aims to reduce the impact of floods. The quantification and evaluation of flood consequences is one of the most important factor to be considered in deciding how to reduce flood damages and to evaluate alternative intervention strategies in terms of their relative benefits and costs (Albano et al, 2014). In this context, an open source and free analysis toolbox, part of the open-source geographic information system Quantum GIS, was developed for estimating flood impacts due to flooding and, hence, to help authorities better understand and manage flood risk. These tool are not intended to be business-ready software applications, however it is usable by third parties for evaluation and demonstration purposes.

The proposed prototype software tool, called "FloodRisk", is able to calculate and view the number of people affected and direct damages to properties caused by any flood scenario in any chosen area.

For example, if there has been the need for interventions to ensure the safety of a number of hydraulic structures (eg. dams or levees), which could result in

a hazard downstream, it is necessary to decide how selecting the highest-priority of interventions. In these cases, the assessment of the consequences of any failures or accidents, it is an important element to support the choice of priority interventions. This is especially true given the limited financial resources available.

In this context, furthermore, the spatial distribution of people and property within the flooding area can cause different consequences and therefore a GIS tool is particularly useful to make an analysis that takes into account the actual characteristics of the territorial system downstream the hydraulic structure.

After this brief introduction, sect. 2 focuses on the conceptual framework and the utilized methodology while sect. 3 on the software tool called "FloodRisk".

## 2 "FloodRisk"  tool Conceptual Framework

### 2.1 General "FloodRisk" Framework for flood risk assessment

The term "*risk*" has a range of meanings and multiple dimensions relating to safety, economic, environmental and social issues.

The terminology of "*risk*" has been developed across a wide range of disciplines and activities, therefore there is potential for misunderstanding in technical terminology associated with risk assessment.

Most important is the distinction that is drawn between the words "*hazard*" and "*risk*". To understand the linkage between hazard and risk it is useful to consider a simple conceptual model: for a risk to arise there must be hazard that consists of a 'source' or initiator event (i.e. high rainfall); a 'receptor' (e.g. flood plain properties) and a susceptibility of receptor to be damaged (*vulnerability*), (Gouldby & Samuels, 2005) .

A hazard does not automatically lead to a harmful outcome, but identification of a hazard does mean that there is a possibility of harm occurring. The actual harm depend upon the exposure to the hazard and the characteristics of the receptor. In practice exposure and vulnerability are often captured in the assessment of the consequences; thus risk can be viewed in simple terms as "probability times damage", and thus describes the expected damage that can occur or will be exceeded with a certain probability in a certain period (Merz et al, 2010).
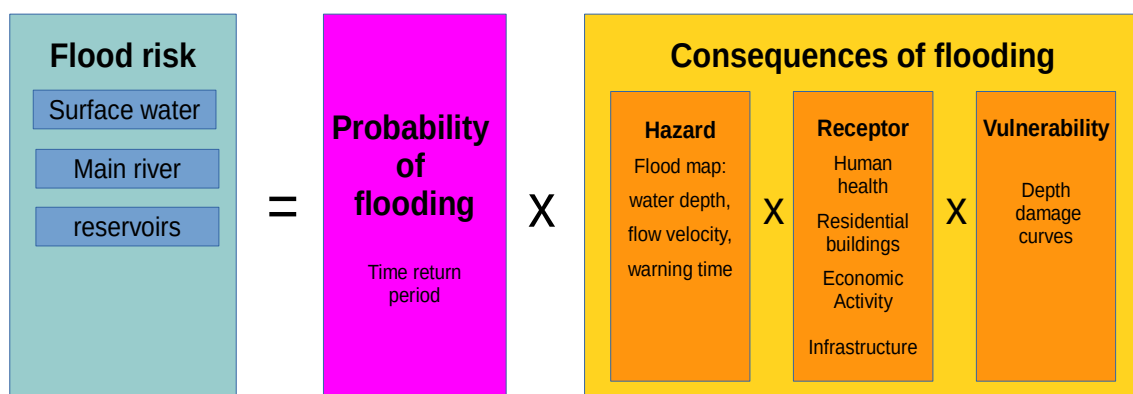
## Risk = (Probability) x (Consequence)



*Figure 1 :Framework for flood risk assessment*

The conceptual framework for flood risk assessment it is represented in Figure 1. The proposed GIS tool, within this framework, deals with the assessment of the consequences, and therefore it helps to perform the operations described in the last part of the graph. Therefore, "FloodRisk"  can support the identification of people and assets at risk, the planning and evaluation of effective flood mitigation and control measures, the creation of flood risk maps for awareness raising.

