D3.3 Report

A toolkit for holist/multiple risk and impact/damage assessment at strategic and operational level

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Abstract (for dissemination, 100 words)	This report describes the toolkit and its models developed in PEARL project to support the holistic risk assessment framework which is described in detail Deliverable 3.1. The application of some of the tools in the study areas was presented in Deliverable 3.4. The following tools are described: 1. Long term / Strategic Coupled ABM-flood modelling tool; 2. Operational / evacuation ABM modelling tool; 3. Flood-traffic integration tool; 4. Direct damage assessment tool; 5. Indirect damage assessment tool; and 6. ABM SAS: PEARL institutional ABM modelling tool that supports policy evaluation and selection of resilience strategies. All of the above tools are described in terms of their methodology, code implementation/development details and application instructions of how to use it with a short tutorial.
Keywords	Toolkit, risk assessment, ABM, flood impact assessment

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Summary

This report describes the toolkit and models developed in PEARL project to support the holistic risk assessment framework which is described in detail in Deliverable 3.1. The application of some of the tools in the study areas was presented in Deliverable 3.4. The following tools are described in this report:

1. Long term / Strategic Coupled ABM-flood modelling tool
2. Operational / evacuation ABM modelling tool
3. Flood-traffic integration tool
4. Direct damage assessment tool
5. Indirect damage assessment tool
6. ABM SAS: PEARL institutional ABM modelling tool that supports policy evaluation and selection of resilience strategies

Every tool is described in a chapter that includes its methodological framework, details of the code implementation/development, application of the tool with a short tutorial. What follows is a brief description of each tool.

1. Long term / Strategic Coupled ABM-flood modelling tool

The aim of “long term / Strategic Coupled ABM-flood modelling tool” is to help in gaining understanding of how vulnerabilities and exposure to flood can be created and propagated in response to different policies, regulations and practices. The drivers include different policy and planning alternatives that aim to reduce flood risk, their implementation and community response. This tool is here referred to as a Coupled fLood-Agent-Institutions Modelling (CLAIM) modelling tool. CLAIM includes five components: *agents*, *institutions, urban environment*, *physical processes* and *external factors*. The actual analysis or model implementation is done by coupling agent-based models (ABM) with physically-based flood models. The ABM is used to model the social system (i.e., agents and institutions); whereas, the flood model is used to model the physical system (i.e., flooding). The Coupled ABM-Flood Model is described in detail in Chapter 2.

2. Operational / evacuation ABM modelling tool

The aim of operational / evacuation ABM modelling tool is to support evaluation of large scale evacuation strategies and planning tool for flood disaster risk prevention or mitigation. It is focus on disaster risk reduction to people by minimizing exposure to the hazards itself. Therefore, the tool is focus in modelling the human behaviour before and during a major flood event. The tool can be used to test different scenarios of flooding. After each simulation the overall performance of the evacuation is measured by the number of people that reach safe area/shelter and the number of people that can get in contact with flood waters. The tool can be used by city planners and/or emergency agencies for the development of evacuation plans.

3. Integration of an ABM Traffic-Flood model

PEARL flood-traffic integration tool aims to support assessment of flood impacts on road transportation. This tool is the first of its kind that translates flood maps into a specific input for the traffic model SUMO. The tool integrates flood and road transportation models in Python and ArcGIS environments. The preliminary results are promising and there is a need to advance the present tool by integrating the two models in a dynamic way.

4. Direct damage calculation tool

Direct damage calculation tool aims to support estimation of direct damages at different scales and data formats and to enable linking hydraulic modelling results, assets and vulnerability information for risk analysis. In PEARL, the previous version of this tool developed for ArcMAp during the CORFU project, was reprogrammed to incorporate with QGIS and enhanced with more flexible functionalities. This advancement allows stakeholders to adopt the tools in Open GIS environment that will strengthen the research impact.

5. Indirect damage calculation tool

The toolbox is based on a new methodology that comprises two consecutive steps; a matrix for transforming land uses in business activities, and an econometric regression for quantifying indirect damages. The methodology has been translated into a toolbox useful for quantifying the indirect damages of several business activities affected by a flood event.

6. Other Tools – ABM SAS

PEARL ABM SAS is a new Agent Based Model developed under the PEARL project. The PEARL ABM SAS simulates how authorities prepare against flood risk and aims to support exploration of intervention options under different socio-economic conditions and different flood event scenarios.

The developed PEARL ABM SAS has been applied to the case study of Rethymno, Crete. The LAA of Rethymno was involved in the development of the tool and was also able to use it during training session in October 2017. The tool is linked to an online user interface available from the PEARL toolbox and it is integrated into the PEARL Web Learning and Planning platform. The tool is also linked with the PEARL Knowledge Base. This tool was developed by NTUA in WP5: Task 5.4 and it is documented in detail in Deliverable 5.4 “A toolbox of methods and tools supporting selection of resilience strategies”.

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1 Introduction

PEARL aims to develop adaptive, sociotechnical risk management measures and strategies for coastal communities against extreme hydro-meteorological events minimising social, economic and environmental impacts and increasing the resilience of Coastal Regions in Europe.

Traditionally risk is defined as a combination of vulnerability and hazard of a particular event. This approach has proved to be valuable in taking financial decisions. However, when dealing with complex dynamic systems such as urban areas, there are other visions or perspectives that need to be addressed such as social justice, poverty, risk perception and acceptance, etc. Vojinovic and Abbott (2012) argue for the need to adopt a holistic approach to flood risk management, rather than a narrow techno-centric approach. PEARL adopts a holistic approach to assessing impacts from flood events. In the assessment of impacts, the following aspects are considered: assessment of potential direct and indirect tangible damages, social and health impacts, impacts on cultural properties and other indirect effects or business interruption. To address this range of impacts a set of tools has been developed to assess the system characteristics over a long period of time (i.e., strategic planning level in relation to policies for which implementation effects may take longer period of time) and relate to emerging system characteristics relevant during disaster event (operational level).

This report describes the toolkit and the models in the following way: Chapter 2 presents the Long term / Strategic Coupled ABM-flood model tool; Chapter 3 describes the operational / evacuation ABM tool; Chapter 4 describes integration of an ABM traffic model with an inundation hydro-dynamic model; Chapter 5 presents a tool for direct damage assessment; Chapter 6 describes a new methodology/tool for the estimation of indirect damages; Chapter 7 describes an ABM model that supports exploration of intervention options under different socio-economic conditions and different flood event scenarios.

2 Long term / Strategic Coupled ABM-flood model tool

2.1 A brief description of the tool

One of WP3 objectives is to develop concepts and tools for holistic risk assessment. This section addresses the tool that can be used to study long-term drivers of flood hazards, vulnerabilities and exposure. The drivers include different policy and planning alternatives that aim to reduce flood risk, their implementations and community response. As these drivers shape individuals' behaviour towards flood risk management, they can be collectively regarded as "institutions" (Crawford and Ostrom, 1995; North, 1990). To incorporate the human dimension (i.e., vulnerability, exposure and decisions related to flood hazard reduction) besides the physical phenomena (i.e., flooding) in flood risk management studies, a Coupled fLood-Agent-Institutions Modelling framework (CLAIM) is proposed. CLAIM includes five components: *agents* (i.e. the stakeholders related to flooding that ranges from individuals to municipalities and government entities), *institutions* (i.e., the different policies, strategies, rules, ordinances, etc that define the implementation of structural and non-structural flood risk reduction measures), the *urban environment* (considering that the focus of PEARL is coastal urban regions, the environment is an urban environment where the agents live and interact, and floods happen), *physical processes* (i.e., hydrologic and hydraulic processes/components that include natural and manmade drainage networks, hydraulic structures and parts of the hydraulic cycle) and *external factors* (i.e., factors that affect the system under investigation but are not directly affected by the local system settings - these include external political and economic factors and the hydro-meteorological events that are sources of flood).

CLAIM is a means to conceptualise the system/problem as it helps to systematically define different components of the problem, the boundary and scope of the system, and data needed. However, the actual analysis or model implementation is done by coupling agent-based models (ABM) and physically-based flood models. The ABM is used to model the social system (i.e., agents and institutions); whereas, the flood model is used to model the physical system (i.e., flooding). The following sections describe the Coupled ABM-Flood Model.

2.2 Introduction to the tool

2.2.1 *Description of the components developed*

As already indicated, the coupled modelling tool is composed of an ABM and a hydrodynamic flood model. There are multiple modelling environments for both the ABM and flood model. However, in this tool, the MIKE FLOOD hydrodynamic model that couples one-dimensional drainage network flows and two-dimensional surface flows (DHI, 2016a) is used to develop the flood model; and the Repast Simphony environment that uses the Java programming language (North et al., 2013) is used for ABM coding.

- **Flood Model**

The flood model is used to simulate fluvial, flash, pluvial, groundwater or coastal floods and their combinations. The physical processes that are included in flood simulations can be broadly categorized as hydrologic (rainfall-runoff) and hydrodynamic (routing) processes. Within MIKE

FLOOD, rainfall-runoff processes and one-dimensional (1D) flow in channels is modelled using the MIKE11 package. The two-dimensional (2D) surface flow along the flood plains is modelled using the MIKE21 package. A coupled MIKE11-MIKE21 model through the MIKE FLOOD environment provides the full flood model. For setting up flood models in MIKE FLOOD the readers may refer to DHI user manual (DHI, 2016a).

- **ABM**

ABM is used to model heterogeneous actors' actions, interactions and their decision making. In addition, ABMs are also used to model institutions that shape actors' actions and interactions. The initial and crucial steps in building ABMs include decomposing and conceptualizing the system and describing it in a modelling language. For that purpose, the ABM in the coupled modelling tool is structured using the MAIA (Modelling Agent systems using Institutional Analysis) meta-model (Ghorbani et al., 2013). MAIA provides a comprehensive modelling language to build ABMs of social systems, and it systematically and explicitly incorporates institutions into models. There are five structures in MAIA: *social structure* defines agents and their attributes such as properties, behavior and decision making; *institutional structure* defines the social context such as role of agents and institutions that govern agents' behavior; *physical structure* defines the physical aspects of the system such as infrastructure; oper*ational structure* defines the dynamics of the system; and finally, the *evaluative structure* defines the concepts that are used to validate and measure the outcomes of the system.

- **Coupled Model**

In the coupled modelling tool, the ABM is considered as a "principal" model. The reason is that the ABM runs for the entire simulation period since the human dynamics (i.e., social, economic and political dynamics) happen all the time. However, since floods may not occur in every time step, the flood model runs only if there is a source of flood. The components of the coupled model (based on the ABM environment) are described below.

As shown in Figure 1, the coupled model has five Java packages: `collectiveStructure`, `physicalStructure`, `operationalStructure`, `contectBuilder` and `dataCollection`.

1. `collectiveStructure` package – this package holds agent related java classes. For example, if the modeller identified five agents that are important to define the problem under investigation, there will be five Java classes. For each agent, the modeller must define the attributes that characterise the agent.

2. `physicalStructure` package – this package holds java classes related to the physical aspects of the system. The physical aspects are houses, catchments, coastlines, flood maps, roads, drainage channels, rivers, etc. Java objects created using these class templates are based on GIS vector data. Some objects might be used in the agent dynamics, and others can be used solely for visualization purpose. For those classes used to create visualization objects, related Java classes that implement the `SurfaceShapeStyle` interface must also be created so that Repast Simphony uses the correct rendering for the type of vector data (i.e., point, line or polygon).

3. `operationalStructure` package – this package holds Java classes related to the human and flood dynamics. The human dynamics include urban development and flood risk management decision making such as when, where and how to implement flood hazard, vulnerability and

exposure reduction measures. The flood dynamics include running the MIKE FLOOD model (calling the executable file), updating the MIKE FLOOD input files if the human dynamics result in change in the surface imperviousness, hydraulic structures or drainage network.

4. `contectBuilder` package – this package (shown as `stMaarten` in Figure 1) holds the main 'builder' class and a `GlobalVariable` class. The builder class creates the 'context' and 'geographic projections' (these are Repast Simphony related terms. See the following documentation (Collier and North, 2016)). All the agents and physical structures are initialized and added to the context and geographic projections in this class. In the `GlobalVariable` class, global variables that are used in many different classes.

5. `dataCollection` package – this package (shown as `mainDataCollection` in Figure 2.1) holds Java classes used for 'data collection' (i.e., in this context, data refers to the generated result, not the input data). In Repast Simphony, results can be recorded in a unique way by defining 'data sources' and 'data sets'. In this package, classes implement `AggregateDataSource` methods (Collier and North, 2016).

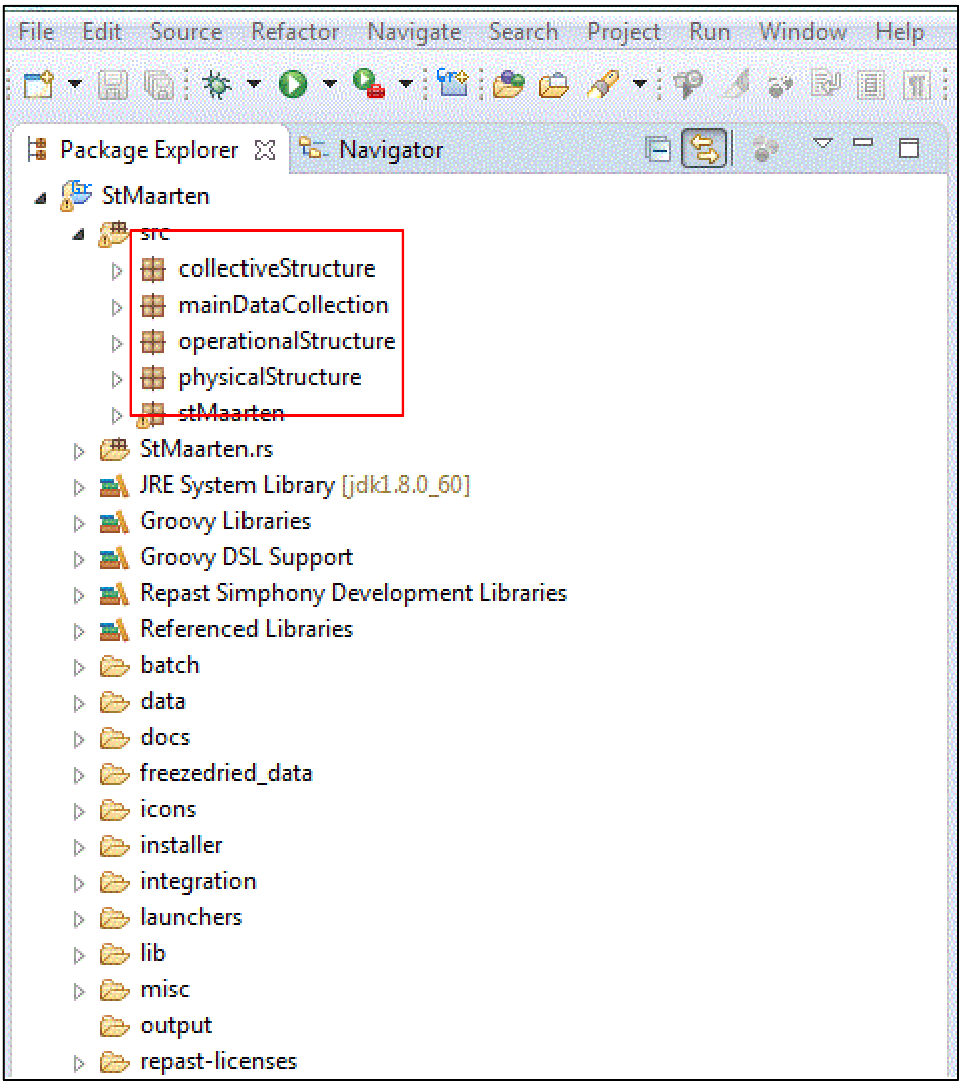


Figure 2-1 Coupled ABM-Flood Model tool components in the Repast Simphony environment. The five Java packages (red rectangle) holds the main software code

2.3 Methodology

2.3.1 Description of the flowchart with all steps

The following steps can be followed for setting up and running the coupled modelling tool:

1. Conceptualizing the system using CLAIM

The first step towards building a coupled ABM-flood model is to formulate the human-flood interaction problem that needs to be investigated, and to decompose and structure the concepts related to the two subsystems. Besides guiding the collection of primary and secondary data, this step provides different knowledge domains or expertise required to build the agent-based and flood models. Basically, this step is about deciding the model boundary and identifying the five components of the CLAIM framework in the coupled system.

2. Building the ABM

Once the CLAIM elements are identified, the MAIA meta-model is used to conceptualize and structure the human subsystem and to formally describe it as a model. Agents in CLAIM, their states and behaviors, are defined in the social structure of MAIA. Agents' physical artefacts and the urban environment in CLAIM are defined in the physical structure. Institutions and the external political and economic policies in CLAIM are defined in the institutional structure. The dynamics of the subsystem, which include agents' actions and their interactions with other agents and the environment are defined in the operational structure. Then, the MAIA-structured descriptions of the human subsystem is converted to pseudo-codes that can be implemented in Java programming language in the Repast Simphony environment.

3. Building the flood model

The third step is to build the coupled 1D-2D MIKE FLOOD model. The type of flood model is dependent on the type of the flood. For example, if the case study is impacted only by the coastal flood, the model required would be 2D MIKE21 model. However, if the source of flood in the case study is pluvial, fluvial, flash flood or combination of these floods with coastal flood, then both 1D MIKE11 and 2D MIKE21 models would need to be built. Before coupling the 1D and 2D models, each model must be able to run independently. After that they can be coupled in the MIKE FLOOD environment and calibrated.

4. Coupling ABM and flood models

Based on the magnitude and extent of flood hazard and their social, economic, political and governance makeup, agents may decide to implement different flood reduction and adaptation measures. To model and evaluate these measures, the ABM and the flood models are coupled dynamically. Figure 2.2 illustrates the coupling processes.

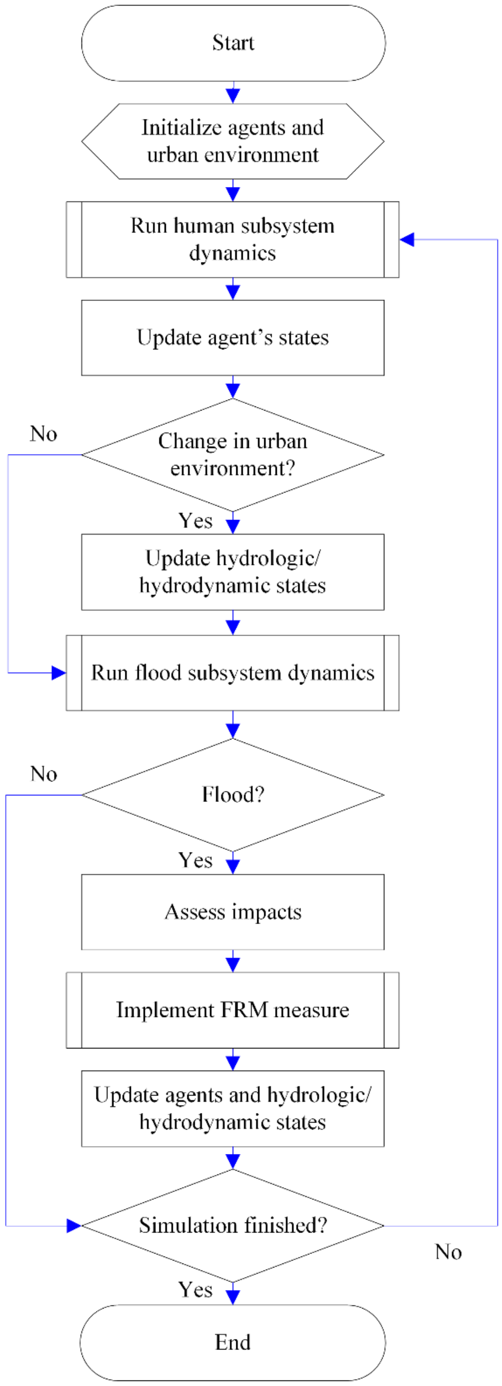


Figure 2-2 Coupled model implementation flowchart for long-term FRM planning.

5. Model verification, experimentation, result analysis and validation

These are generic steps that can be more or less applied to any kind of modelling. Verification is related to the ABM software code developed. It refers to checking if the formalization and conceptualization done in Step 2 have been correctly translated into the computational model (Nikolic et al., 2013) developed in Repast Simphony. Experimentation includes setting up scenarios and deciding on the number of runs of simulations and the computational resources to use. After

collecting and analysing the results, a model validation is performed to check if the models, the experimentations and the results make sense and provide insight to the problem defined in Step 1.

2.3.2 Description of the code, repository, how to install, settings etc.

The source code for the coupled modelling tool is available at: (https://github.com/yaredo77/Coupled_ABM-Flood_Model). The tool is developed within the Windows OS. Software requirements are:

- The ABM is developed using the open source modelling environment Repast Simphony 2.4.0 (available at https://github.com/Repast/repast.simphony/releases/). Repast Simphony 2.4.0 is compatible with Java 8 (the Java jdk-8 is an open source software and it is available at http://www.oracle.com/technetwork/java/javase/downloads/jdk8-downloads-2133151.html). Detailed documentation manual on how to download, install and use Repast Simphony can be found in https://repast.github.io/docs.html.
- The flood model is developed using the MIKE FLOOD hydrodynamic modelling software (available at https://www.mikepoweredbydhi.com/download/mike-2017). MIKE FLOOD is a licensed, commercial software. Detailed manual on how to download, install and use the MIKE FLOOD software can be found in (DHI, 2016a).