## 2.2 Required data for consequences estimation

The tool performs a simple risk assessment in which it consider fixed event scenarios where the probability of each scenario is estimated separately and it calculates the consequences deterministically.

The key data required, described in the following, therefore concern: hazard, receptor and vulnerability.

### 2.2.1 Hazard

The data needed to quantify the flood hazard are the inundation map detailing the characteristics of the flood. "FloodRisk" tool requires specifically maps of:

- maximum depth values;

- maximum velocity values.

These data are the output from a 2D hydraulic model or integrated 1D-2D model. Outputs generated from a 2D hydraulic model, indeed, can include maximum depth and maximum velocity values for every inundated grid cell in the study area. Using a GIS, depth grids can be multiplied by velocity grids to obtain maximum  "Peak Unit Flow rate (DV)" values, that can be calculated also by the ratio of discharge and water depth. These DV values are then categorized into ranges of values which define low, medium, and high severity zones.

Since timely flood warnings can save lives, warning time is a very important data to assess the consequences for people.

Therefore the tool needs as input the information of the zones with different warning time, called here:

- warning time map.

The warning time indicates the amount of time between the reception of a warning and the instant in which the population of each structure could be affected by the flood event, i.e. the amount of time in which the population of each structure can mobilize or adopt mitigation measurements. It may be different from zones even if the alarm should be launched instantly for all people, because there is a propagation time of the flood, and, then, the territories are flooded at different times. Indeed, the warning time depends also by the propagation time of flood wave that can be calculated by using a hydraulic model.

### 2.2.2 Receptor

The quantification of the receptors, called exposure, refers to people, assets

and activities, threatened or potentially threatened by a hazard.

"FloodRisk" tool stores exposure data of the study area in a geo-database. The dataset must consists of the following maps:

- the polygon boundary of the study area;
- census map of population;
- buildings and/or land use map;
- infrastuctures lines maps (eg. roads, railways etc.) .

An essential infromation on the buldings map is the classification by occupancy type (eg. residential, commercial, industrial buildings, etc.). Indeed, the most widely used tool for estimating damage before an event, i.e. the vulnerability curves/functions, (which are described in the next paragraph), relations an hazard parameter, generally the flood depth, with the specific occupancy type of the exposed elements.

## 2.2.3 Vulnerability

Vulnerability is a characteristic of a system that describes its potential to be harmed.

Catastrophic floods, such as those by dam-break or levee failure, can cause more fatalities: for the quantification of the vulnerability, in this case, it is generally adopted the parameter "*fatality rate*" that is the percentage of population at risk who die. Fatality rates are based on *flood severity*, *warning time*, and *warning quality*.

There are empirical methodologies of literature calibrated on historical cases that provide values of fatality rates as a function of the parameters mentioned above. FloodRisk tool contains some of these tables of values.

A flood can cause, also, many types of economic damages that can be classified in a variety of ways: the tool is able to calculate the tangible direct physical damages, that are, the damages result from the actions of floodwaters on property and structures.

Tangible damages are usually quantified and measured as monetary losses.

Flood damages depend on many variables. These variables might include depth of water, velocity of floodwaters, duration of flood, sediment load, contamination. But flood damage to structure is strongly dependent on the water depth of a flood (Merz et al., 2010): depth of flooding  is always expected to be associated with an increase in flood damages; at some point the water will be so deep as to have caused all the damage possible and the damage curve would eventually go horizontal.
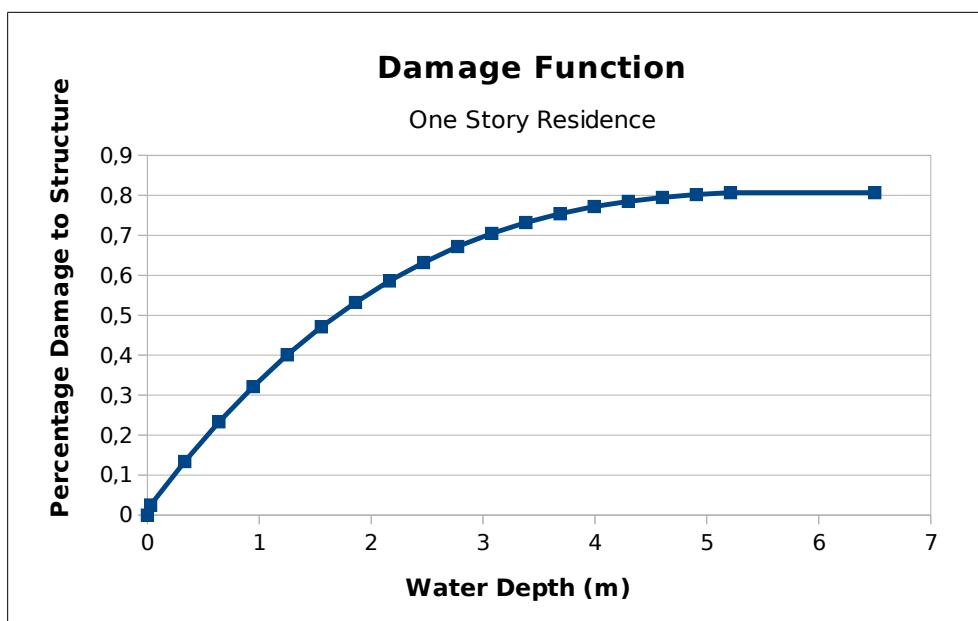
*Figure 2 :Example of depth-damage function*

Figure 2 above shows a graph of the mean (%) values of damage for single family residential structures. This curve represents structure damages only, content damages are evaluated separately using a depth-percent damage curve for the contents of a house.

To calculate the monetary value of the damage, percentages are multiplied by the maximum damage value of proprieties.

For each class of asset the tool needs to be provided, as input, with the two curves of depth-percent damage for structure and contents. The values of assets are included as properties of the individual elements of the map in unit terms (eg. Euro / sq m).

The tool contains default curves and values derived from the literature. Users can develop, and upload in the tool, their own depth-damage functions deduced following standard methods. However, this can be expensive and time-consuming, and is only recommended for very high value properties that dominate local damage estimates and/or for large, mixed used sites such as hospitals, power stations and water treatment works.

## 2.3 Utilized methodologies

This section focus on the description of the methods currently available for the direct flood impact estimation through "FloodRisk" tool.

The direct flood impact can subdivide in tangible and intangible (non-market) damage. On one hand, the direct tangible damage covers, for example, damage to structures and contents, destruction of infrastructure such as roads, rail roads. On the other hand, the evaluation of the direct intangible (non-market) damage can be ascribe, for example, to the estimation of loss of life. The methods chosen to evaluate the aforementioned direct impact is described in the following sub-sections.

2.3.1 Direct economic damages estimation

A common method to  to assess potential tangible direct physical damages is

the application of depth–damage curves. The damage to residential, commercial and industrial property can be assessed using depth–damage curves, which describe the relationship between levels of inundation and damage incurred.

Surveyed damage estimates for a range of flood levels are essential to their production. It is recommended, where possible, to use depth–damage curves that represent local conditions and the types of buildings present. Where this is not possible because locally specific data does not exist, use available depth–damage curves produced as a result of previous flood damage studies.

There are two different approaches for the application of depth–damage curves. These are the land use based approach and the object based approach. Both methods use land use types as an input variable. The object based approach adding more detail to urban areas; this has been done by replacing the urban land use type of the classical land use based approach through the buildings map. FloodRisk tool can perform the analysis according both approaches, depending on the type of data that the user loads into geo-database. The important thing is that depending on the type variable used for land use/buildings map to be associated with the proper depth-damage curves.

In the GIS-systems, the input variables as land use or buildings map, inundation depth, associated depth-damage curves, maximum damage value, can easily be aggregated to perform an analysis of the amount of damage that would occur, should a flooding happen.


## 2.3.2 Population at Risk and Loss of Life estimation

Different methods currently existing fo the estimate the loss of life. "FloodRisk" utilized simple and parsimonious methods based on the contributing factors that could be generally available: hazard factors, such as water depth and water velocity,  the general preparadness of the society, such as existence of public education on flood risk, warning and communicatation system, coordination between emergency agencies and authorities, time of day, and warning factors, such as warning time. Other more sofisticated models take into account other contributing factors, for example, the physical condition of the people potentially invoved in the calamitous event, such as age, gender and so on, or the water quality and temperature, floating debris, that are of great interest but they are not easy to collect.

In "FloodRisk" the first step for the loss of life estimation is to obtain the map of the population at risk by superimposing the inundation map and the population density map.  The first is an input data, the second  was created by converting vector files of population census into raster files. In the conversion is assumed, for simplicity, a uniform distribution of the total population for each polygon of census map.