Because of the licensing issue related to the MIKE FLOOD software, the coupled model source code shared above does not require setting up and running the MIKE FLOOD model. Instead, flood model result files are provided to assess the flood impact. To be able to use the ABM tool, knowledge of the Java programming language is required.

For result analysis and graphical presentation, the R computer language is used. This language provides a large set of packages for processing functionality and result presentation. R for Windows is available at https://cran.r-project.org/bin/windows/base/. An open source environment for R coding, editing, debugging and visualization called RStudio is available at https://www.rstudio.com/products/rstudio/download/.

2.4 Using the tool

2.4.1 Description of the interface steps and menus

The following steps describe how to use the Coupled ABM-Flood Model tool.

Step 1. Open the Repast Simphony environment (Figure 2.3) and load the project file that is provided in the above section (Figure 2.4).

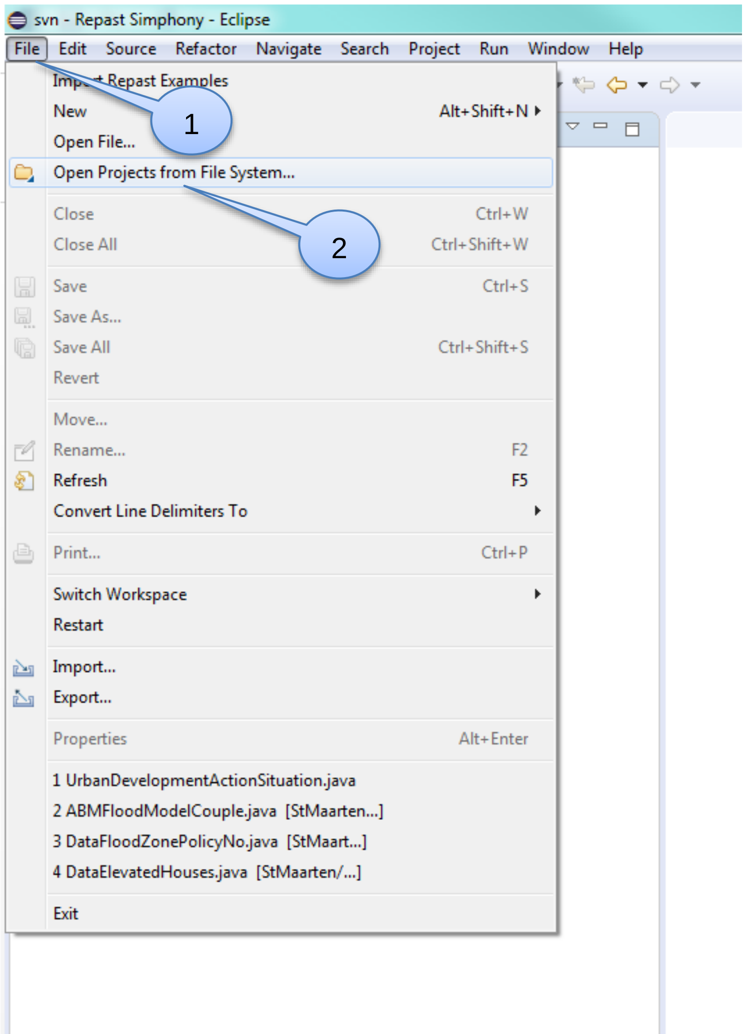


Figure 2-3 Repast Simphony – Import projects from file

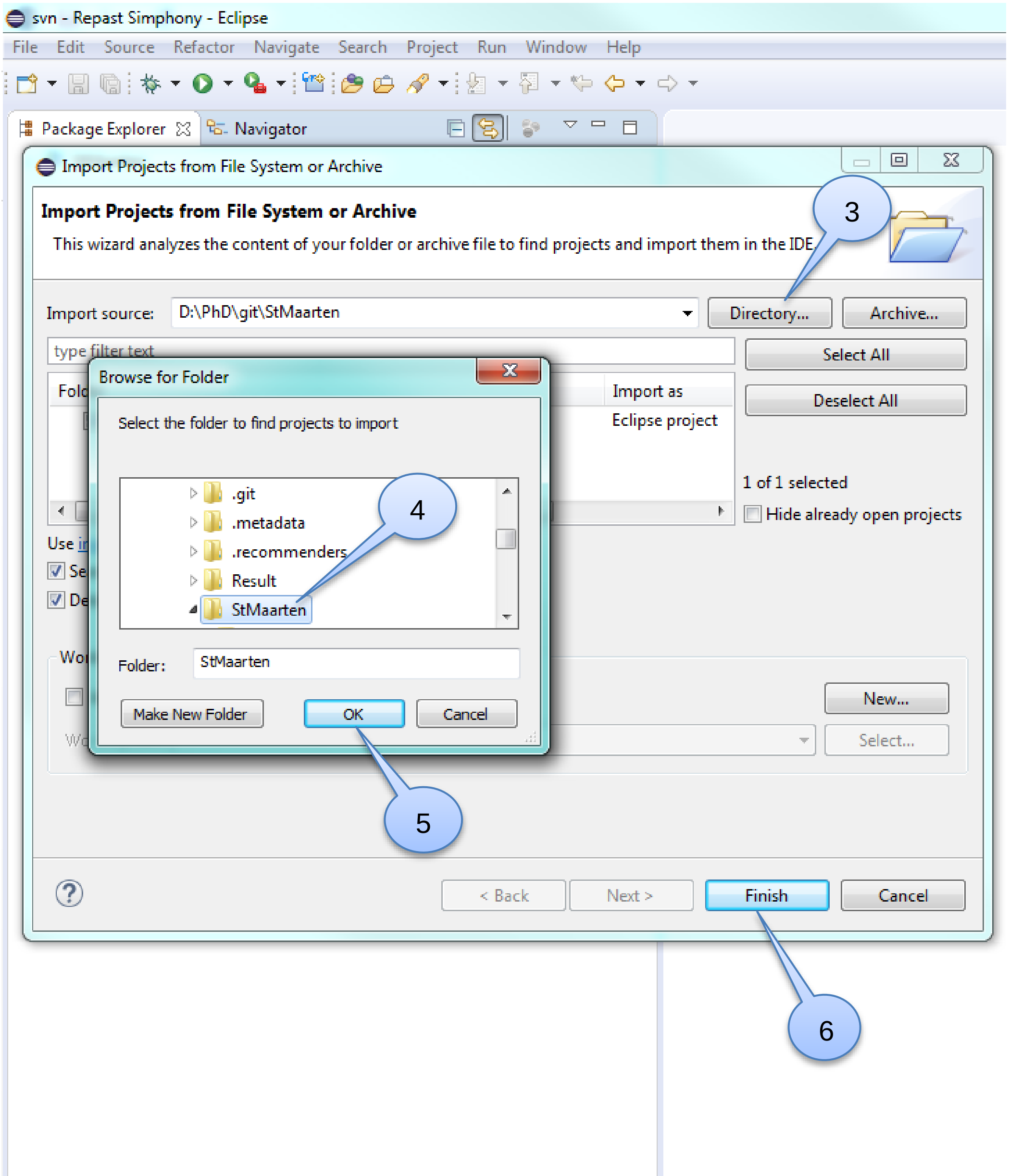


Figure 2-4 Repast Simphony – load the file

Step 2. Start the model runtime environment (Figure 2.5)

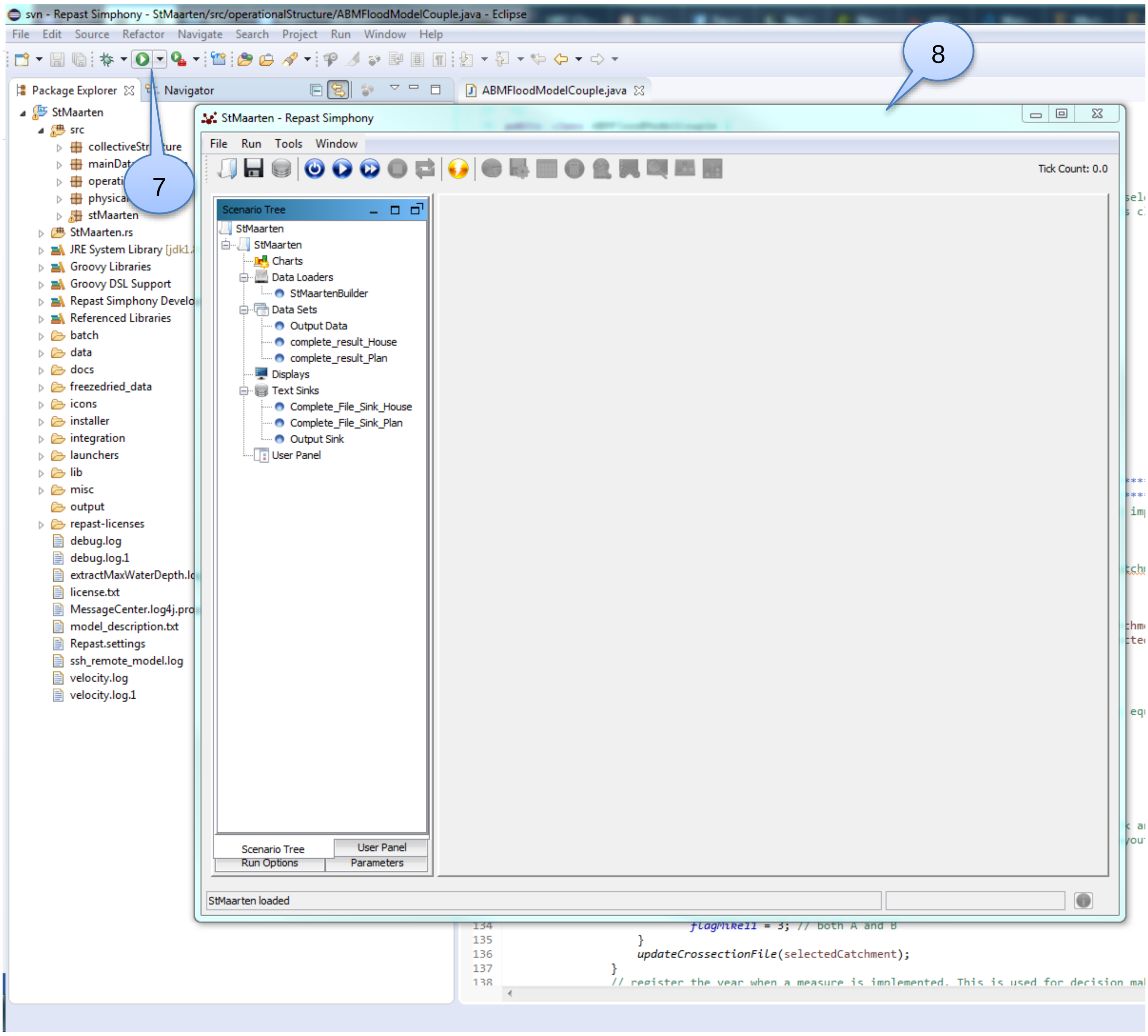


Figure 2-5 Repast Simphony – launch the runtime environment

Step 3. Set the parameters used in the model within the runtime environment (Figure 2.6)

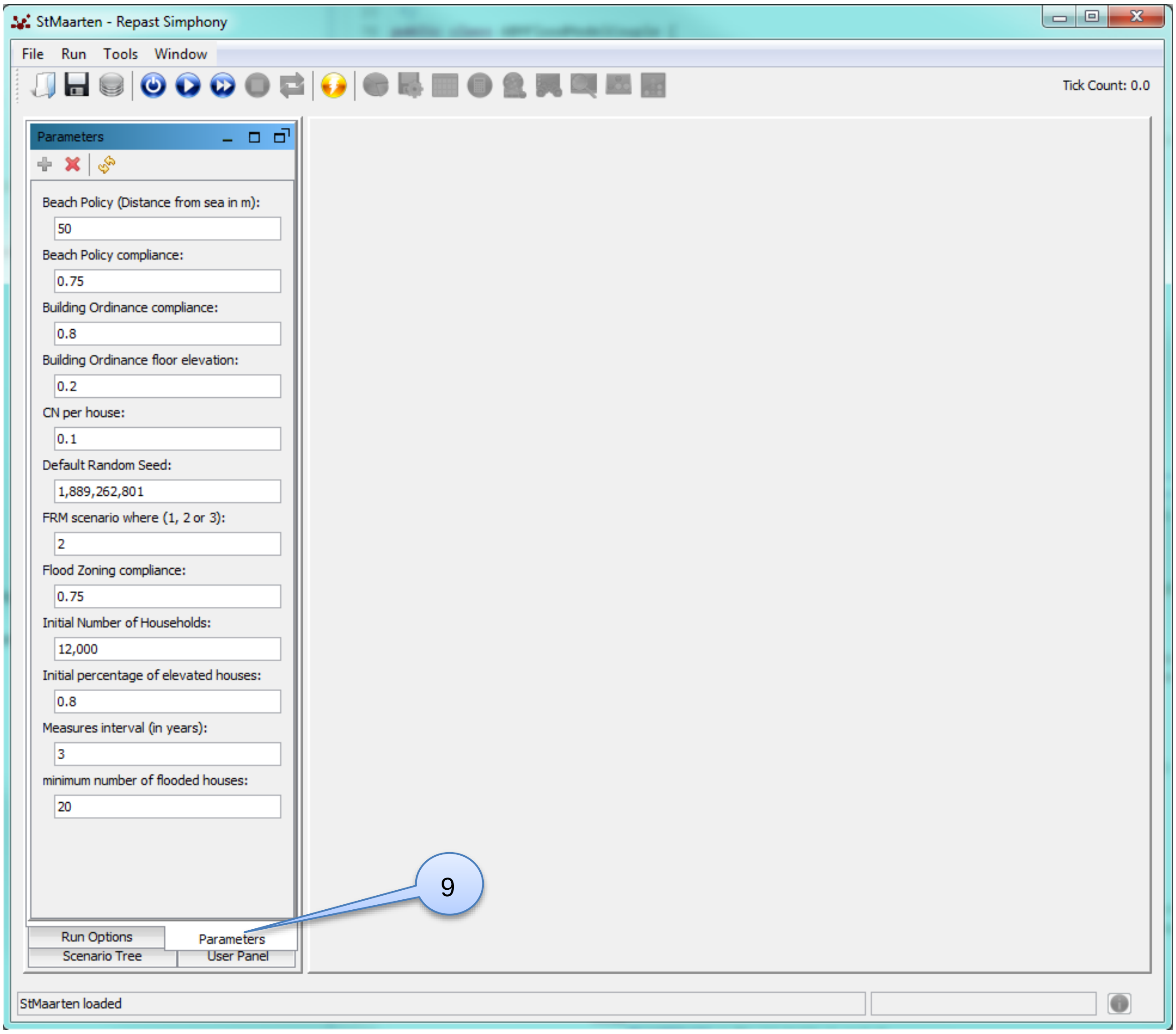


Figure 2-6 Repast Simphony – set the parameters

Step 4. Initialize and start simulation run (Figure 2.7)

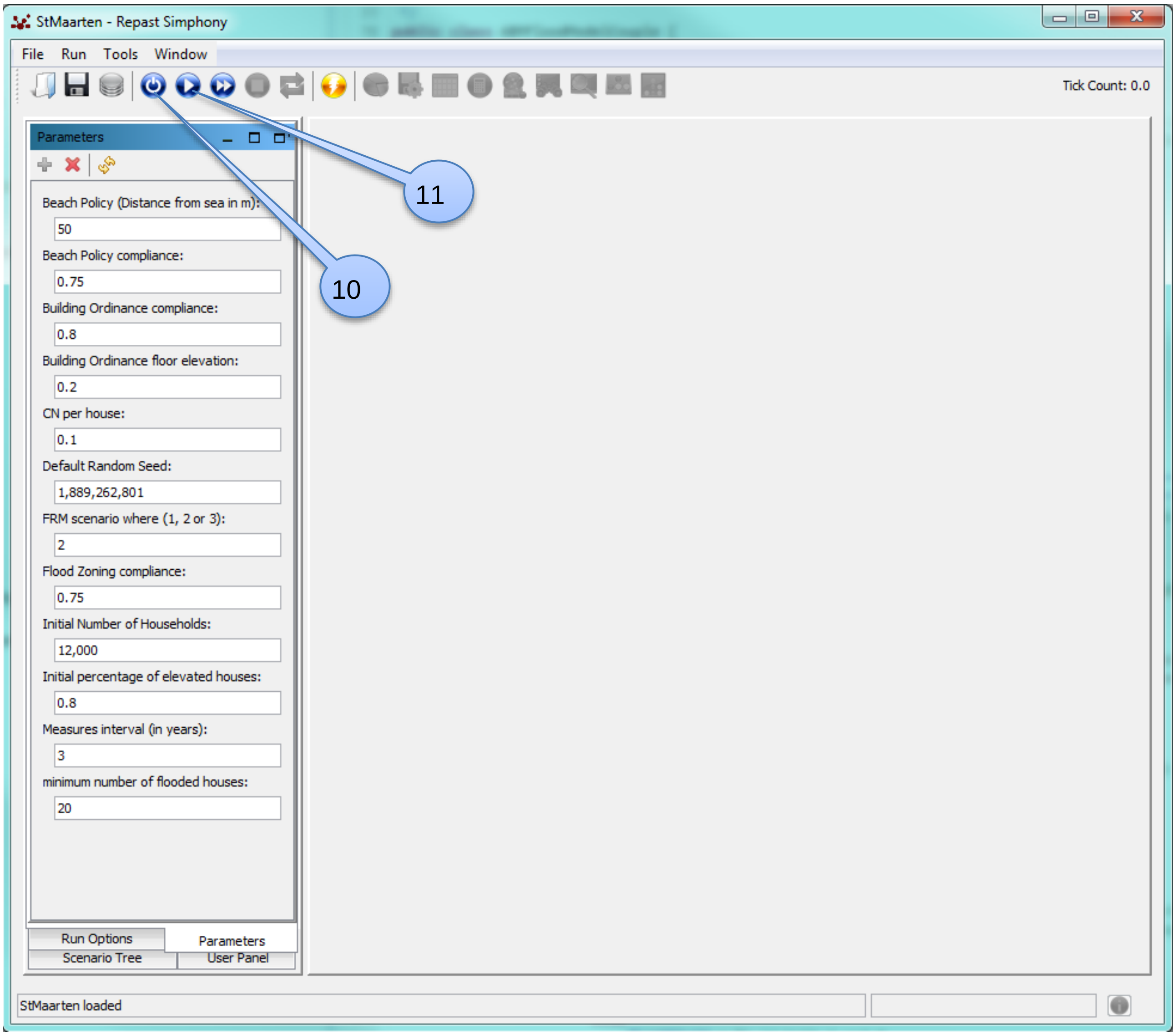


Figure 2-7 Repast Simphony – initialize and start run

2.4.2 Input data set

Setting up and running the coupled ABM-flood model requires a number of data sets. The data required for each model is are listen in Table 2-1.