Once calculated the map of the population at risk, the number of potential fatalities is obtained by multiplying population at risk time the fatality rate.

Values of fatality rates are found in several sources in the literature.

The tool allows the user the choice of the fatality rate between two of the available scientific methods:

- US Department of Homeland Security (DHS 2011)
- SUFRI Methodology for pluvial and river flooding risk assessment (Escuder Bueno et al, 2011)

The first concerns the potential risks associated with the failure or disruption of dams, the second for river flooding.

For both methodologies fatality rates depend on warning time, flood severity and on the effectiveness in the evacuation of the population.

Warning time is an input data. **Flood severity** is a parameter that assumes the values **low**, **medium** and **high** in function of the parameter hydraulic *DV* that is the depth of water multiplied by velocity and it is representative of the general level of destructiveness that would be caused by the flooding.

The third factor is evaluated differently by the two methodologies.

In DHS it is defined as "Flood Severity Understanding" and describe the degree to which the events that are about to unfold are understood.

The flood severity understanding categories are as follows:

- **Vague** Understanding of Flood Severity: warning issuers have not yet seen the dam fail or do not comprehend the true magnitude of the flood that is about to ensue.
- **Precise** Understanding of Flood Severity: warning issuers have an excellent understanding of the flooding due to observations of the flooding

In SUFRI methodology the third factor is a degree of readiness of population. Ten categories (C1 to C10) are established, dependig on the existence of public education on flood risk, warning and communicatation system, and, coordination between emergency agencies and authorities.

## 3 Flood Risk tool Interface

The assessment of the consequences of flooding requires the analysis of the extent and distribution of intensity of the hazard (for example, depth of the water and its velocity) and the overlap with the spatial distribution of people and property exposed.

Geographical information systems (GIS) tools are ideal to manage spatial information, providing adequate spatial processing and visualization of results. For this reason, we chosen to adopt a GIS as a basis for the development of a tool for assessing flood risk. Moreover, in this study, a free and open-source GIS solution is utilized as platform to integrate the described tool, called "Floodrisk", taking into account the quality and dissemination nowadays reached by Geographic Free/Open-Source Software (GFOSS) and having it in order to make available the results of the project.

Analyzing different desktop free and open sources GIS projects, we chose Quantum GIS (QGIS): the main advantage of QGIS relies on the easiness and quickness in developing new plug-ins, using Python language. Therefore, this project was developed in QGIS platform and the interface was created in Python.

FloodRisk tool is therefore a plug-in for QGIS, the application groups in a unique toolbar all the procedures needed to produce the assessment of the consequences of the floods.
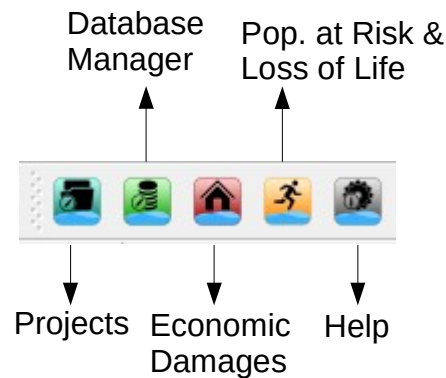
*Figure 3 : Application toolbar of FloodRisk plug-in*

The toolbar developed for this application is presented in Figure 3. Each button is linked to a window with several options, such as menus, labels, edition windows, combo boxes, and simple buttons, such as Ok, Close, and Help, among others, that help the user to access input and output directories.
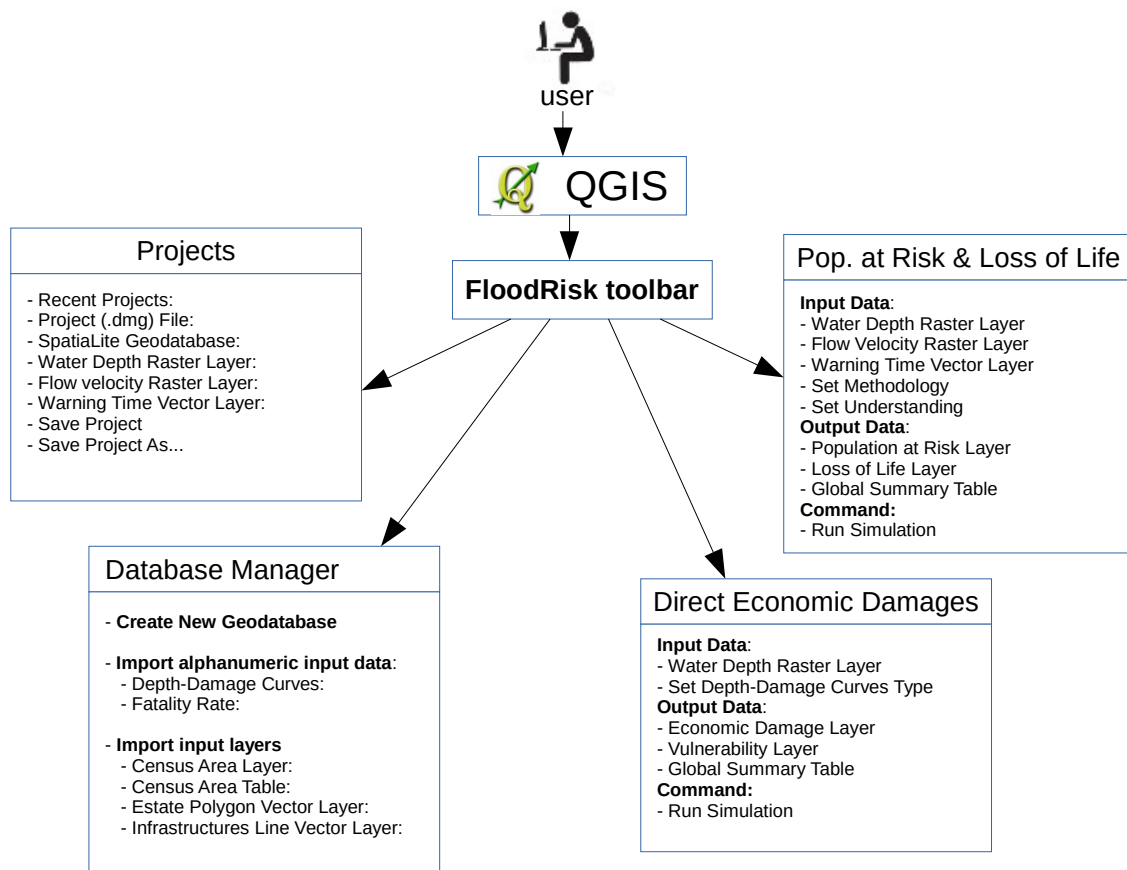


*Figure 4 : GUI components*

As shown in Figure 4, from the toolbar is possible to activate four windows, two of which for data management and two to run core modules.
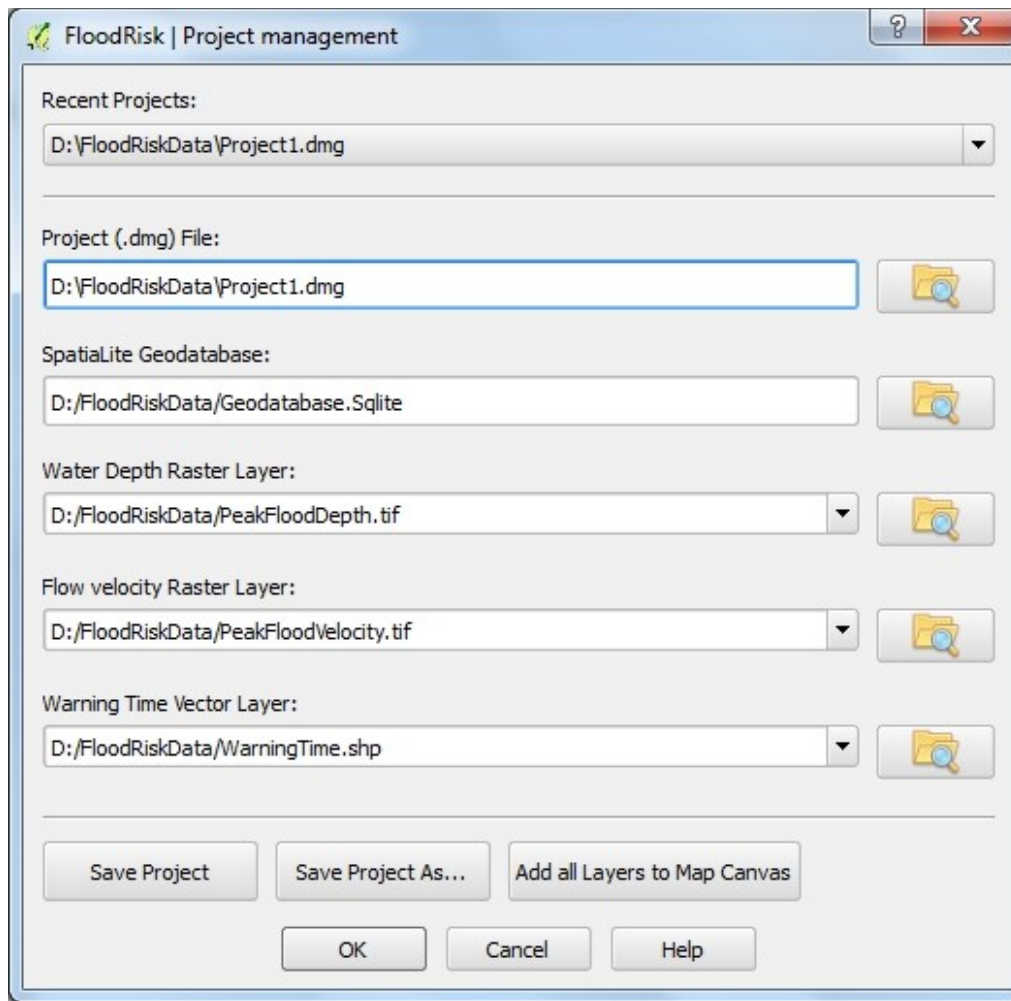
*Figure 5 : GUI of project management*