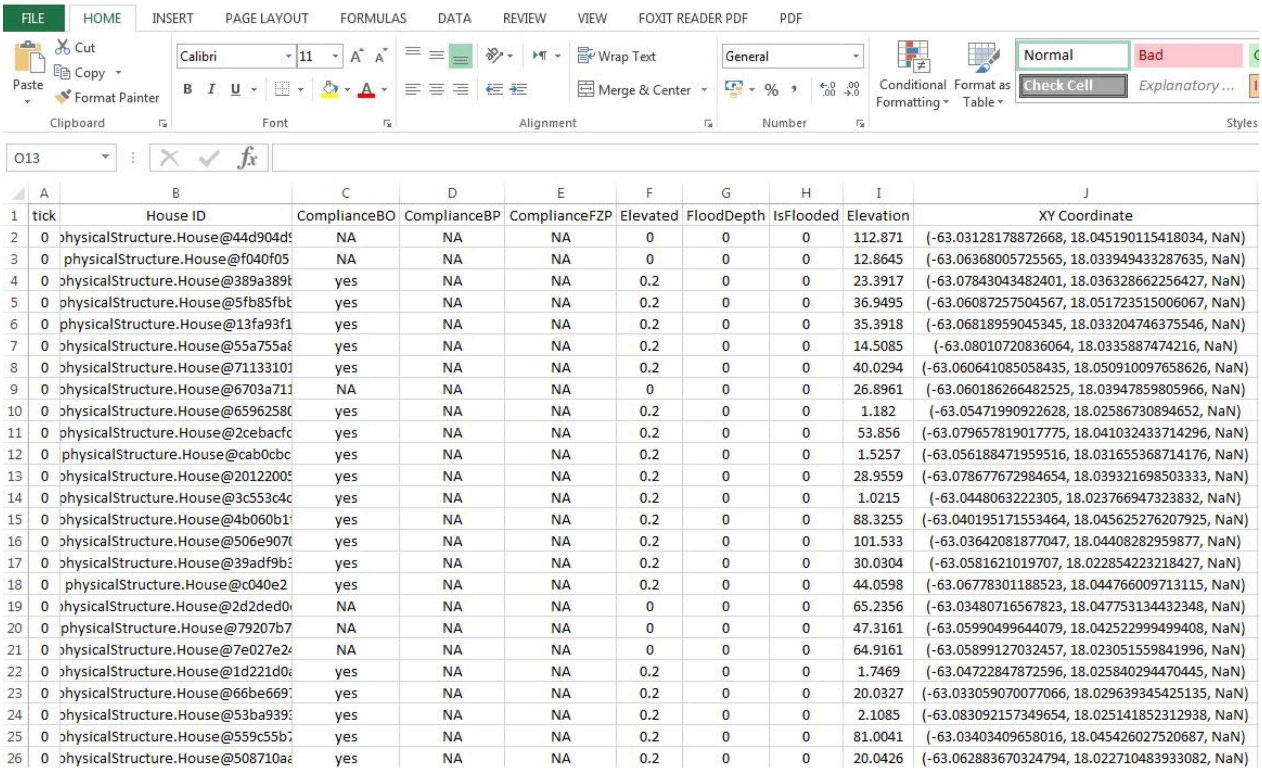
Table 2-1 Data requirement for the ABM and flood model

Model	Data type	format	Remark
	Topographic data (DTM)	Raster	
ABM	Geographic boundary	Shapefile (polygon)	
	Hydrologic catchments	Shapefile (polygon)	

	Building layer (number of agents)	Shapefile (point)	This data may contain building attributes such as elevation, building function and flood height
	Future development locations	Shapefile (point)	
	Institutional data		These are policies, ordinances, strategies, plans, laws, directives, norms, strategies, etc.
	Agent data		These are various attributes of the different agents in the model.
Flood model	Channel network layout	Shapefile (polyline)	
	Channel cross-section characteristics		These include depth, width, shape, elevation and
	Catchment characteristics		These include catchment area, curve number (imperviousness),
	Rainfall data	Time series	
	Discharge data	Time series	
	Bathymetry data	Raster	
	Boundary data	Time series	Water level or discharge data

2.4.3 Outputs

The flood model outputs include a raster flood depth/level and discharge over the simulation period. However, these outputs are processed within the ABM to directly compute the flood impact on agents. Hence, the main output of the Coupled ABM-Flood Model tool is agents' flood impact level given the type of institutions and the decisions made by the agents. This output is presented in CSV file (Figure 2.8). The file contains the time steps, the agents' houses locations, whether agents follow policies, and the flood depth in case a house is flooded.



	tick	House ID	ComplianceBO	ComplianceBP	ComplianceFZP	Elevated	FloodDepth	IsFlooded	Elevation	XY Coordinate
2	0	physicalStructure.House@44d904d	NA	NA	NA	0	0	0	112.871	(-63.03128178872668, 18.045190115418034, NaN)
3	0	physicalStructure.House@f040f05	NA	NA	NA	0	0	0	12.8645	(-63.06368005725565, 18.033949433287635, NaN)
4	0	physicalStructure.House@389a389	yes	NA	NA	0.2	0	0	23.3917	(-63.07843043482401, 18.036328662256427, NaN)
5	0	physicalStructure.House@5fb85fbl	yes	NA	NA	0.2	0	0	36.9495	(-63.06087257504567, 18.051723515006067, NaN)
6	0	physicalStructure.House@13fa93f1	yes	NA	NA	0.2	0	0	35.3918	(-63.06818959045345, 18.033204746375546, NaN)
7	0	physicalStructure.House@55a755a	yes	NA	NA	0.2	0	0	14.5085	(-63.08010720836064, 18.0335887474216, NaN)
8	0	physicalStructure.House@7113310	yes	NA	NA	0.2	0	0	40.0294	(-63.060641085058435, 18.050910097658626, NaN)
9	0	physicalStructure.House@6703a71	NA	NA	NA	0	0	0	26.8961	(-63.060186266482525, 18.03947859805966, NaN)
10	0	physicalStructure.House@6596258	yes	NA	NA	0.2	0	0	1.182	(-63.05471990922628, 18.02586730894652, NaN)
11	0	physicalStructure.House@2cebacfc	yes	NA	NA	0.2	0	0	53.856	(-63.079657819017775, 18.041032433714296, NaN)
12	0	physicalStructure.House@cab0cbc	yes	NA	NA	0.2	0	0	1.5257	(-63.056188471959516, 18.031655368714176, NaN)
13	0	physicalStructure.House@2012200	yes	NA	NA	0.2	0	0	28.9559	(-63.078677672984654, 18.039321698503333, NaN)
14	0	physicalStructure.House@3c553c4c	yes	NA	NA	0.2	0	0	1.0215	(-63.0448063222305, 18.023766947323832, NaN)
15	0	physicalStructure.House@4b060b1	yes	NA	NA	0.2	0	0	88.3255	(-63.040195171553464, 18.045625276207925, NaN)
16	0	physicalStructure.House@506e907	yes	NA	NA	0.2	0	0	101.533	(-63.03642081877047, 18.04408282959877, NaN)
17	0	physicalStructure.House@39adf9b	yes	NA	NA	0.2	0	0	30.0304	(-63.0581621019707, 18.022854223218427, NaN)
18	0	physicalStructure.House@c040e2	yes	NA	NA	0.2	0	0	44.0598	(-63.06778301188523, 18.044766009713115, NaN)
19	0	physicalStructure.House@2d2ded0	NA	NA	NA	0	0	0	65.2356	(-63.03480716567823, 18.047753134432348, NaN)
20	0	physicalStructure.House@79207b7	NA	NA	NA	0	0	0	47.3161	(-63.05990499644079, 18.042522999499408, NaN)
21	0	physicalStructure.House@7e027e2	NA	NA	NA	0	0	0	64.9161	(-63.05899127032457, 18.023051559841996, NaN)
22	0	physicalStructure.House@1d221d0	yes	NA	NA	0.2	0	0	1.7469	(-63.04722847872596, 18.025840294470445, NaN)
23	0	physicalStructure.House@66be669	yes	NA	NA	0.2	0	0	20.0327	(-63.033059070077066, 18.029639345425135, NaN)
24	0	physicalStructure.House@53ba939	yes	NA	NA	0.2	0	0	2.1085	(-63.083092157349654, 18.025141852312938, NaN)
25	0	physicalStructure.House@559c55b	yes	NA	NA	0.2	0	0	81.0041	(-63.03403409658016, 18.045426027520687, NaN)
26	0	physicalStructure.House@508710a	yes	NA	NA	0.2	0	0	20.0426	(-63.062883670324794, 18.022710483933082, NaN)

Figure 2-8 An example of a Coupled ABM-Flood Model result in CSV format

In addition, Repast Simphony also provides visualization with an interface (Figure 2.9)

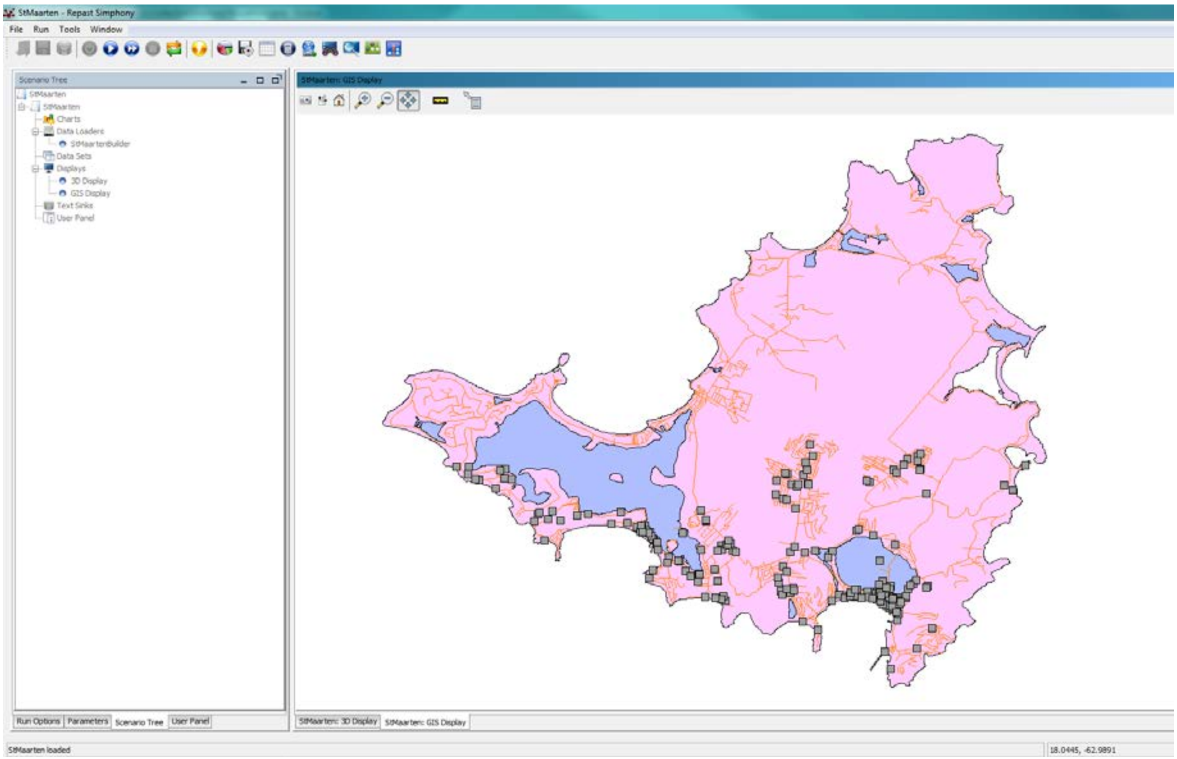


Figure 2-9 An Example of Repast Simphony visualization: The squares represents buildings/houses

2.5 Tutorial / Cases

2.5.1 Description of the application of the tool in a case study

A demonstration of the application of the CLAIM approach is presented using Sint Maarten FRM as a case study for a complex human-flood system. The ABM is structured using MAIA. In the social structure, two agent types are identified: household agents and the government agent. Household agents are characterized by location and elevation, and they have houses. The government agent is characterized by budget and level of enforcement. In the institutional structure, flood zoning policy is considered. This policy is part of a National Development Plan, which is at the time of the production of this report still in a draft phase. The institutional statement for the policy is written as: Households must elevate their house if they are located in a flood zone or else they will be fined. Since the statement has a formal sanctioning, the institution is a rule. However, the government agent may not strictly enforce the rule. The physical components defined in the physical structure are houses, drainage channels, hazard triggering factors (rainfall and storm surge) and flood. In the conceptualization, households are represented by houses. Houses are characterized by location, elevation and floor height, and are the only physical components defined in the ABM. If they follow the policy, household agents may raise the floor of houses by 0.5m, 1m and 1.5m depending on the flood zone they are located. In the operational structure of the ABM, agents' actions and interactions are defined. For example, considering urban development, household agents build new houses. Before building, they may decide where to build it and if they would follow the institutions.

In the flood model developed, design rainfalls of 5yr, 10yr, 20yr, 50yr and 100yr average recurrence intervals (ARI) are used. It is assumed that any rainfall magnitude below the 5yr ARI does not result in flooding. For rainfall-runoff analysis, the unit hydrograph method with SCS runoff curve number (DHI, 2016b) is used. The curve number values are updated based on the number of new houses built in a given catchment to reflect increase in imperviousness due to urban development.

The ABM is set up considering three scenarios – one without zoning policy, another with zoning policy (strict implementation), and the last one with zoning policy (random implementation). The strict implementation can be associated with either strict enforcement of the policy or all agents follow the policy not to get fines for violation. The random implementation is to simulate "no-so-strict" level of enforcements which can be, for example, due to shortage of inspection officers.

The simulations were instantiated with 10000 households and each experiment run for 30 time steps with similar design rainfall event series. One time step represents one year. It is assumed that a maximum of one flood event happens in a given time step where a time step represents one year.

2.5.2 Outputs from the case study

The case study used for this purpose is the Sint Maarten case study. The result in Figure 2.6 shows that, comparing the damage from a rainfall with 5 year ARI, in about 20 years (from time step 3 to 22) the number of flooded houses rises by about 60%. This is mainly attributed to the increase in the number of new houses in exposed areas. Even if there is increase in flood depth between the mentioned time steps, the contribution of the higher flood to the rise in the number of flooded houses is minor as the flood extent is the same. The number of flooded houses for the three scenarios is very close, i.e., the effect of the flood zoning policy, even with strict enforcement, is minor. This is because there were already substantial number of houses built (or instantiated in the model) in the flood zones before the policy is introduced. In addition, the flood zoning does not include some areas

which are flood-prone and developments are occurring. Therefore, based on the modelling exercises carried out, for the zoning policy to have a reasonable effect on the overall flood risk reduction in Sint Maarten, the delineated flood-zones must cover all flood-prone areas and there should be other complementary measures that reduce the risk of new developments outside the zones.

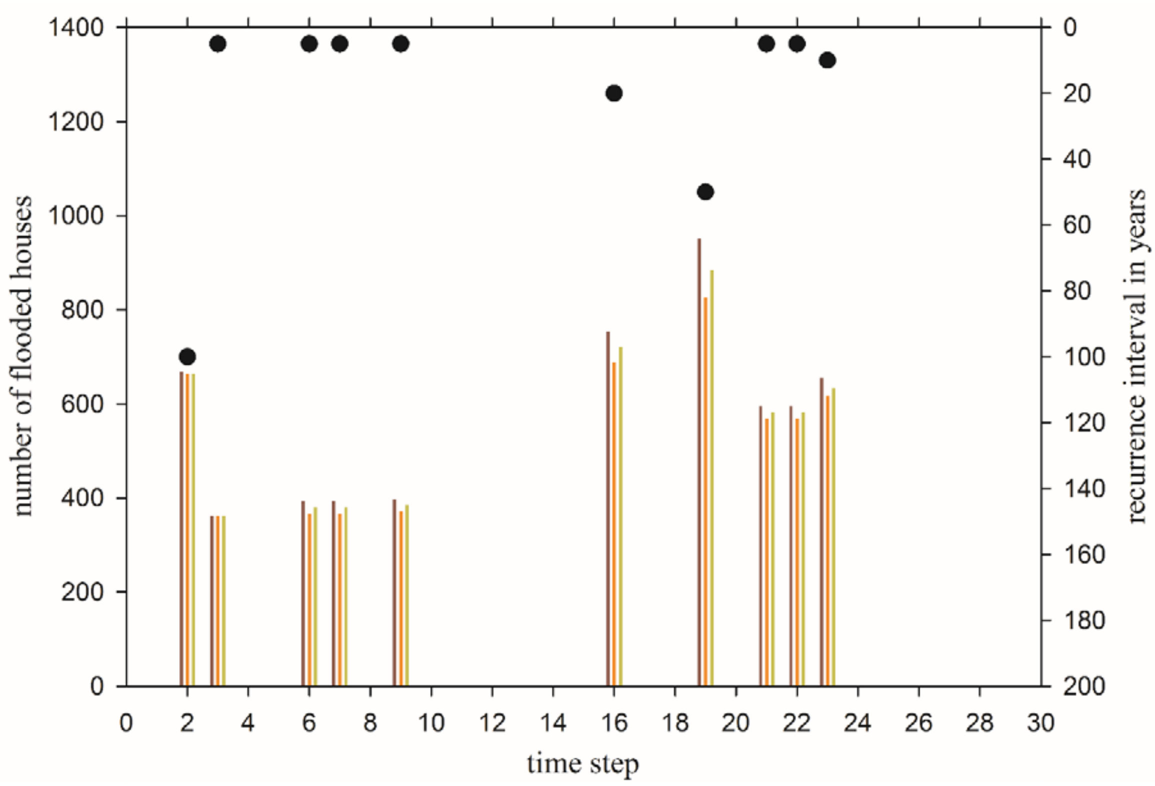


Figure 2-10 Number of flooded housed for different zoning scenarios. The right axis is for the rainfall recurrence intervals shown in black circles. The left axis is for number of flooded houses shown in colored bars, corresponding to the design rainfalls. The purple bars show the number of flooded houses without flood zoning policy while the orange and green bars show number of flooded houses with zoning policy but with strict and random implementations, respectively.

2.6 Concluding remarks

The coupled ABM-flood modelling tool allows to incorporate and model the physical changes made by humans on the urban environment and to assess how that process changes the flood risk over time. As shown in the application, modelling human-flood interaction using coupled ABM-flood model can be beneficial in gaining understanding of the system. In addition, it can be used to investigate possible future directions in flood risk management. The coupled model can also help to examine how levels of exposure (i.e., number of assets-at-risk), flood hazard (i.e., flood magnitude and extent) and vulnerability (i.e., propensity to be affected) change with respect to the changes in human behavior (i.e., policies and their implementations). It also helps to conceptualize and model the whole system in one integrated model and to analyze feedback between the subsystems. This, in turn, gives a broader perspective for FRM decision makers in adopting policies. The outputs of the coupled model include the level of flood risk, in terms of assessed impact, as a way to measure the

effectiveness of formal and informal institutions; and types of measures favored (or not) in an urban area based on the social and governance factors.

The tool provides an interdisciplinary approach by allowing knowledge contributions from hydrologists/hydraulic engineers and social scientists. For example, within PEARL, the qualitative Risk and Root cause Analysis report from the WP1 (Fraser, 2016) was helpful to conceptualize the model and identify the relevant actors in the Sint Maarten FRM. Vulnerability analysis report from WP1 was also beneficial as input data for the Coupled ABM-Flood Model.

The CLAIM framework is a generic modelling framework that can be used to conceptualize almost any FRM problem. However, to use the tool provided in Section 2.3.2, the modeler must update the software code so that it reflects the case study situation. In terms of coupling ABM with a flood model, the tool is developed for coupling ABM with MIKE FLOOD. If one wants to couple the ABM with another flood modelling tool (e.g. HECRAS), the relevant modules of the software code should be improved to handle the appropriate input-output data formats. Further, the coupled model can be applied to a combination of flood events (pluvial, fluvial, coastal and flash). An important remark is that the coupled model simulation requires large data and computational resources, especially, when the system complexity increases and when there are multiple scenarios to examine.

2.7 References

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3 Operational / Evacuation ABM modelling tool

3.1 A brief description of the tool

The operational Agent Based Model (ABM) was also implemented as a tool to support large scale evacuation strategies for flood disaster risk prevention and mitigation. It addresses disaster risk reduction by minimizing exposure of people to the hazards itself. Therefore, the tool is focused on modelling the human behaviour before and during a flood event.

The model mimics daily behaviour of individuals and their interactions at a city scale and how this collective behaviour evolves following the event of a flood disaster. The aim of this approach is to support understanding of some critical factors that have influence on evacuation processes.

The tool can be used to test different scenarios of flooding as well as different communication strategies and communication means. The overall performance of the evacuation is measured by the number of people that reach safe area/shelter and the number of people that can get in contact with the flood water.

The tool developed can be used by city planners and emergency agencies for planning their evacuation strategies and disaster risk management plans. In addition, the tool can be also used to identify what physical infrastructure needs further strengthening (e.g., widening of roads and strengthening shelters, etc.).

3.2 Introduction to the tool

3.2.1 Description of the components developed

This section discusses different components or modules that were used to set up the Agent Based Model to test multiple evacuation strategies. The first part of this section deals with the framework developed to represent human behaviour as well as some of the main assumptions and characteristics of the ABM. The final part describes the software and hardware used to run the simulations.

- Human behavioural model

Two general concepts were used during the implementation of the ABM:

1. The ABM was built to represent daily behavioural pattern of a complex urban environment: interactions between agents (humans) and agents with the environment (the city).

2. The ABM includes a module where human cognition is captured to represent the complex human decision making process during evacuation in flood events. The process of implementing the ABM can be summarized to the following five-step process:

Step 1: Description of agents

The first step is to define types of agents that will be considered. Two different types of agents where considered in the present work: **individuals** (where every agent represents one person) and **organizations** (i.e., those organisations in charge of the city evacuation, e.g., civil defence, police, fire brigade, etc.), see Figure 3-1. Also, the warning forecast and communication agencies were modelled as organizational agents (i.e. weather forecast institutions).

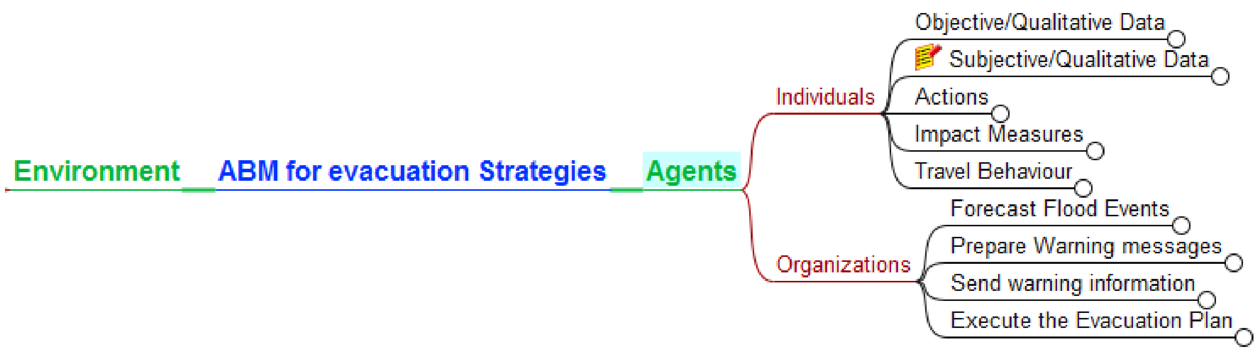

Figure 3-1. Types of agents

Step 2: Classification of agents

This step deals with classification or grouping of different types of agents. The purpose of this is to specify behaviour of agents during different phases of flood disaster. In this work three major phases are considered (Figure 3-2): before, during and after disaster. The warning phase is a moment when agents become aware of a possible threat. The focus of this tool is on the first and second phase of disaster (i.e., before and during disaster). Table 3-1 presents the main parameters that were used in the classification of individual agents. These also include subjective and objective characteristics.