Figure 5 shows the first window: it is the interface for the project file management: this is an xml file in which are stored the pathnames of all the files that make up the project. In figure 6 is shown an example of a file.

```
<?xml version="1.0" encoding="UTF-8"?>
<FloodRisk>
  <General>
    <File Button="FilePeakFloodDepth" name="D:/FloodRiskData/PeakFloodDepth.tif"/>
    <File Button="FilePeakFloodVelocity" name="D:/FloodRiskData/PeakFloodVelocity.tif"/>
    <File Button="FileWarningTime" name="D:/FloodRiskData/WarningTime.shp"/>
    <File Button="FileGeodatabase" name="D:/FloodRiskData/Geodatabase.Sqlite"/>
  </General>
</FloodRisk>
```

*Figure 6 : Example of project file (*.dmg)*

In the example above, the project file contains the names and path of the input files, three of which are files concerning the hazard (flood depth map, flood velocity map and warning time map) and one refers to the geo-database, which contains all the data of receptors and their vulnerability. Hazard maps can be

any file type GDAL Raster Formats, except the warning time map which should be a polygons shapefile.

The data concerning population and assets at risk, are instead organized in a spatialite geo-database. The database manager (figure 7) allows you to create a new geodatabase (a Spatialite DB) having the expected data model and upload all the data into it. The alphanumeric data of the database tables are uploaded from csv file.
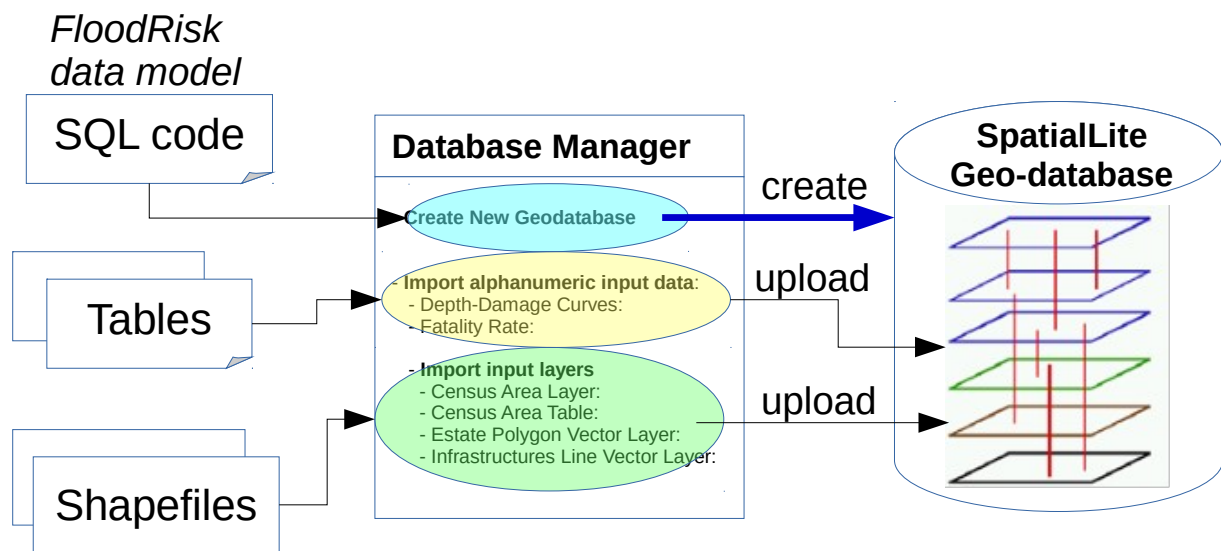