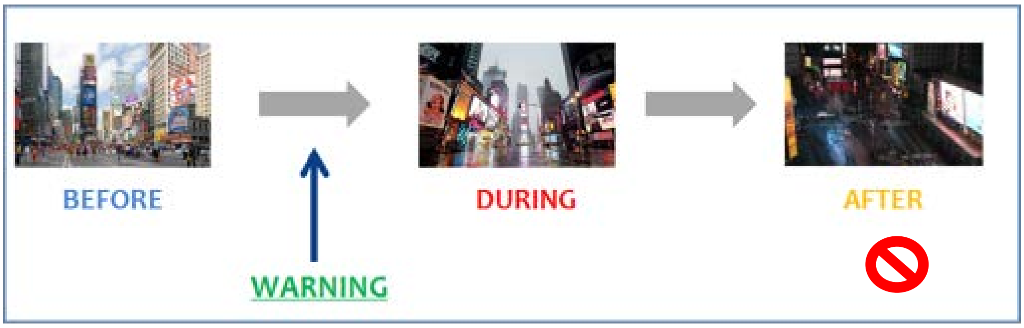

Figure 3-2. Different phases of a flood disaster

Table 3-1 Individual Agents Classification Parameters

Type of Parameter	Parameter
Objective Parameters	Age Gender Employment Status Financial Resources Mobility Language Abilities

Type of Parameter	Parameter
Subjective Parameters	Awareness Education Level Flood risk perception Willingness to Follow orders Altruism/Willingness to help others Resilience / Adaptability Access to Information

Step 3: Environment characterization

In the present work, environment classification refers to those elements that form the physical space in a city (i.e. buildings, roads, water bodies, etc.). It also includes the way how agents interact with the environment and how they interact among themselves, see Figure 1.

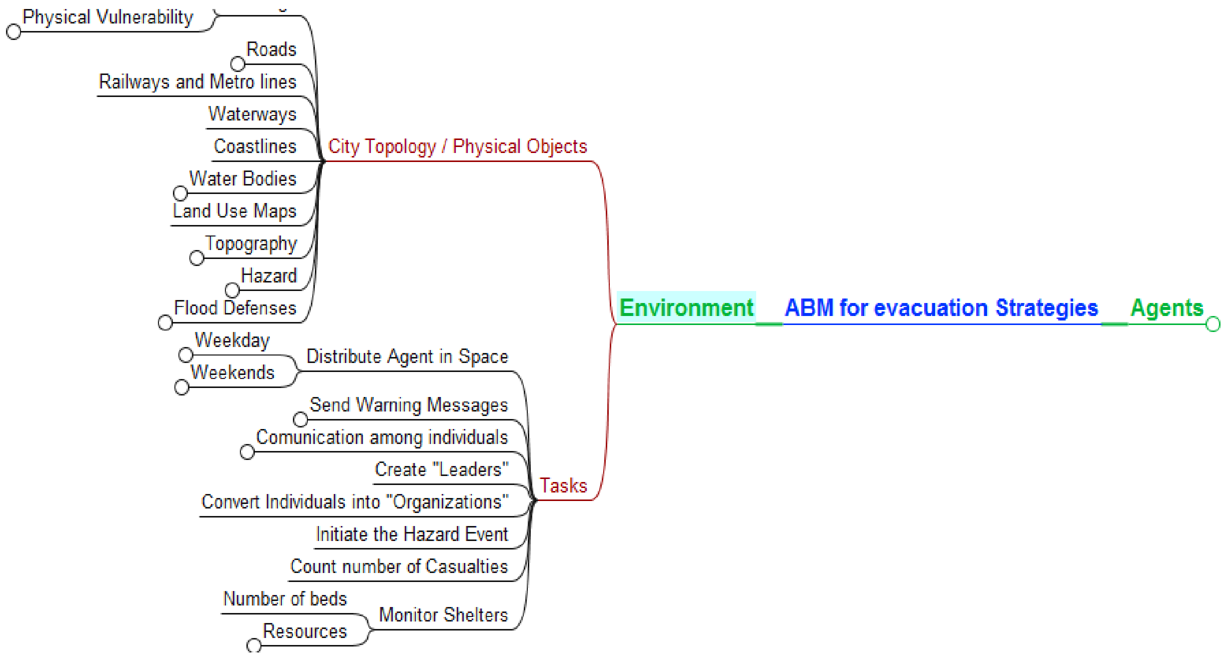

Figure 3-3. Environment - physical representation of space where agents interact;

Step 4: Model formalization and parametrization

This step deals with a set rules that define the agents' behaviour in simulations. This is done by combining narrative rules and flow charts. For each agent (WHO), the actions to perform (WHAT) at

which specific timeframe (WHEN). Refer Figure 3-4 for a description of daily behaviour or routine for individual agents before a flood event is anticipated/forecasted (i.e., before disaster phase).

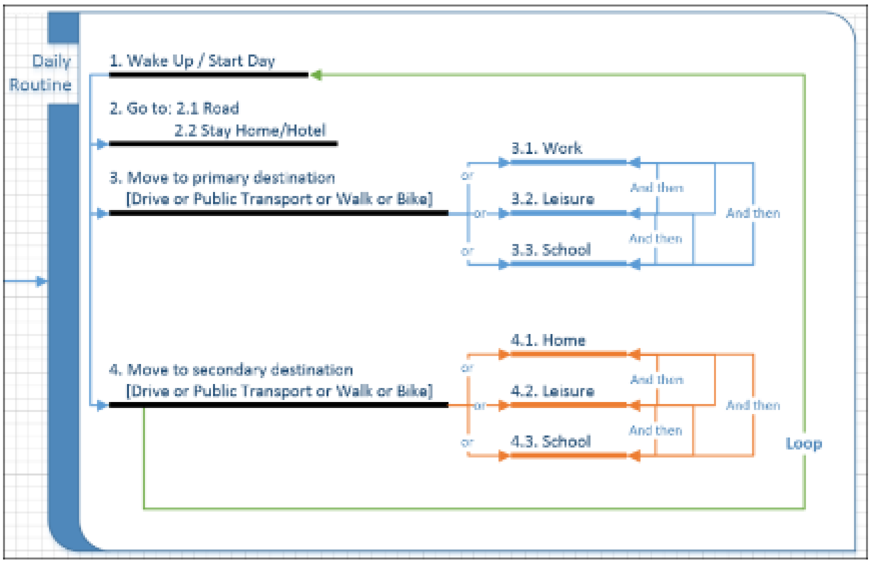

Figure 3-4. Model formalization – daily routine for individual agents.

Probability functions were built into the ABM code for each type of individual agents to perform the most likely activity. The probability varies according to the day (week day or weekend) and also the time when it was taken into account.

Step 5: Cognitive module

This step deals with development of the module within the ABM code to allow individual agents to react in a “human” like manner with respect to the warning information. For this tool the PECS reference model was selected because it allows to specify the influence of physical, emotional, cognitive and social factors and their interactions during emergency situations. PECS intends to support design process of agent-based simulations in which individual human behaviour and decision making process, the interactions between individuals as well as the interactions of individuals with the environment are in the centre of interest. The PECS reference model provides a frame for the construction of agents, a communication infrastructure and an environment component. The internal structure of PECS is presented in Figure 3-5. The structure is composed from a sensor and perception component that allows the agent to sense and perceive data from the environment as well from other agents in the system. The central part of the PECS structure is used to describe the state of the agent regarding its physical, emotional, cognitive and social status. The bottom part in Figure 3-5 is intended to provide the response or behaviour of the agent given the perception and state of the agent during the simulation.

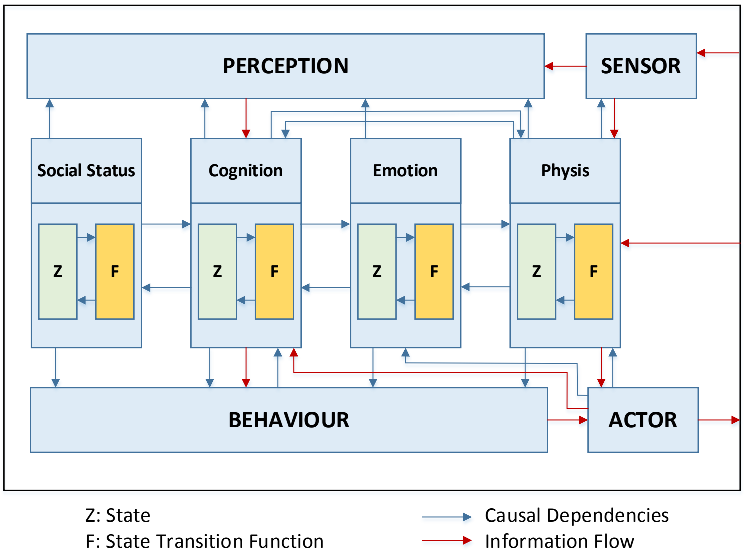

Figure 3-5. Internal structure of PECS reference model (Urban and Bernd, 2001).

Once each agent is aware (or not) of the existing or an upcoming hazard it will react according to a probabilistic function based on the agent characteristics listed in Table 3-1. The list of possible behaviours or reactions is presented in Table 3-2.

Table 3-2. Individual Agents Classification Actions

Action	Observation
Evacuation	Planned and Organized, Follow instructions.
Fight	Prepare in situ
Flight	Random Evacuation (not follow orders)
Sideration[1]	Inability to respond
Search Relatives	Wife, children, parents, etc.
Return home or work place	Feel safe in these places and stay there.
Assist Others	The agent becomes an organization actor.
Antisocial Behaviour	Panic, looting, etc.

In terms of the flood hazard representation, a time series raster file with water depth and velocity is needed. For this purpose, the 2D Mike FLOOD model can be used.

[1] The sideration term within this research is defined as the inability to respond from the psychological perspective.

To explore and evaluate the effects of the warning information in terms of content and dissemination strategies, a module that can allow testing of different scenarios is also needed. This module is here referred to as the Information/Communication Module. In the present work, four scenarios were tested: 1. a baseline scenario, were agents evacuate randomly based on previous knowledge of where to evacuate. 2. a clear message as to where to evacuate is sent to the population in the case study area. 3. a stage evacuation message, this message is sent gradually according to the expected arrival time of the hazard and 4. a targeted message to only those that are within the area expected to be affected by the hazard.

The implementation of the ABM code was done in Repast Symphony as a Java base, free and open source modelling system for creating, running, displaying and collecting data from Agent Based Simulations. This software is currently considered for many ABM modellers as the most powerful and popular free and open source environment to implement ABMs due to its robustness and the available support from online community and repast forums. Another advantage is that its implementation is fully object oriented and it allows easy construction of any ABM model. The version used in the present work is Repast Symphony 2.5 running under Windows 7 Professional, 64-bit operating System on a laptop with an Intel Core i7 processor and CPU @ 2.4GHz with 16 GB of RAM memory.

3.3 Methodology

3.3.1 Description of the flowchart

To be able to set up and run the Operational ABM the following steps need to be undertaken:

1. Software installation.
2. Data collection and preparation.
3. Model formalization and parametrization.
4. Software implementation.
5. Model verification.
6. Experimentation and validation.
7. Result analysis.

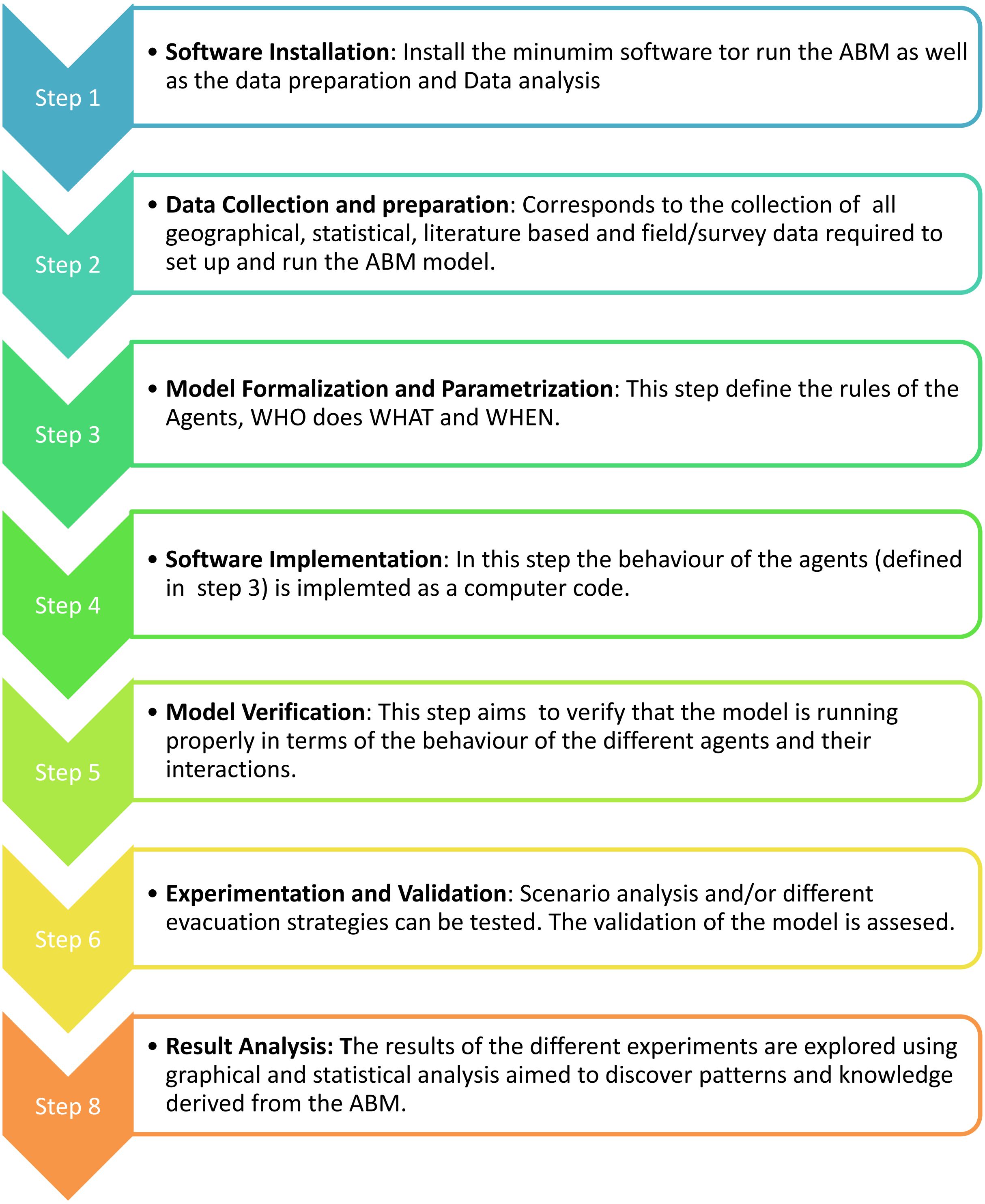

Figure 3-6. Outline of the steps to build the Operational ABM.

3.3.2 *Description of the code, repository, how to install, settings, etc.*

1) Software Installation.

The following software is the minimum software needed to prepare the data, run the model and analyse the results.

a) Repast Symphony

The version of Repast symphony that must be installed is: Repast Symphony 2.5. Installers can be found in the following github repository: https://repast.github.io/download.html. It will install Eclipse Version: Oxygen.1a Release (4.7.1a). For this version of Eclipse to be able to run, Java Oracle must be install as well, the Oxigen 1a version is compatible with Java 8. and Java 9 (download links below). Figure 3-7 shows the versions used in the ABM current development.

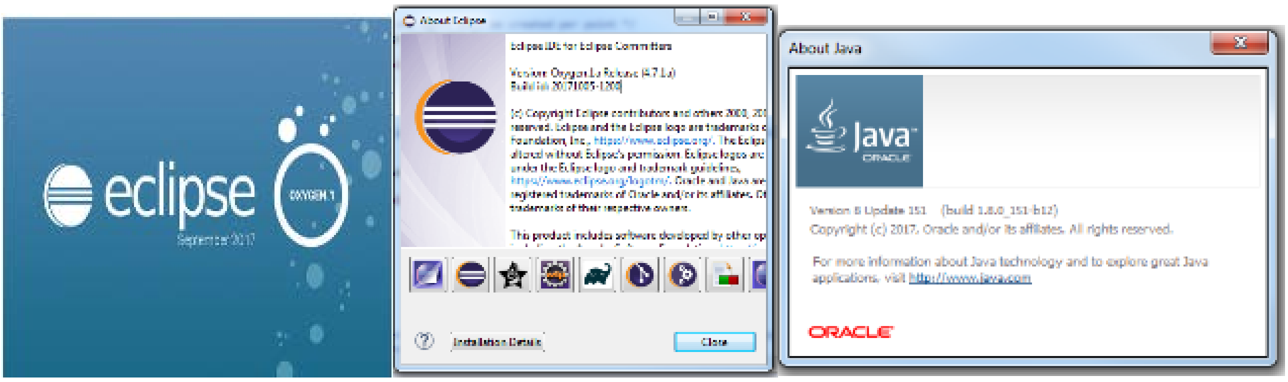

Figure 3-7. Software Requirements

Download Java.

Version 8 Java SE Development Kit 8u151

http://www.oracle.com/technetwork/java/javase/downloads/jdk8-downloads-2133151.html

Version 9 Java SE Development Kit 9.0.1

http://www.oracle.com/technetwork/java/javase/downloads/jdk9-downloads-3848520.html

b) GIS software

Any software with the ability to manipulate: visualize, edit and process spatial geographical data can be used for data preparation and input into the ABM model. For example, the following GIS software can be used for this purpose:

- QGIS

QGIS is a user friendly Open Source Geographic Information System (GIS) licensed under the GNU General Public License. QGIS is an official project of the Open Source Geospatial Foundation (OSGeo). It runs on Linux, Unix, Mac OSX, Windows and Android and supports numerous vector, raster, and database formats and functionalities[2].

Any version of this software can be use. At the moment of writing the latest version was QGIS 2.18. Download link:

https://www.qgis.org/en/site/forusers/download.html

- ESRI ArcGIS - ArcMap

ArcMap, which is the central application used in ArcGIS. ArcMap is where you display and explore GIS datasets for your study area, where you assign symbols, and where you create map layouts for printing or publication. ArcMap is also the application you use to create and edit datasets. ArcMap represents geographic information as a collection of layers and other elements in a map. Common map elements include the data frame containing map layers for a given extent plus a scale bar, north arrow, title, descriptive text, a symbol legend, and so on[3].

Any version of this software can be use. For example, the latest version (desktop based) ArcGIS Desktop 10.5. can be used:

http://desktop.arcgis.com/en/

Whichever GIS software is selected it must have the ability to read Shapefiles (*.shp) as vector files which are used to represent the topology of the city and raster files (*.tif format) which are used in the ABM to represent the flood scenarios.

c) Spreadsheet processor

A spreadsheet processor is needed to prepare (and analyse) tabular data for construction of different agents. This can be:

Free version

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[2] https://www.qgis.org/en/site/about/index.html

[3] http://desktop.arcgis.com/en/arcmap/10.3/main/map/what-is-arcmap-.htm

As a free version the user can opt to install OpenOffice package. Apache OpenOffice Calc.

https://www.openoffice.org/product/calc.html

Commercial software

As commercial software Microsoft Excel can be used.

https://products.office.com/en/excel

d) Statistical Analysis

A software to perform statistical analysis of the outputs as well to plot the results of each simulation is recommended. For this purpose basic users can use a spreadsheet processor as mentioned in the paragraphs above. Alternatively, more advance users can use specialized software packages such as R Studio software.

For this purpose R Studio Desktop package for the statistical Analysis and ggplot package for enhanced data visualization can be recommended.

https://www.rstudio.com/products/rstudio/download/#download

http://ggplot2.tidyverse.org/

2) Operational / Evacuation ABM.

The development of the Evacuation model is done in the Repast Symphony environment. It was built on top of the RepastCity project developed by Dr. Nick Malleson[4] and EV Virtual City 1.0 developed by Dr Chao Luo[5]. More classes and behaviours were added into the code in order to properly represent the large city evacuation due to flood events and to test the role of communication in the evacuation process. To use this model the user needs to paste the folder containing all the code and classes needed to run the ABM for evacuation. The name of the folder is ABM_Evac_City

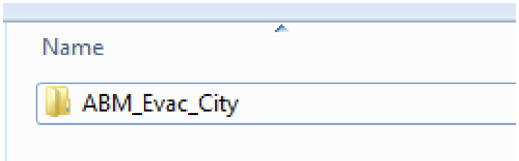


Figure 3-8. Folder containing the ABM for Evacuation (Operational);

The source code can be found in the following repository:

ftp://ftp.pearl.unesco-ihe.org/WorkPackage_3/Del_3_3/ABM_Evac_City

To use the ABM in the Repast Symphony environment the user should proceed with the following steps:

---

[4] https://github.com/nickmalleson/repastcity

[5] https://github.com/chaoluond/EVVirtualCity

1) **Open Repast Symphony.**

Start menu → RepastSimphony 2.5 → Repast Symphony

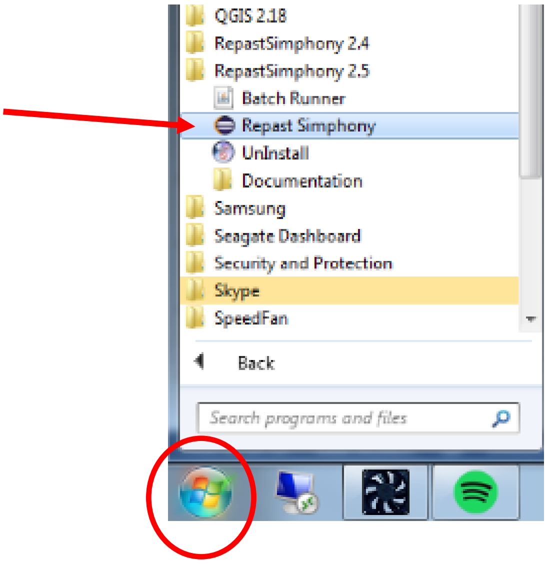


Figure 3-9. Start the Program

2) **Select workspace.**

Select the main directory that contains the folder ABM_Evac_City[6]. Use the browse button to locate it. Press **Launch** once you locate the proper folder.