*Figure 7 : Database Manager diagram*

Geographic data of exposures, which are uploaded from shapefile and stored in the geodatabase, are vector data type: the data detail depends on the scale of the cartography source. The system thus does not have its own scale but is flexible and able to manage different data sources: from maps of land use with a different degree of detail until detailed urban maps.

Data of exposures therefore may refer to maps of large areas or detailed local maps.

The scale of the final result depends not only by exposure but also from the detail of the maps of the hazard.

The type of data that the tool uses to quantify the hazard is of raster data.

The cell size of the raster Hazard define its scale. The vector data of exposure during the processing are also converted in raster having the same cell size.

Data set of exposure in a given area, which are stored in the geodatabase can be used for analysis with hazard data having more resolutions: for each case, vector data of the exposures are automatically converted to a raster with a request resolution.

Data of the vulnerability are stored in database tables and FloodRisk tool, using SQL queries, extract them according to the elaboration required.

Figure 8 shows a diagram of the inputs and outputs of the software components that perform the computation of the consequences for the population and the economic damages.

The software components of computing are python scripts that use open sources libraries, eg. GDAL and numpy, and perform processing using Map
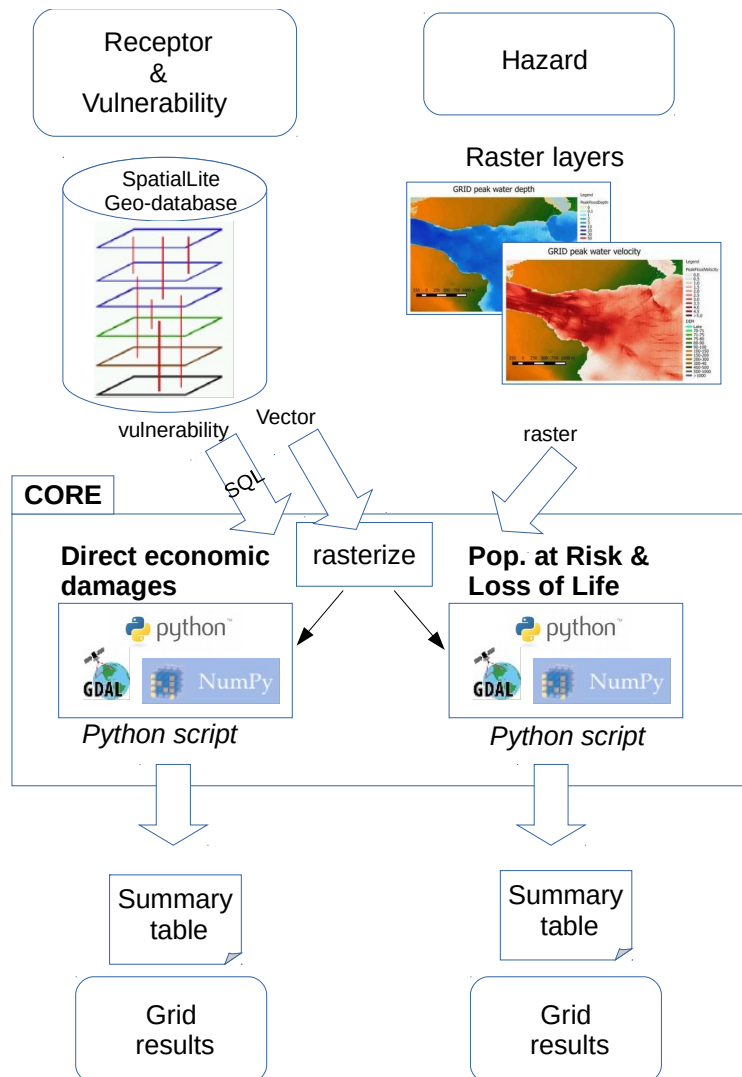
Algebra techniques.