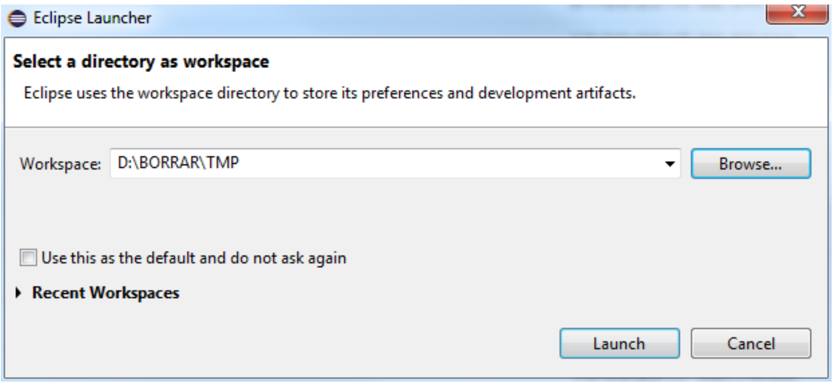


Figure 3-10. Selecting the workspace – Eclipse Launcher;

[6] In this example the ABM_Evac_City folder has been stored in: D:\BORRAR\TMP

Once Repast-S Eclipse is launched the user should be able to see the following structure:

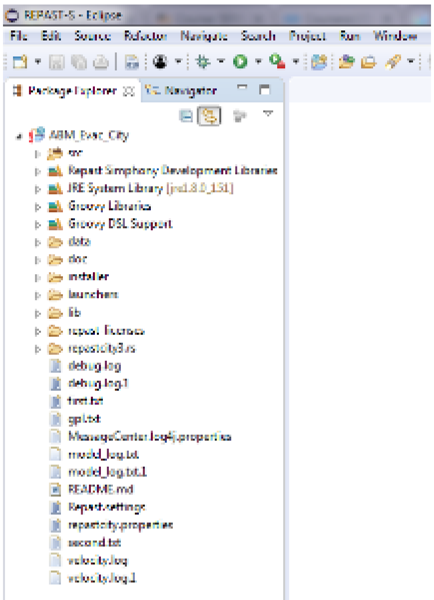


Figure 3-11. Structure of the ABM code in Repast Symphony;

Now the user have all elements to run the AMB model and to make changes in the source code to adapt it to a different set of rules for a given case study area.

If the user is not able to see the ABM for evacuation in the package explorer as shown in Figure 3-11 the following steps will enable to import the model into the working space.

- ✓ File → Import (Figure 3-12)

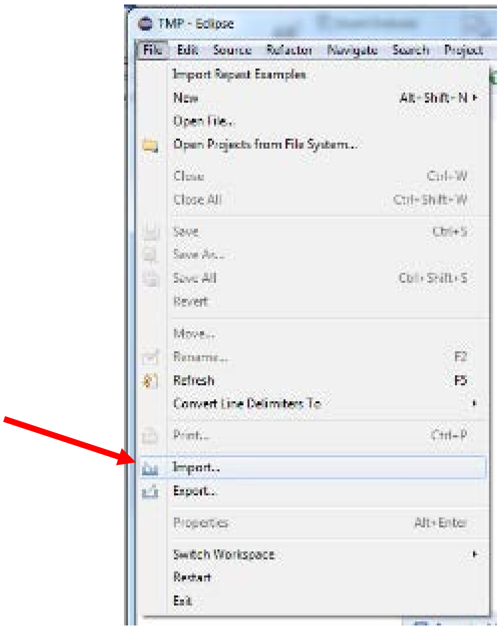


Figure 3-12. Import Model into Repast function;

✓ Follow the Import Wizard steps. General → Existing Projects into Workspace (Figure 3-13)

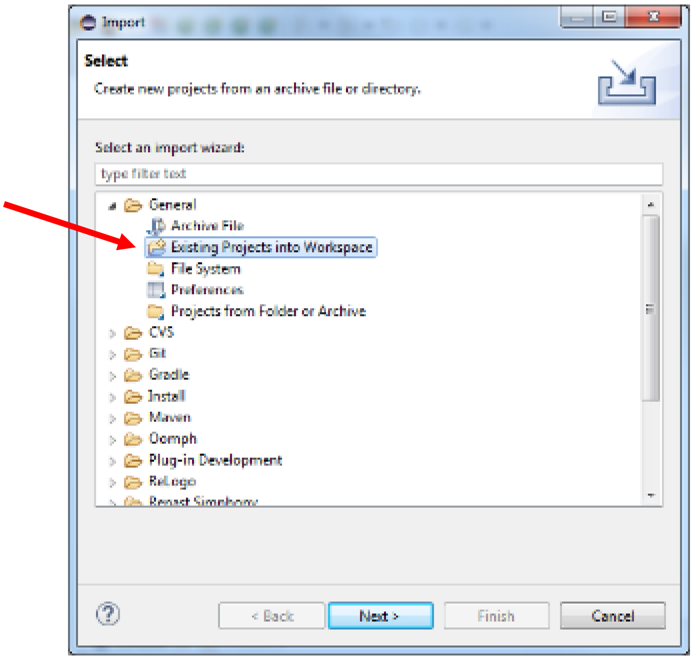


Figure 3-13 Import project into Repast. Wizard – Step 1;

✓ Select root directory **(Browse…)**

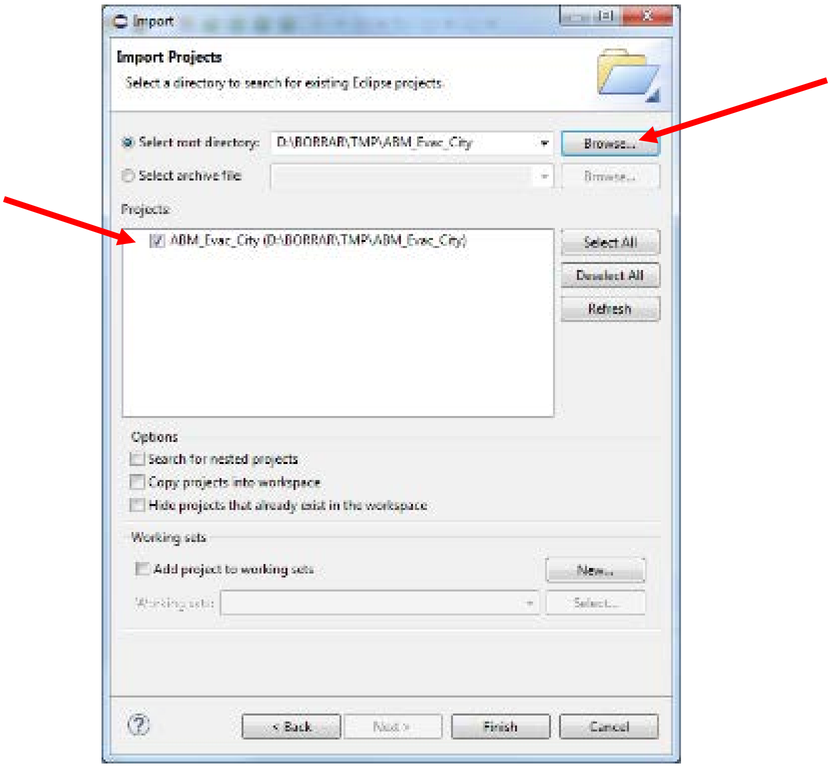


Figure 3-14 Selecting the ABM folder. Wizard – Step 2;

The user should ensure that the box next to the ABM_Evac_City is checked, as shown in Figure 3-14. Once the box is checked (if needed) press **Finish**. After this the user should be able to see the project as shown in Figure 3-11.

For a tutorial on how to use Repast symphony visit: https://repast.github.io/docs.html. This repository contains the necessary documentation.

3.4 Using the tool

3.4.1 Description of user interface

To Run the model the user must load the ABM_Evac_City into the working directory as specified in the previous section. Once the model is loaded the user can proceed by pressing the Run Button and then selecting EV_Virtual_City (Figure 3-15)

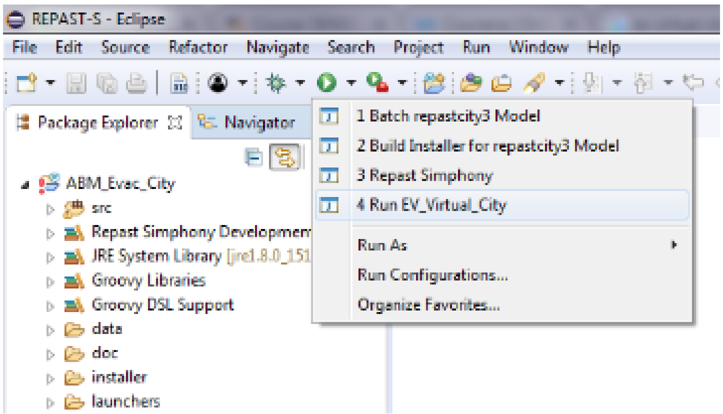


Figure 3-15. Running the ABM for evacuation model;

This will launch the Repast Symphony viewer.

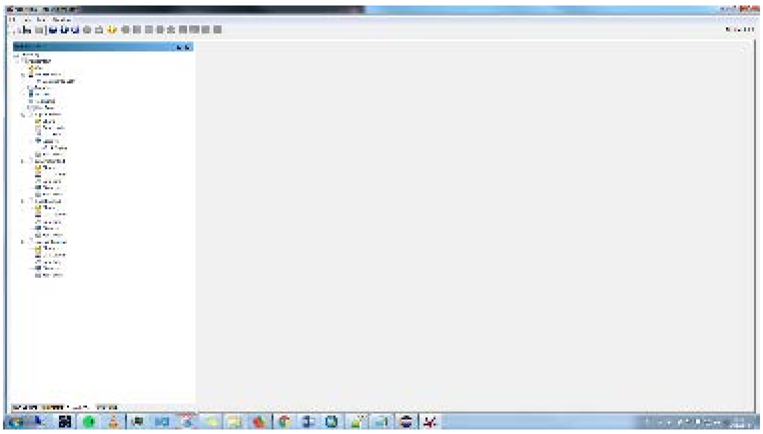


Figure 3-16. Initial window of Repast Viewer;

Now the user needs to press the Initialize Run button. It may take a while for the model to start running depending on the computer specification.

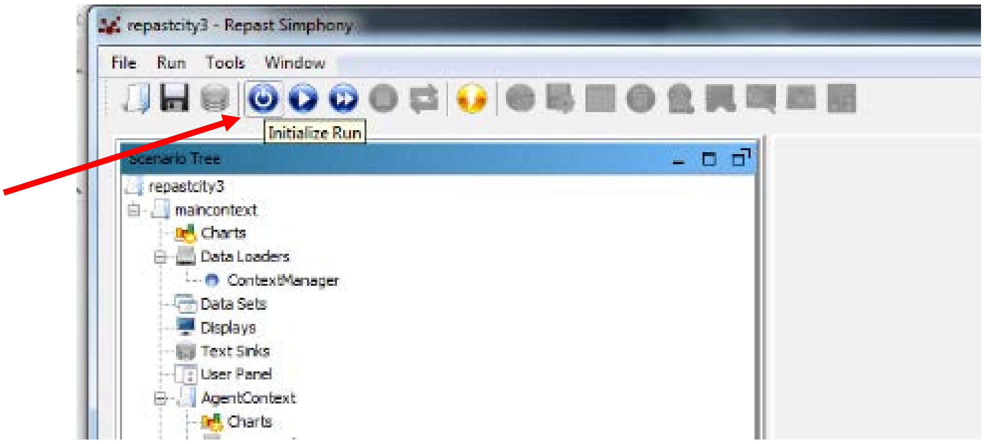


Figure 3-17. Run Button

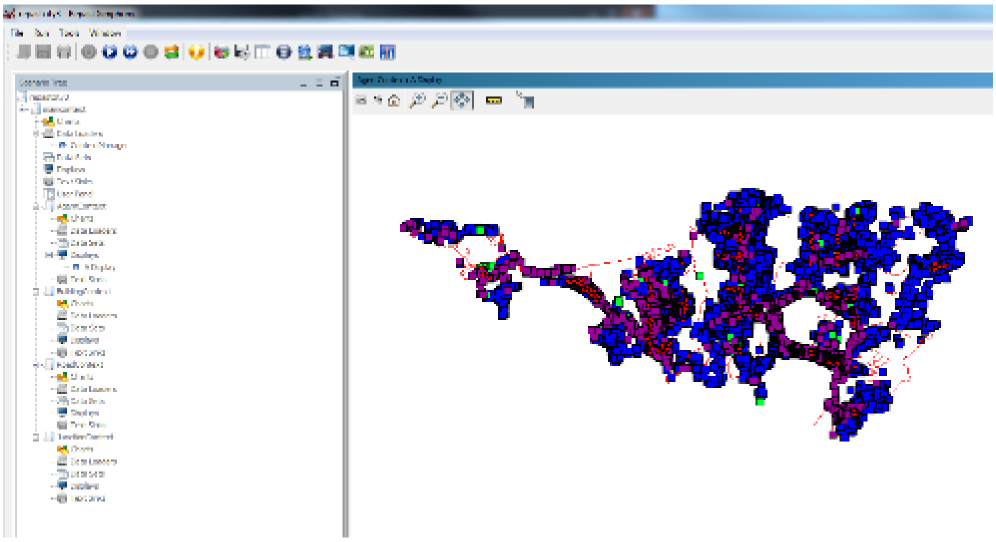


Figure 3-18. Graphical visualization of the ABM Model after initialization: the case of Sint Maarten;

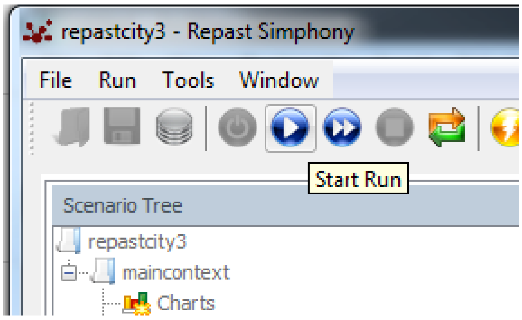


Figure 3-19. Start Run Button;

3.4.2 Input data set

- **Geographical Data**

There is a minimum of geographical data (Shapefiles) that needs to be prepared in order to build and run the ABM for evacuation purposes. The structure of files is given below.

Buildings shapefile.

Type: Polygon

Attribute table Structure:

Table 3-3. Structure of the Attribute Table of the Shapefile of Buildings

Attribute Name	Type/Format	Observation
FID	Object ID	Assigned automatically by the software
Shape	Geometry	Assigned automatically by the software
TYPE	Numeric: Short Integer Precision: 4	A value representing the type of building/Land use.
ID	Numeric: Long Integer Precision: 5	A unique value representing each one of the buildings. Assigned by the user
identifier	Text. Length: 10	A unique alphanumeric code for each one of the buildings. (Can be the same as the ID)

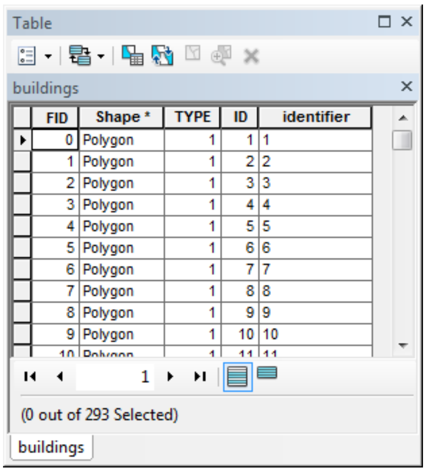


Figure 3-20. Attribute Table look in ArcMap – ESRI©

For this ABM model there are 4 types of buildings that are considered according to the final destination given to the building. The aim is to represent daily flux of inhabitants and/or tourists between different types of buildings during the week, see Figure 3-21 and Table 3-4.

Table 3-4. Type of Buildings used in the Operational ABM

Building Type	Code in Attribute table	Observation
1	(1) Residential	Every building that has as a primary land use the housing of the inhabitants
2	(2) Hotel / Accommodations	Buildings which primary destination is the temporal accommodation such: Hotels, hostel, motels, Airbnb, etc.
3	(3) Work Related Building	Corresponds to those buildings with land use dedicated to industry, commerce and services.
4	(4) Public and Leisure Building	Educational, religious, Sport, Hospitals, Governmental buildings are considered within this category.

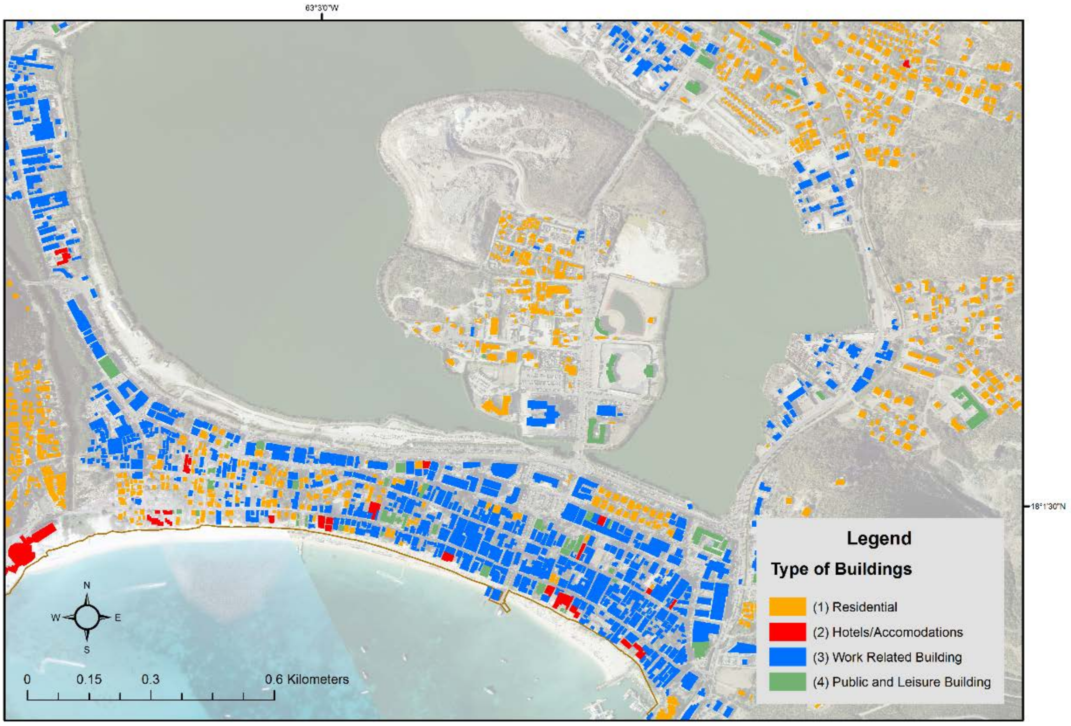


Figure 3-21. Type of Buildings for the operational ABM;

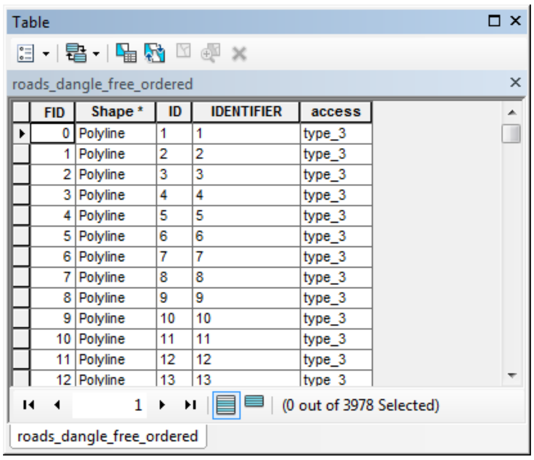
Roads shapefile.

Type: Polyline

Attribute table Structure:

Table 3-5. Structure of the Attribute Table of the Shapefile of Roads

Attribute Name	Type/Format	Observation
FID	Object ID	Assigned automatically by the software
Shape	Geometry	Assigned automatically by the software
ID	Text. Length: 10	A unique value representing each one of the buildings. Assigned by the user
identifier	Text. Length: 10	A unique alphanumeric code for each one of the buildings. (Can be the same as the ID)
Access	Text. Length: 10	A descriptive information that represents the type of road



Table

roads_dangle_free_ordered

FID	Shape *	ID	IDENTIFIER	access
0	Polyline	1	1	type_3
1	Polyline	2	2	type_3
2	Polyline	3	3	type_3
3	Polyline	4	4	type_3
4	Polyline	5	5	type_3
5	Polyline	6	6	type_3
6	Polyline	7	7	type_3
7	Polyline	8	8	type_3
8	Polyline	9	9	type_3
9	Polyline	10	10	type_3
10	Polyline	11	11	type_3
11	Polyline	12	12	type_3
12	Polyline	13	13	type_3

1 (0 out of 3978 Selected)

roads_dangle_free_ordered

Figure 3-22. Attribute Table look in ArcMap – ESRI©

For this ABM model there are 4 types of roads are considered according to the maximum velocity that the vehicles can have in each road, see Figure 3-23 and Table 3-6,

Table 3-6. Type of Roads used in the Operational ABM

Road code	Code in Attribute table (access field)	Observation
1	type_1	Main Roads. Velocity 0-80 km/hour
2	type_2	Secondary Roads. Velocity 0-60 km/hour
3	type_3	Tertiary Roads. Velocity 0-40 km/hour
4	type_4	Pedestrian Roads / Access.