*Figure 8 : CORE components & inputs and outputs*

These scripts produce the grid maps of the spatial distribution of the population at risk, the potential loss of life and economic damage expected for the structures and for the content of the property at risk.

Two global summary tables of the results are provided, which are also displayed in graphical form (histogram).

Example of loss maps produced using FloodRisk engine and presenting the expected economic losses for a benchmarking study case, proposed by the organizer committee of the 12th ICOLD International Benchmark Workshop on Numerical Analysis of Dams, are presented in Fig. 9: for more details see Mancusi et al, 2013. The results were compared, by the formulators of the Benchmark, with those of five other international participants who have used the same input data but different methodologies and softwares: the results of comparisons are presented in the Proceedings of the Workshop (Zenz & Goldgruber 2013). By using the data set of the workshop and taking into account the results of the comparisons, we are preparing a new data set for a

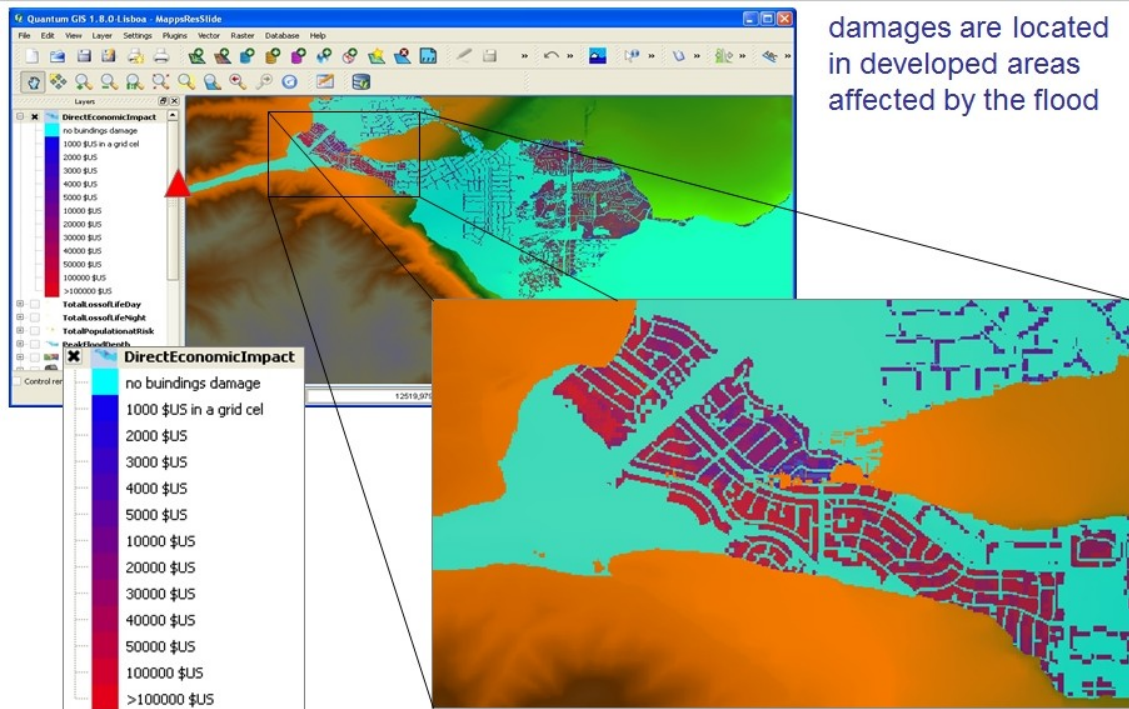tutorial of the plug-in that the authors aim to distribute in a repository.



damages are located in developed areas affected by the flood

*Figure 9 : Example of damages map*

## 4 Conclusion

In this paper a QGIS plugin called "FloodRisk " is described. The tool can be used for the rapid and consistent evaluation of consequences of flood in terms of number of people at risk, number of loss of life and economic damages for residential, commercial, industrial buildings and properties in general. The rapidity is allowed by using aggregate data: maps of land-use, buildings and population census. The consistency is required to ensure comparability between evaluations. This can be obtained if, for the series of scenarios to be compared, the user adopts the same type of data to the same scale. For this purpose the tool is flexible and can process data of different types depending of those that are actually available.

In conclusion the tool can be used to prioritize corrective actions to achieve an informed  risk reduction or for the identification of the "optimal" measures of risk mitigation.

## Acknowledgements

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