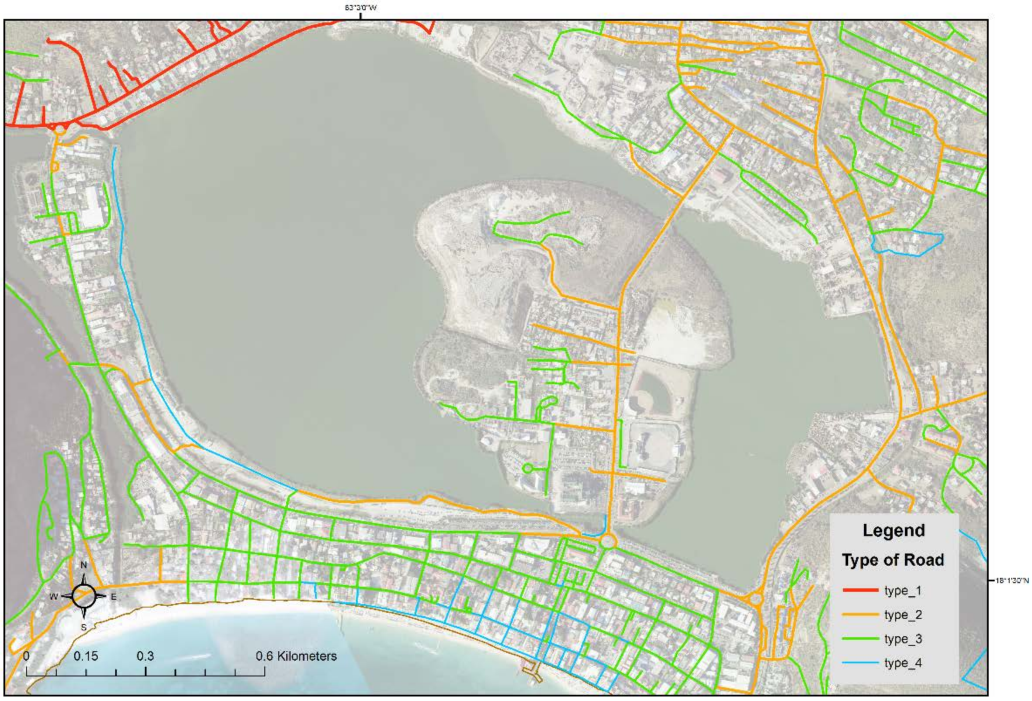


Figure 3-23. Type of Roads for the operational ABM;

In addition, there are some specific requirements for roads shapefile data:

1) The entire network must be joined together, there should be no disconnected roads.
2) At any intersection of roads, the roads must be split for all roads involved in the intersection. If two roads cross then each polyline object needs to split at the point that they cross

The previous two conditions can be met easily using the **Planarize Lines** function in ArcGIS[7]. It should be noted that if the previous conditions are not fellfield the model will not run.

Individual's shapefile.

Type: Points

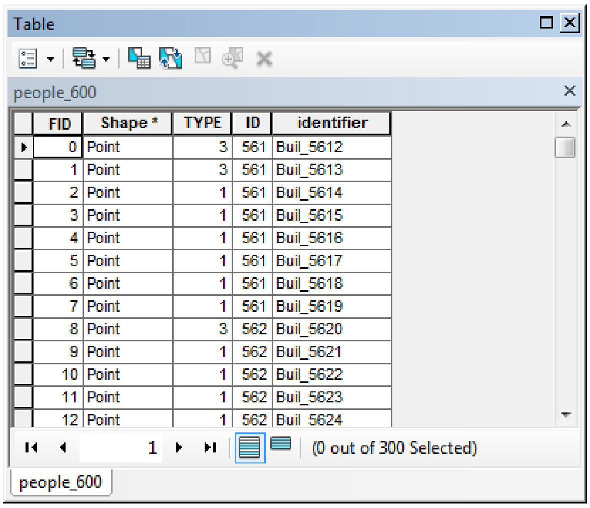
Attribute table Structure:

---

[7] http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#//001t0000008t000000.htm

Table 3-7. Structure of the Attribute Table of the Shapefile of Roads

Attribute Name	Type/Format	Observation
FID	Object ID	Assigned automatically by the software
Shape	Geometry	Assigned automatically by the software
TYPE	Text. Length: 10	A value representing each one of the Individual agents according with the characterisation described in Table 3-1 and Figure 3-1. There can be as many types as combinations of characteristic's as possible.
ID	Numeric: Long Integer Precision: 10	A unique value representing each one of the buildings. Assigned by the user
identifier	Text. Length: 10	An alphanumeric code for each one of the Individuals in order to represent the building they live in. Is not Unique, so all members of a family in the model need to have the same identifier.



FID	Shape *	TYPE	ID	identifier
0	Point	3	561	Buil_5612
1	Point	3	561	Buil_5613
2	Point	1	561	Buil_5614
3	Point	1	561	Buil_5615
4	Point	1	561	Buil_5616
5	Point	1	561	Buil_5617
6	Point	1	561	Buil_5618
7	Point	1	561	Buil_5619
8	Point	3	562	Buil_5620
9	Point	1	562	Buil_5621
10	Point	1	562	Buil_5622
11	Point	1	562	Buil_5623
12	Point	1	562	Buil_5624

Figure 3-24. Attribute Table look in ArcMap – ESRI©;

The geographical initialization of individuals must match with the statistical data of each case study. In terms of the number of inhabitants per geographical area, their age, sex, income, etc. (see Table 3-1 and Figure 3-1) it is recommended that the generation of type of agents is done outside from ArcGIS. For this purpose Excel or R studio can be recommended.

Figure 3-25. Illustration of individuals in the operational ABM model.

- **Changing the Code**

By default, the ABM creates agents of each type according to the types defined in the shapefile of individuals (Table 3-7). This is done by: **DefaultAgent.java** (Figure 3-26). This source file contains a method called **step ()**; located at line 89 (Figure 3-27). This method is used for the behaviour of each agent. Hence, any change on the expected behavioural rules must be done in this segment of the code.

By default, each agent in the ABM model starts in the assigned building (identifier) then it chooses randomly a building of a different type to work or recreation depending on the time of the day and day of the week as well its own characteristics. After a period of time (working hours for instance) each agent travels home again. When a flood warning is announced or when the agent get in the contact with the hazard it will change its behaviour to either return home or to search for a shelter.

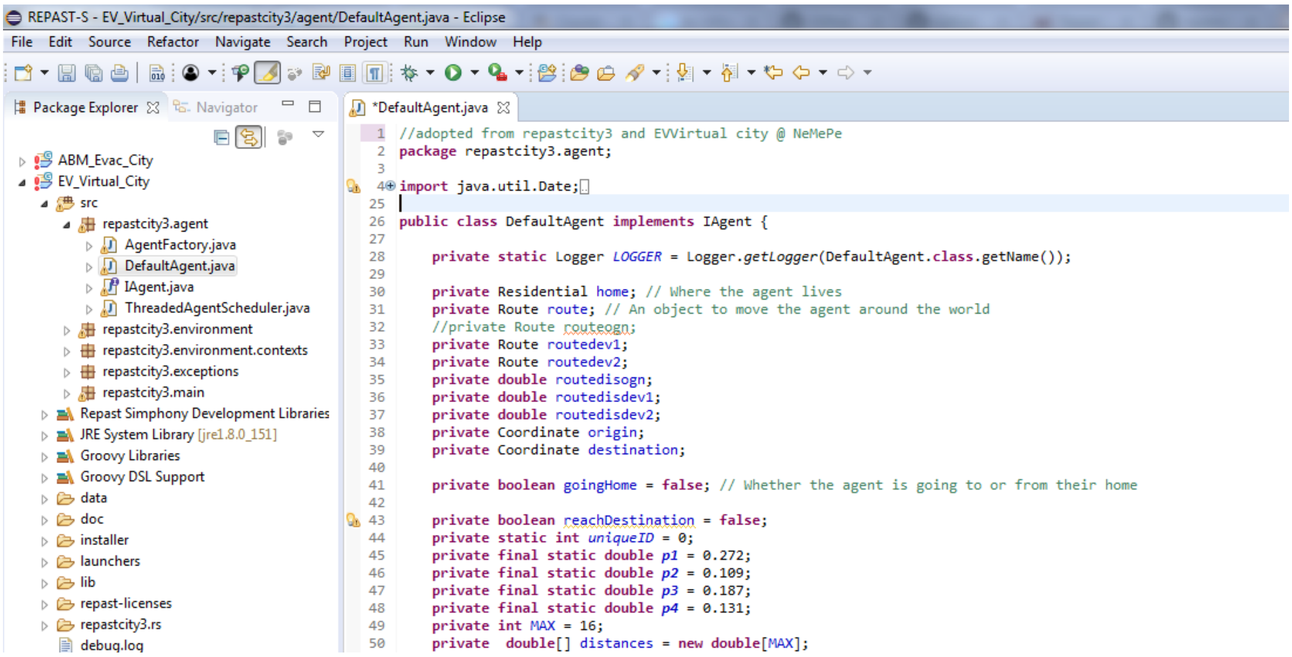


Figure 3-26. Location of DefaultAgent.java;

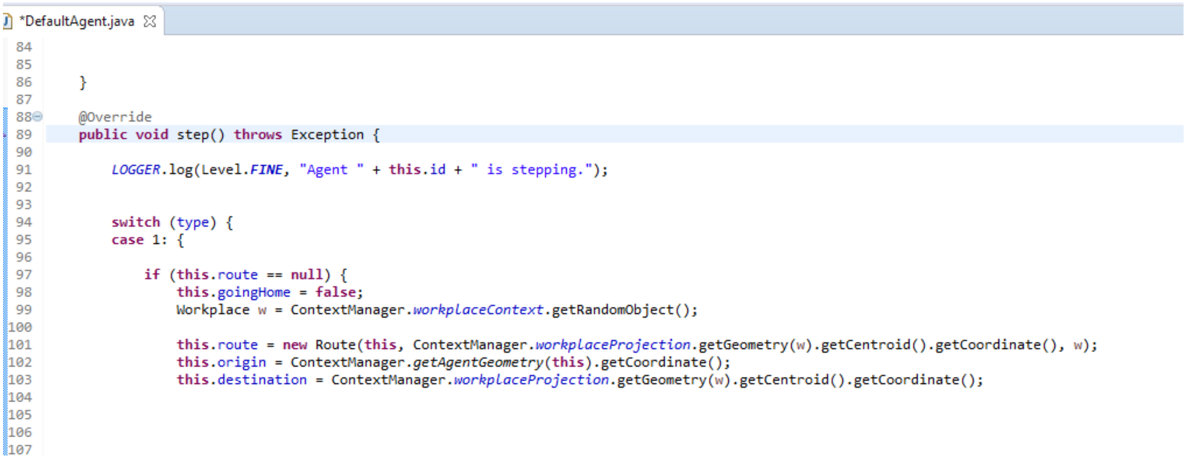


Figure 3-27. Step() method for individual agents in the operational ABM;

3.4.3 Outputs

Figure 3-28 illustrates the ABM model at the beginning of a new simulation at full scale and a zoom over a specific area of the case study. Figure 3-29 shows the zoom area after some steps (virtual hours) of the model run.

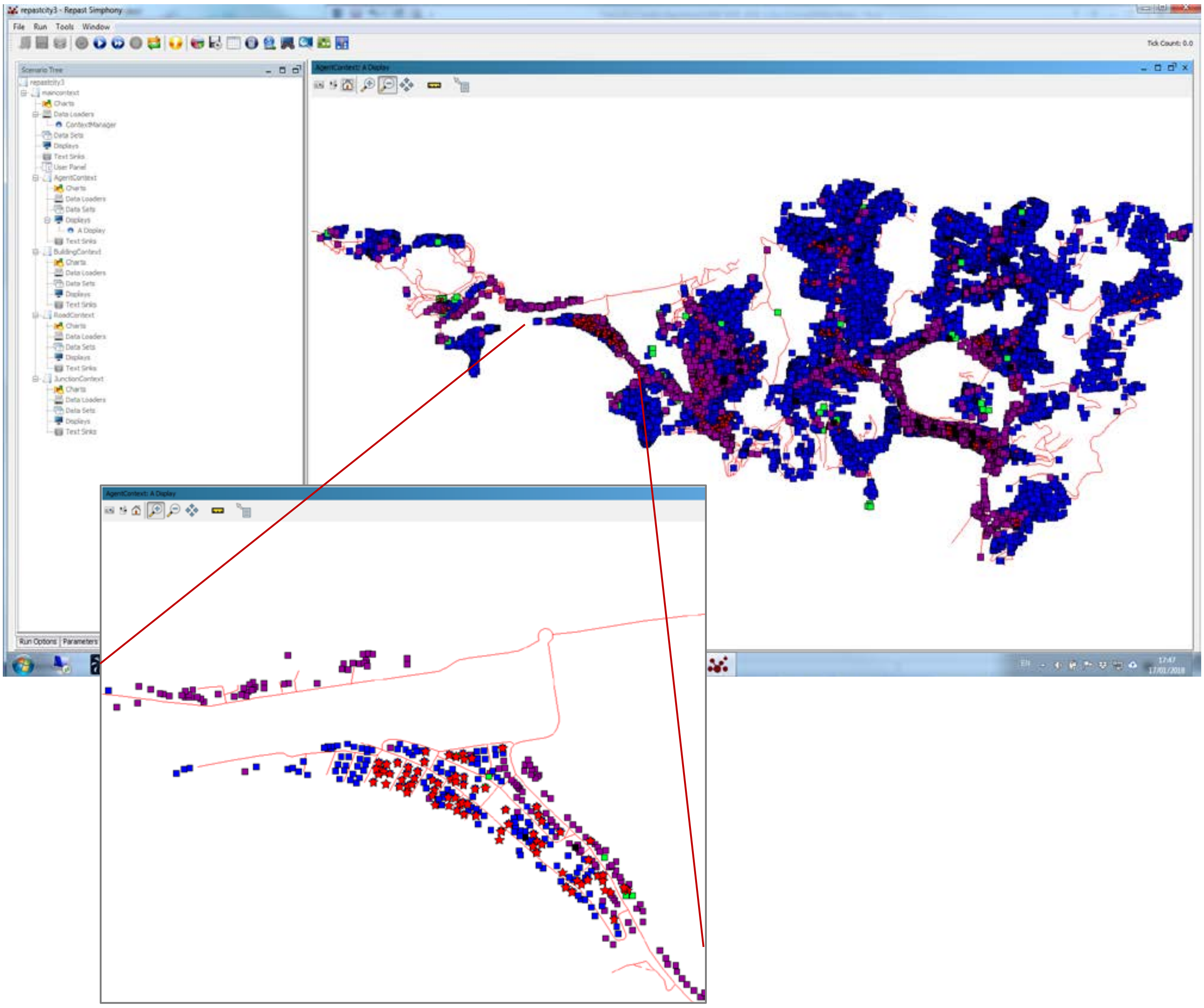


Figure 3-28. Illustration of the ABM simulation and zoom to a particular area;

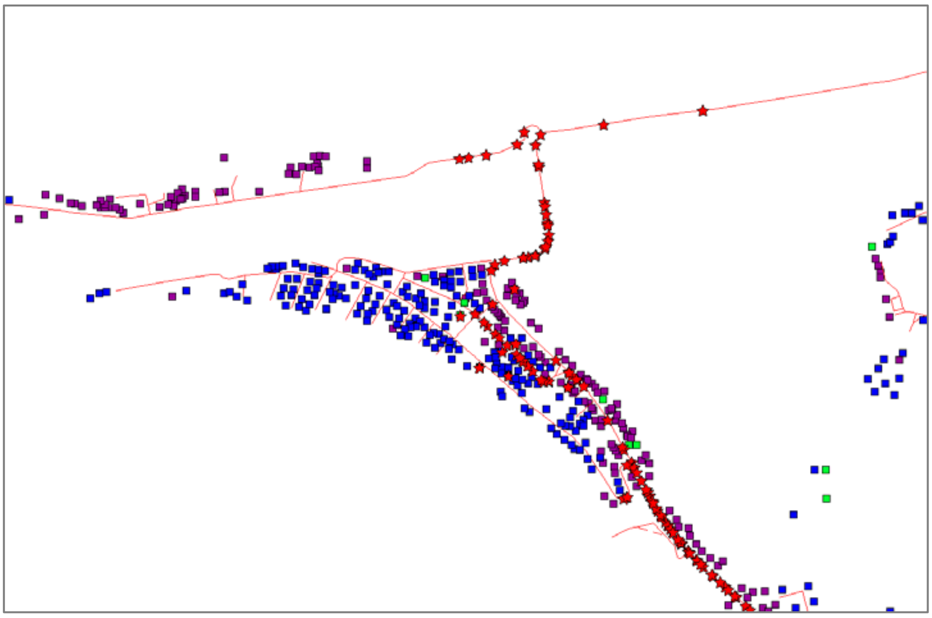


Figure 3-29. A screen shot of simulation;

The main outputs that can be extracted from the operational ABM are:

- Number of individuals that can be in contact with the water;
- Number of individuals that can reach shelter during an evacuation;
- Number of individuals that cross each road;

3.5 Tutorial / Cases

3.5.1 Application of the tool on a case study area

The agent based model for evacuation strategies was implemented for the case of the Dutch side of Sint Maarten in the Caribbean. A total of 33609 agents were used to represent the population of the island and a total of 13679 buildings (accounting for the 4 types) were used. The model was simulated for an entire week, i.e., from Monday to Monday. Start of simulation was set to be at 4 am considering that rush hour will occur at around 9 am. At the beginning of the simulation every agent selects a destination and it starts moving in that direction, which is chosen based on the individual's classification and according to the day and the time of the day for each agent (e.g., going from home to work, leisure, school and so on). As a source of hazard, a hurricane was introduced into the ABM scenario to test evacuation capabilities of agents. For this purpose, the 2D MIKE FLOOD was used and the hurricane Omar was simulated (Hurricane Omar, 2008)

Furthermore, to explore and evaluate the effects of the warning information in terms of the content and dissemination strategies, 4 different scenarios were set in the ABM: 1. A baseline scenario, were

agents evacuate randomly based on previous knowledge of where to evacuate. 2. A clear message as to where to evacuate is sent to the population on the island (scenario 1). 3. A stage evacuation message is send gradually according to the expected arrival time of the hazard (scenario 2) and a targeted message to only those who are within the affected area (Scenario 3).

3.5.2 Outputs from the case study

As can be seen in Figure 3.30 for all three scenarios that were tested in this case study, it can be seen an increase in the number of inhabitants that manage to reach a shelter or safe area in comparison with the base line scenario, with values of 24159, 25531 and 22456 agents for scenario 1,2 and 3 respectively. The results for people in contact with the hazard (orange bars in the graph) for all three scenarios show an increase in the number of exposed if compared with the base line in relative values as low as 3795 agents for scenario # 2 up to 4339 agents or 1081 more people exposed in Scenario # 3.

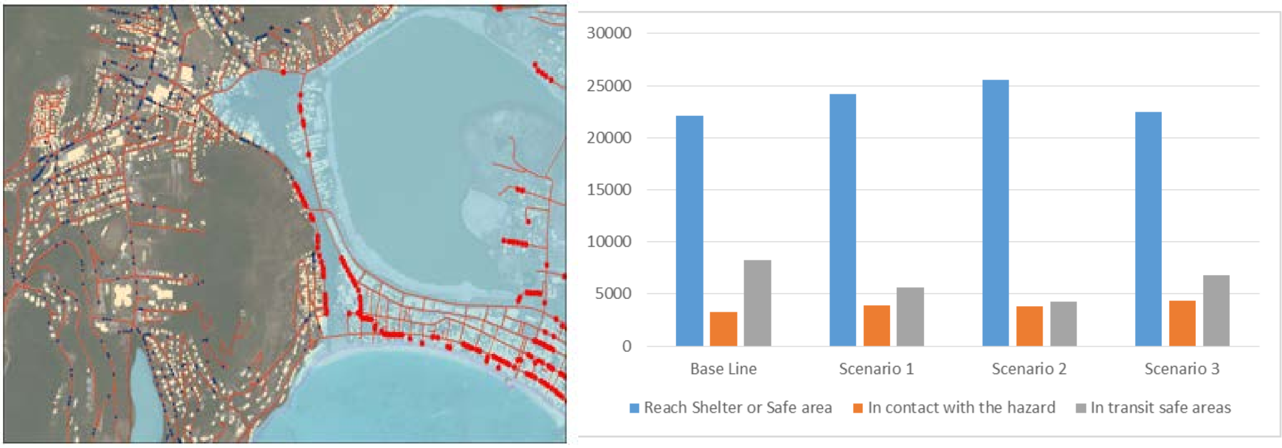


Figure 3-30. Application of the operational ABM in the case of Sint Maarten island

Upon the simulation of four scenarios, some infrastructure improvements to the Sint Maarten Evacuation plan can be inferred. Two major roads were identified as the primary routes to get into the shelters, see (Figure 3-31).

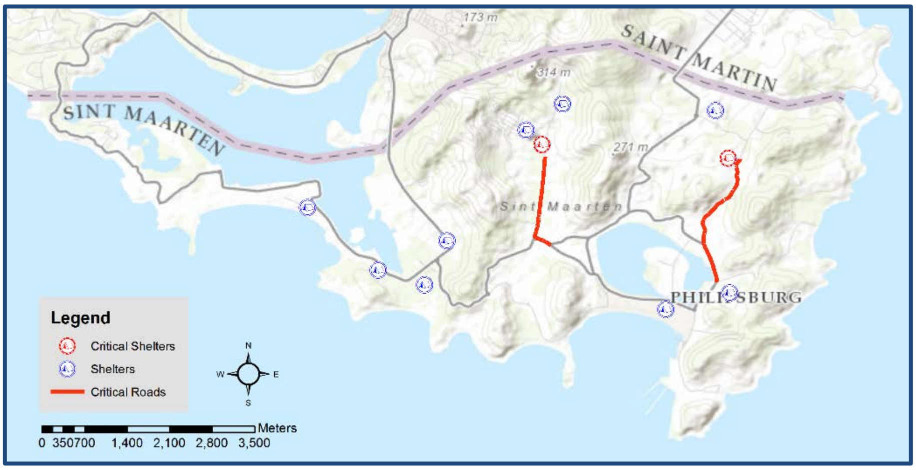


Figure 3-31. Critical roads and critical shelters in the Sint Maarten case study area;

3.6 Concluding remarks

The operational ABM developed in PEARL can be seen as a tool that integrates social or human behavioral model with hydrodynamic model (hazard) and communication module. The results obtained demonstrate usefulness of this tool for gaining better understanding of some important aspects involved in emergency evacuation. They also show feasibility of ABM to test large scale city evacuations.

Some of the main conclusions that can be drawn from the preliminary work undertaken are:

- During large city evacuation, not only that the message content matters but also the way how the message is delivered, accepted and understood by the community is important for consideration in evacuation planning,
- There is a need to better understand the effects that social networks have on evacuation processes and how they can be used to achieve better evacuations, and
- ABM has the potential of be a useful tool for operational risk management activities such as: identification of evacuation patterns, identification of critical infrastructure and identification of the needs for improvement of existing emergency locations (i.e. number of beds, food storage, etc.).

The work to date also shows that having a more informed community on how to react to a certain flood threat will increase the number of people reaching safe area and therefore minimizing the risk to life. It was also noted that having a stage evacuation (scenario #2) can outperform scenario # 1 where all the community is informed at the same time. This is mainly due to the congestions in major roads for scenario number 1 and the fact that many would people try to evacuate at the same time.

It was also interesting to observe that for all three simulated scenarios of warning dissemination there was an increase of the number of people being exposed to the hazard. On one hand this can be explained as more people are aware of the threat and would look to reach the shelter, while on the other hand it is also a clear indication that the lead time for flow of information should increase to minimize the number of people being exposed to the hazard.

Our future work will explore the effects of different lead times on the overall performance of different evacuation strategies. In addition, a module that can evaluate the potential loss of life, i.e., how many of agents may die, when they get into the contact with flood water will be developed and it will include the following features: characteristics of the hazard (e.g., water depth and velocity) and characteristics of individuals (e.g., age, gender, etc.). Such module will contain more information of the system (city) and as such it is expected to enable better evaluation of emergency situations.

3.7 References

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4 PEARL flood-traffic integration tool

4.1 A brief description of the tool

PEARL flood-traffic integration tool was developed to provide a comprehensive assessment of the flood impacts on road transportation. This tool is the first of its kind that practically translates flood maps into a specific input for the traffic model SUMO. The tool integrates flood and road transportation modelling via two Python models that run in ArcGIS environment. The main motivation to develop this tool was driven by innovation, because it enabled us to fill in a gap in the current state of the art. To this date, flood and transport models have not been integrated in a dynamic way. The tool makes this possible via providing a consistent and homogeneous method to combine temporally varying flood propagation with a temporally varying traffic supply in the SUMO model. Another aspect of the tool is that it allows multiple flooding and traffic scenarios to be easily set up and simulated.

The logic behind the tool is quite intuitive – flood conditions dictate the situation in the road network that is linked to the traffic model. A shallow flood depth on the road surface will lead to a speed reduction of traffic. Where the flood depth gets deeper[8], that road will be closed for traffic such that vehicles originally passing through that road will have to choose alternative routes to reach their original destinations. This rationale of rerouting individual vehicles represents drivers' choices in a very detailed, realistic and robust way, as opposed to the existing methods that made assumptions based on homogeneous traffic flow on each link (Chang et al., 2010; Suarez et al., 2005). The rerouting of SUMO assumes that the flood conditions affect drivers in various ways – the ones that cannot reach their destinations via the planned routes will have to choose alternative routes, but others will be indirectly affected by additional traffic in the non-flooded roads. Hence, the results identify the difference between the journeys that were directly impacted by the flood (the rerouted) and the journeys that were indirectly affected by the resultant congestion.

4.2 Introduction to the tool

4.2.1 Description of the components developed

The flood-traffic integration tool consists of two main components:

- The first model selects the flooded roads according to SUMO requirements for street closure and it is a Python script for ArcGIS.
- The second model is a Python script that translates the GIS shapefile output into the required XML file input to SUMO.

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[8] More information about the definition of shallow and deep flood depth can be found in 4.3 Methodology

4.3 Methodology

4.3.1 Description of the flowchart with all the steps

The general function of the flood-traffic integration tool is illustrated in Figure 4-1. The main purpose of the tool is to act as a communicator between a flood map and a traffic model set up. Considering the uncertainty of flood propagation, the tool requires multiple flood events as inputs that trigger consecutive traffic modelling. As mentioned previously, the tool has two main components that run in ArcMap and in Python.

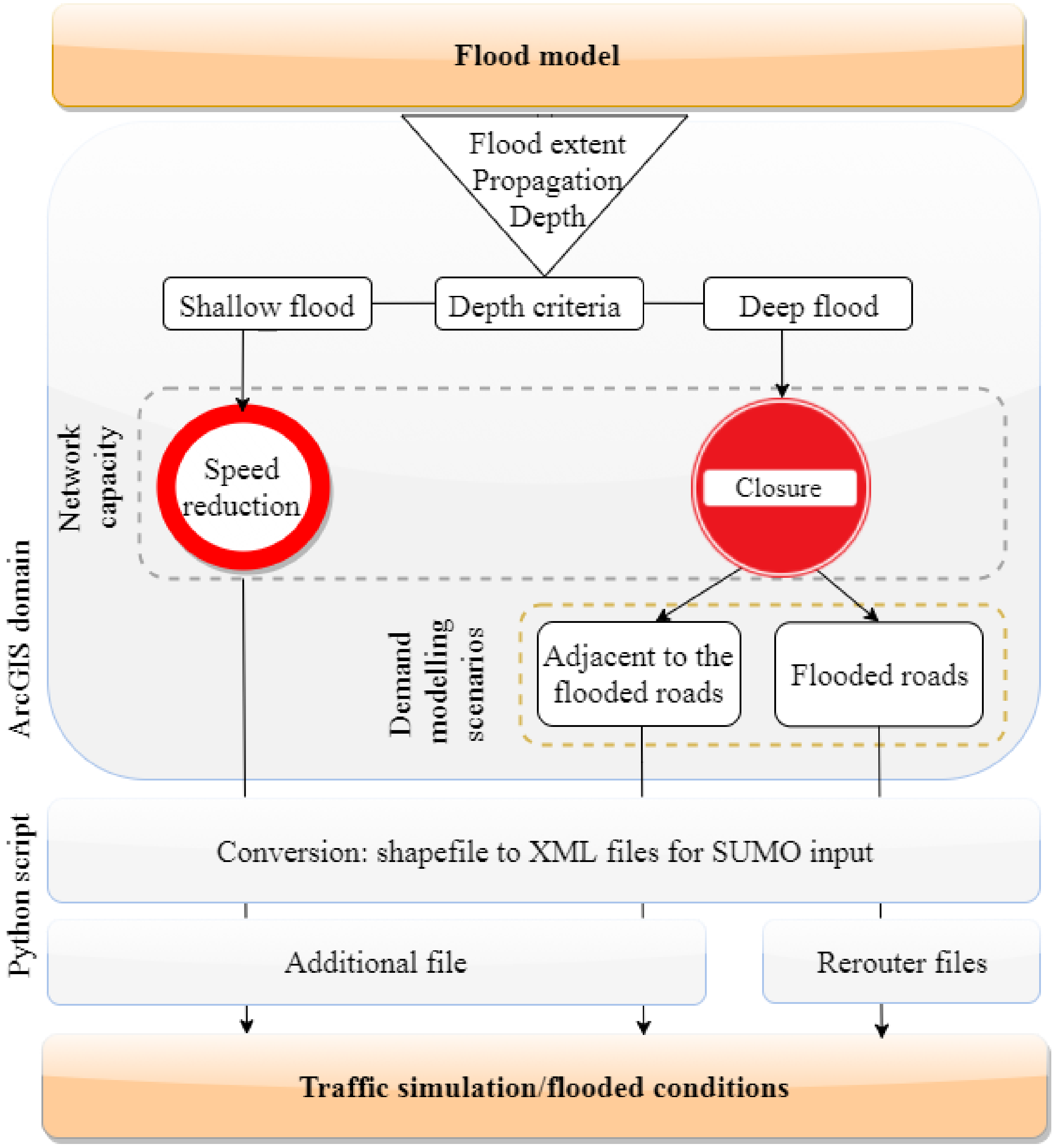

Figure 4-1: Flowchart of the function of the flood-traffic integration tool

The first component of the tool is the ArcGIS based model. Its goal is to identify the operational status (i.e. speed reduction or closure) of roads directly affected by floods. The status is defined by a parameter that determines what flood depths are perceived as shallow and what are perceived as deep. That distinction regulates the type of intervention that will be introduced on each of the flooded roads.

The processing of information must match the SUMO requirements of input XML files. Therefore, a bottom-up approach was necessary to ensure adequate communication between the flood and the traffic models. The rerouting mechanism in SUMO requires the IDs of the flooded roads and the IDs of the adjacent roads to be supplied in separate files (respectively rerouter[9] and additional[10] files in SUMO). On the roads adjacent to the flooded ones the drivers are informed that the next road from their route is closed and that prepares them to select alternative routes.

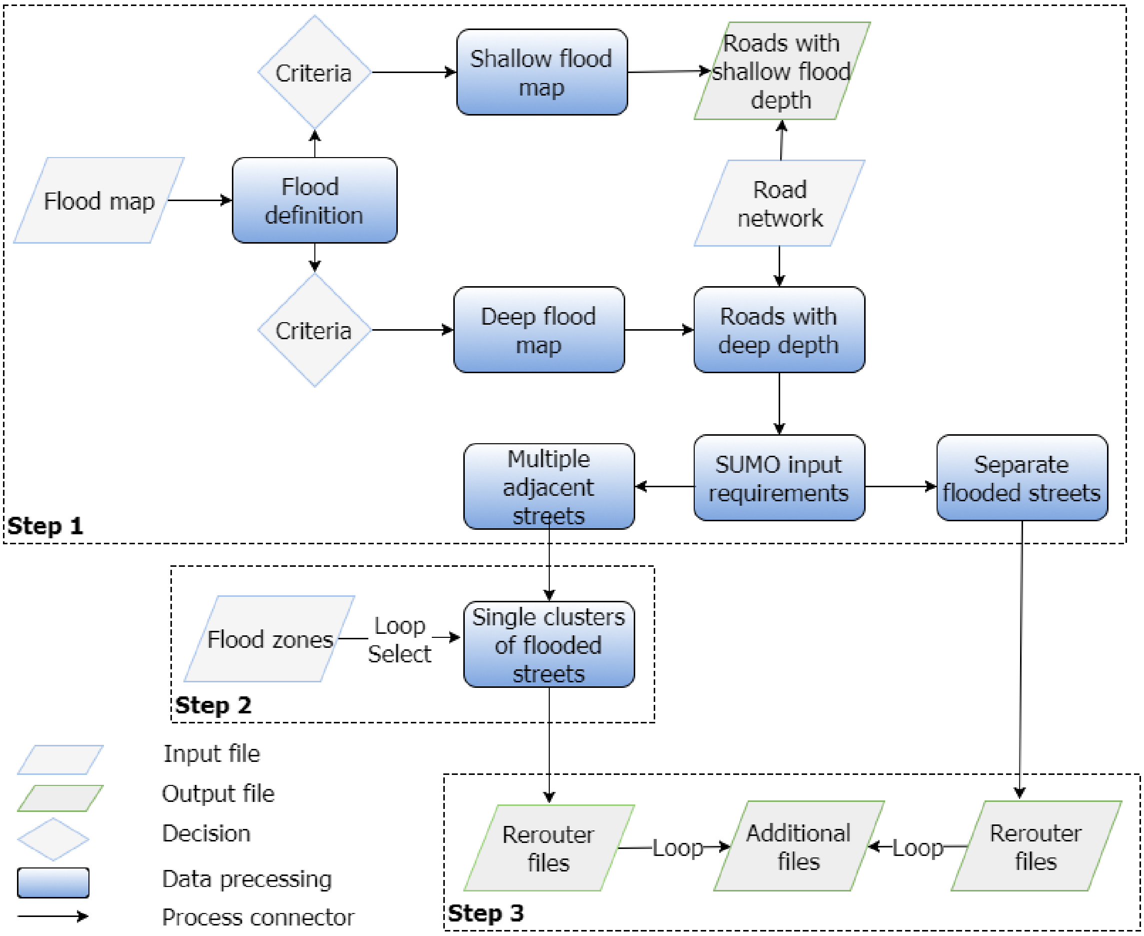

*Figure 4-2: Step by step interpretation of the **first** component of the tool*

[9] Rerouter files determine the roads that will be closed for traffic and the duration of that closure

[10] Additional files supply the adjacent roads to the closed ones. They are connected to the rerouter files via ID.

Figure 4-2 illustrates a step-by-step logic of the first component of the tool, where the straight lines present processes run in ArcGIS and the dotted line is processes run in Python alone.

The first step of the model separates the supplied flood map into two maps according to the defining criteria for the shallow and deep flood. The road network is then overlaid with the flood maps to identify roads flooded with either shallow or deep flood water. If one road is flooded by two separate ponds and one has a deep and the other shallow flood depth, that road is selected among the roads with deep water depth. The roads with shallow depth are saved into a file that is ready for processing from the second model in Python. The requirements in SUMO for a street closure are very specific and the next steps of the ArcGIS model ensure appropriate execution. The rerouting mechanism in SUMO requires each rerouter file to be supplied in a separate file. This is straightforward when it comes to individually flooded roads, but requires a refined process for clusters of flooded roads that each cluster is recognised as an individual rerouter.

Step 2 of the ArcGIS model divides each cluster of flooded streets into separate files. To achieve that, flood zones have been employed. The flood zones are created as polygon shapefiles that outline the individual clusters on the map with the maximum flood depth. If the flood zone has not registered any flooded streets, the script automatically deletes the rerouter file that is originally dedicated to that flood zone.

Step 3 of the ArcGIS model is preparing the result files. The rerouters are saved in separate files using a loop. As mentioned previously, the rerouting scheme in SUMO requires the streets adjacent to the flooded ones to be supplied in additional files to the traffic simulation. This is performed by a loop through the rerouter files and “Select by attributes” function in ArcGIS. Thus, each rerouter file has a corresponding additional file, necessary for the traffic simulation.

The second component of the integration tool is the Python script that translates the shapefile output from the ArcGIS model into the required XML output. The roads in ArcGIS are represented by lines and do not have any information about directions, or lanes. To acquire the required detail, the model writes XML files, assuming two opposite directions for each street (Figure 4-3). Once the XML files are written, they are checked automatically against the real road network and the non-existing edges are removed. This is applied to the re-router and additional files and the same procedure addresses reducing the speed limits, but it is applied to the level of the individual lane.

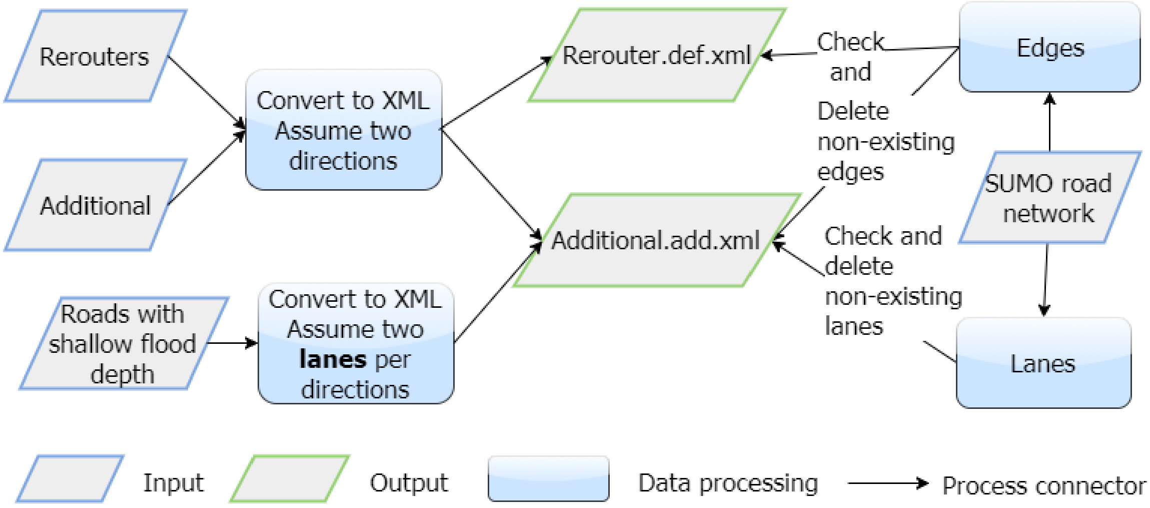

*Figure 4-3: Flowchart of the **second** component of the tool*

4.3.2 Description of the code, repository, how to install, settings etc.

To run the flood-traffic integration tool ArcGIS 10.1 or higher is required. Python 2.7, which is normally installed together with ArcGIS, is also necessary. As mentioned previously, the tool can run both from Python and from ArcGIS. Once the scripts are set up with the correct input data and the desired output, they run with a double click of the mouse in Windows Explorer. If the First component is to be run in ArcMap, a toolbox has to be added to the ArcMap Tool box menu. This operation is described in Section 4.4.

The tool itself is free software and can be redistributed and modified under the terms of GNU General Public License, provided by the Free Software Foundation.

4.4 Using the tool

4.4.1 Description of the interface steps and menus

How to run the first component of the tool?

1) *From ArcGIS.*

The tool is saved as a PEARL Toolbox that can be opened in ArcMap by opening the Arc Toolbox (press ) and add a toolbox (Figure 4-4). After the location of the toolbox is selected, it shows six models. The PEARLfinal model is a sum of all the other models. The other five models are different

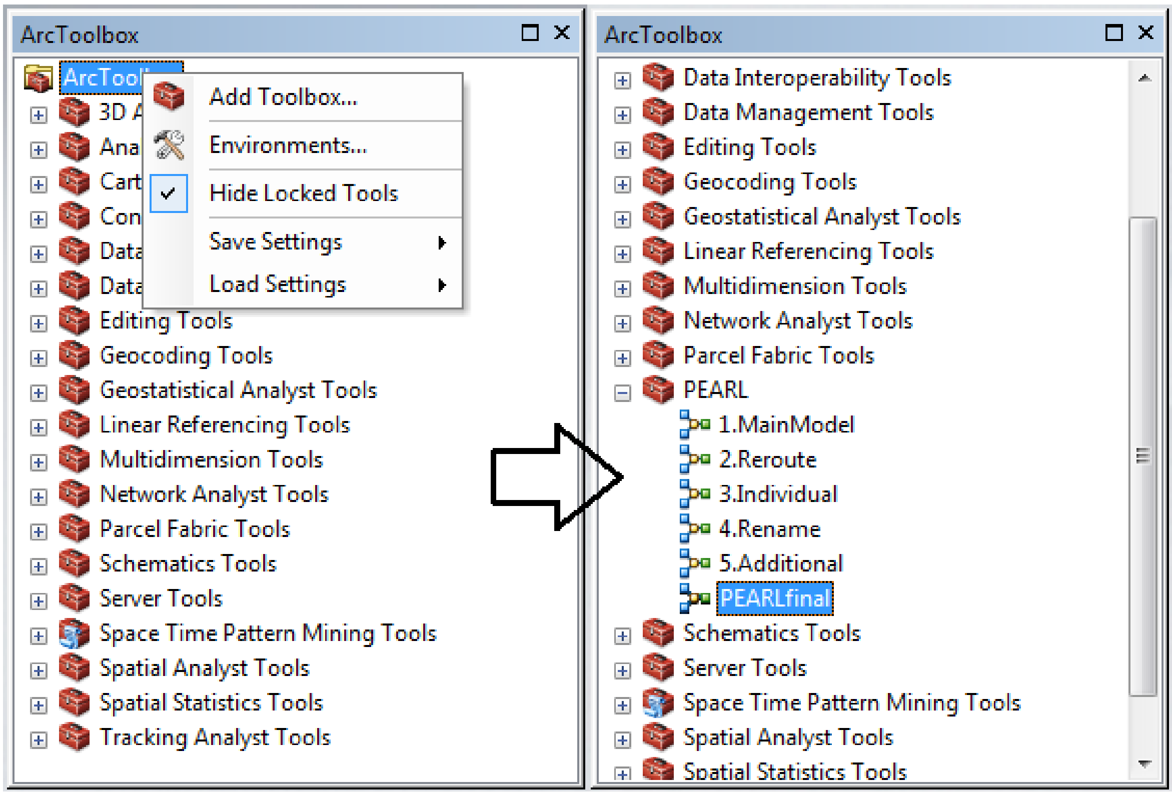

Figure 4-4: How to add the PEARL toolbox

sub-models of the PEARLfinal model that can be run in a sequence. The reason to include the submodels into the Toolbox was to make it less computationally expensive and to make the model flexibile.

The interface of the models is the standard ArcGIS toolbox interface whereby input and output are required (Figure 4-5). The right hand side bar shows tool help when different lines are selected. The model runs with only 3 inputs: Workspace folder, flood map in vector format and road network file. The other inputs are either a choice – to change the definitions for shallow and deep flood depths, or specifying names of the output files. The outputs of the model are ready to use for the next component of the tool – the Python code that translated the shapefile output to a SUMO XML input.

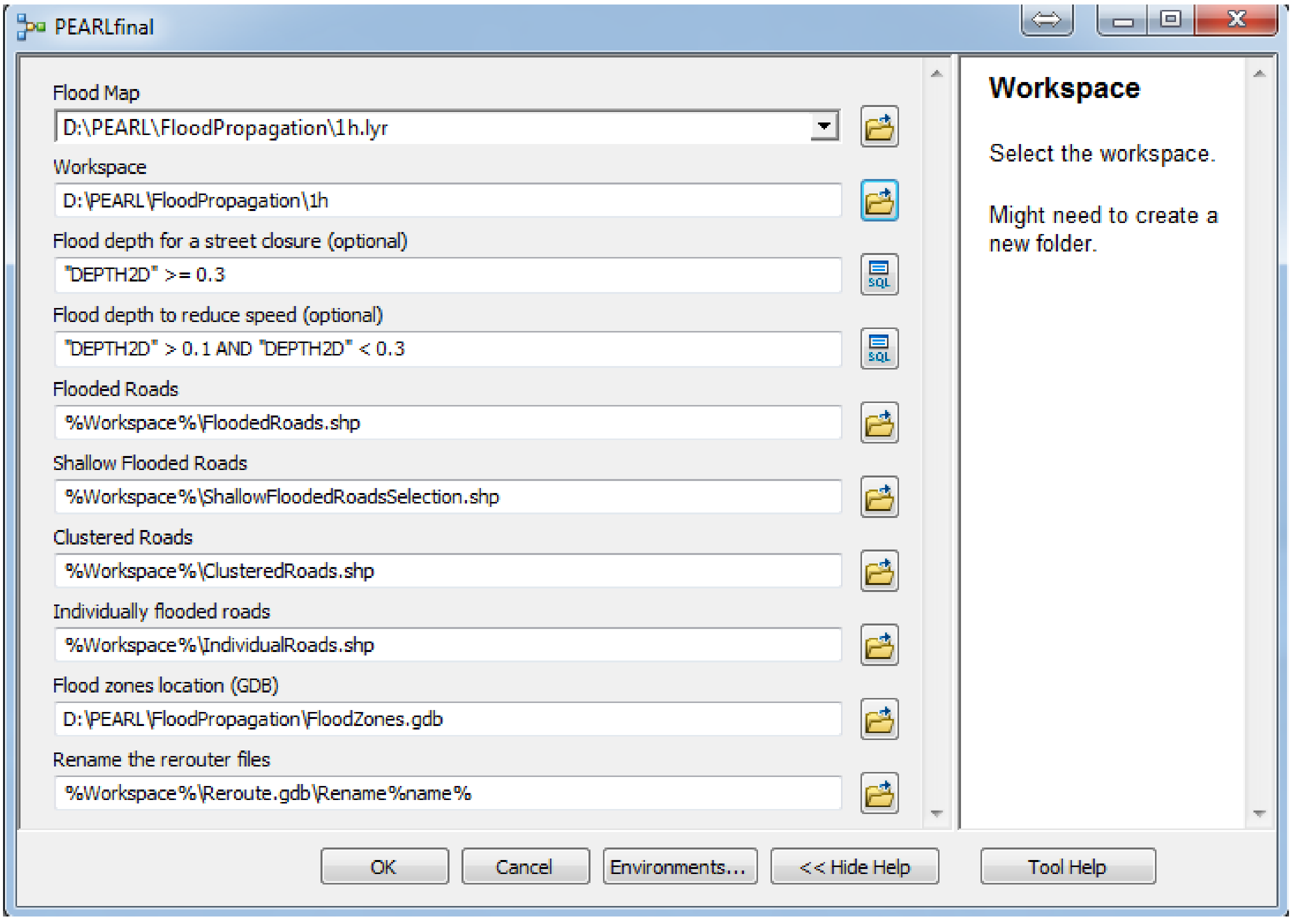

Figure 4-5: Interface of the PEARLfinal model

2) From Python

The model PEARLfinal is adapted in Python and is recommended for multiple simulations. The Python model is also faster – a sample simulation in ArcMap took 6 min and 22 seconds to complete, and the Python script took 4 min and 12 seconds (Python is 34 % faster) on the same machine to run. To make it easier to use, the Python script includes comments that explain the individual steps and offer a reminder when user input is required. The Python model is set up in a way that the user input is limited to a minimum in the case of flood propagation multiple simulations. For example, if it is run with input for simulation time 1h, the only thing that has to be changed in order to run it for another simulation time is to find and replace all entries of '1h' with '1h10min' (provided that the simulation time is contained in the name of the flood map).

How to run the second component of the tool

The second component of the tool is a Python script that translates the ArcGIS shapefile output into a SUMO XML input (Figure 4-3). This script also has added comments to describe different sections of the model and to remind when user input is required. The script is set up in a way that would reduce user input. Once the main input folders are set up, the tool can run multiple simulations with a change of the folder name – for example if all instances of '1h' are replaced by '1h10min'.

4.4.2 Input data set

The tool requires only a few files to run. Table 4-1 presents all the possible input for both components of the tool. The green rows are absolutely necessary to run the tool. The yellow rows are used only when considering dynamic integration of the flood propagation. The peach coloured rows are files that are an output from the first component, which goes into the second component of the tool.

Table 4-1 Table of the input files for the two components of the model.

File	First component		Second component	
	Required	Input type	Required	Input type
Road Network	✓	Polyline Shapefile	✓	SUMO XML
Flood maps	✓	Polygon Shapefile	✗	
Flood zones	✓	Polygon Shapefile	✗	
Workspace	✓	Folder location	✓	Folder location
Rename files	✓		✓	
Update simulation time for SUMO	✗		✓	
Reroute files	✗		✓	Polyline shapefile
Additional files	✗		✓	Polyline shapefile
Shallow Flooded Roads	✗		✓	Polyline shapefile

4.4.3 Outputs

The output files of the model are multiple XML files, that feed into SUMO's rerouting mechanism. These files are the following:

- Multiple rerouter files that supply SUMO with closure periods of roads during the simulation
- Additional file providing all of the adjacent roads to the closed ones
- Second additional file that provides the roads with speed reductions, the new maximum speed limits and the interval of time that will occur

The two additional files must be merged into one before the beginning of the SUMO simulation.

In the case of dynamic integration based on flood propagation, hundreds of output files are created and the specific naming of rerouters is crucial for a correct traffic simulation. It is recommended that the names of the rerouter files consist of the time step of the flood map and their original name (example T1hFloodZone1).

4.5 Tutorial / Cases

The tool is stored in a folder named PEARL. If this folder is directly saved into D disc, the models can be run with the existing scripts. This folder consists of the following folders:

1) 'Tool' folder

a) Toolbox named 'PEARL' runs from ArcGIS and is the first component of the model contains 6 models. 'PEARLfinal' runs the whole code at ones, and the others are sub-models of 'PEARLfinal'. They must be run in a sequence shown by the number in their names.

b) 'Component1' is a Python code that replicates the Toolbox

c) 'Component2' is a Python code which translates the shapefile input for a) or b) into a SUMO XML file input

2) 'Flood propagation' folder

a) '1h' folder - the result files from the first component

b) 'FloodZones' folder - required input for the simulation

c) 'AllStreets' shapefile - a polyline shapefile of the road network in Marbella.Required input for the simulation.

d) '1h' polygon shapefile - the flood propagation at 1h of simulation time.Required input for the simulation.

3) 'SUMOtranslation' folder consists all the outputs of the second component of the model

a) 'map.net.xml' - required input for the simulation. This is the road network file in SUMO.

4.5.1 Description of the application of the tool in a case study

The tool has been applied to the case study of Marbella, where a SUMO model was set up to simulate the daily traffic. A 1D-2D Infoworks flood model was run to simulate flood conditions with a designed rainfall of 100 years return period. The tool allowed us to assume different time of occurrence of the flood in the transportation model – it considered morning peak hour flood, afternoon off-peak flood and evening peak hour flood.

Certain adjustments needed to be made before the tool was run. There is a motorway passing by the study area, which was not implicitly included in the flood model, and the results showed flood ponding just next to the motorway. Usually a motorway has its own drainage system that drains the small ponds on the motorway. To make sure the motorway will not be flooded in the traffic model, it was removed from the ArcGIS model. The same was done for the bridges crossing the motorway. The motorway and the bridges exist in the traffic model, but to make sure they will not be shown as flooded by the tool, they were deactivated in ArcMap. A good visual inspection of the case study area is highly recommended in order to avoid eventual discrepancies between the model and the real world.

4.5.2 *Outputs from the case study*

The morning flood occurs between 7:30 and 9:00 AM, when around 25% of the daily traffic takes place. The normal morning traffic was already suffering from congestion on the main roads and the closure of many streets due to flooding exacerbated significantly the already slow traffic. Figure 4-6 illustrates the change in the number of vehicles over the simulated time. During flood conditions, many vehicles were slowed down and remained circulating in the network for longer. Consequently, the number of vehicles is a good indicator showing how efficient the traffic supply is. Figure 5 shows that the number of vehicles nearly doubled throughout the flooding conditions. Moreover, the number of vehicles remained considerably high long after the flooding has receded, causing some vehicles

Table 4-2 Differences between normal and flooded conditions in the morning traffic for 24 hours of simulation

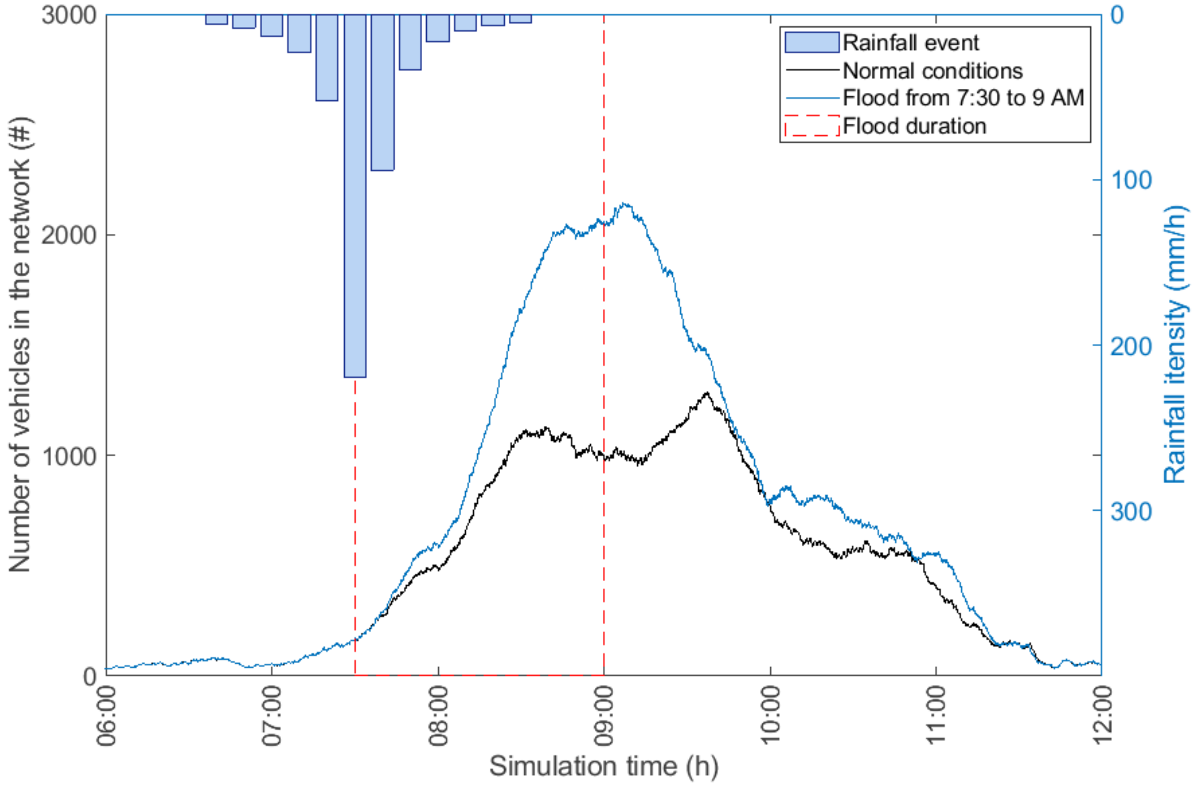

Figure 4-6: Number of vehicles in the network during normal and flooded conditions in the morning hours

to be delayed. The repercussions of the event were felt for more than 2 hours after the full network has become operational again.

	Normal conditions	*Morning Flooding*	*Absolute change*	*Change (%)*
Depart delay (h)	16207	16922.7	715.7	4.4
Duration (h)	7870	9064.6	1194.6	15.2
Travelled distance (km)	202256.5	205094.1	2837.7	1.4

Delayed vehicles with more than 5 min		11249		18.9
CO_2 emissions (t)	52	54.1	2.1	4

Table 4-2 gives an overview of the differences in the traffic conditions between the normal scenario and the one with morning flood conditions when considering 24 hours of simulation. During the flooding 3095 vehicles were rerouted, meaning that they had to choose alternative routes to reach their original destinations. The additionally travelled distance by these vehicles was 2837.7 km hence each travelled extra 1 km on average to complete their journeys. Not only the vehicles that had to change their route suffered the flooding conditions, but also other vehicles experienced indirect impact during the event. Nearly 20 % of all vehicles in the 24h simulations suffered a delay longer than 5 min. The delayed traffic is not the only indicator of the impact of flooding on traffic. Some vehicles had to delay the beginning of their trips because of congestion on the roads where they were supposed to start their journeys (seen in Depart delay in Table 4-2).

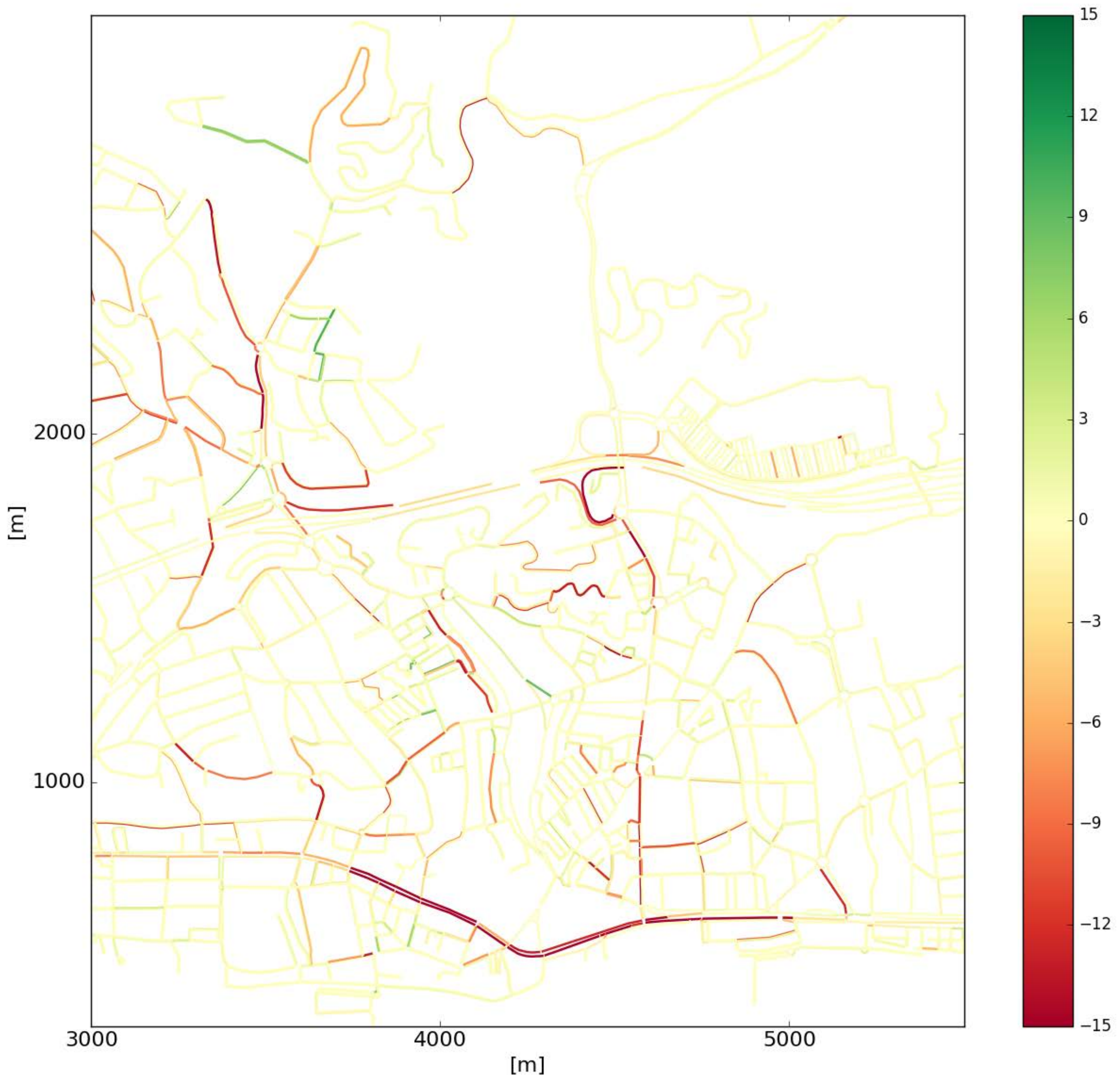

Figure 4-7: Map showing the differences in road speed (m/s) between the normal and the flooded conditions. Values are averaged for all vehicles traveling between 9 AM and 10 AM

Figure 4-7 illustrates a speed map showing the differences in the average speeds of the roads between the normal conditions and the flooded conditions. Here the unit is m/s and the red colours show delays during the flood conditions and the green shows that some roads had faster traffic during the flood conditions. The values are averages over all vehicles travelling between 9 and 10 AM. It is essential to underline that the morning flooding is between 7:30 AM and 9 AM and there are no flooded roads during between 9 AM and 10 AM. The indirect effect of flooding on traffic is significant such that even one hour after the traffic supply is back to normal, the traffic is notably slower than in the dry weather conditions.

4.6 Concluding remarks

This section described the motivation, the methodology, the execution and the application of the PEARL flood-traffic integration tool. This tool is first of its kind to facilitate flooding situation into traffic conditions. The flood impacts on traffic disruption have been overlooked in the past, because they are not as costly and not as straightforward to calculate as the tangible direct damage. The tool addresses this disproportion while making it easier to integrate flood and traffic models. There are several big cities that use SUMO for traffic modelling, e.g. Dresden and parts of Vienna and they can take advantage of this tool.

Urban mobility is very dynamic and vulnerable to external disturbances (Pyatkova et al., in press). Therefore, identifying which parts of the transport network might be problematic in times of disasters, is an important step in the journey to creating more resilient cities.

4.7 References

Chang, H., Lafrenz, M., Jung, I.-W., Figliozzi, M., Platman, D., Pederson, C., 2010. Potential Impacts of Climate Change on Flood-Induced Travel Disruptions: A Case Study of Portland, Oregon, USA. Ann. Assoc. Am. Geogr. 100, 938–952. https://doi.org/10.1080/00045608.2010.497110

Pyatkova, K., Chen, A., Djordjevic, S., Butler, D., Vojinović, Z., Abebe, Y.A., Hammond, M.J., in press. Flood Impacts on Road Transportation Using Microscopic Traffic Modelling Technique, in: Simulating Urban Traffic Scenarios 3rd SUMO Conference 2015 Berlin, Germany, Lecture Notes in Mobility. (in press)

Suarez, P., Anderson, W., Mahal, V., Lakshmanan, T.R., 2005. Impacts of flooding and climate change on urban transportation: A systemwide performance assessment of the Boston Metro Area. Transp. Res. Part Transp. Environ. 10, 231–244. https://doi.org/10.1016/j.trd.2005.04.007

5 Direct damage assessment tool

5.1 Brief description of the tool

To estimate direct flood impact for study areas with various scales, data format and availability, a tool linking hydraulic modelling results, assets and vulnerability information will streamline the risk analysis to support better decision making. In the earlier CORFU project, the flood damage assessment tools were developed using the Geoprocessing functions in the ArcMap environment. In PEARL, the tools were reprogrammed to incorporate with QGIS and enhanced with more flexible functionalities. This advancement allows stakeholders to adopt the tools in Open GIS environment that will strengthen the research impact. The new design also includes more flexibility that users can implement the tools to wider applications (Naso et al. 2016).

5.2 Introduction to the tool

The tool includes three parts (1) interface components; (2) Python scripts; and (3) damage assessment programmes.

The interface components offer input forms for both ArcMap and QGIS software that users can provide the required input data more easily. However, it is possible to run the tools in command mode without using the interface. This allow the tools being integrated with other types of analysis (e.g. simulating multiple flood events or near real-time flood modelling) and estimate flood impact automatically.

The Python scripts were developed to convert the input data, using the geoprocessing function in ArcMap or the gdal library in QGIS, into the required format for damage assessment, and integrate the analysing results back to shapefiles.

The damage assessment programmes were developed in Fortran and complied as executable files to associate hazard, asset, and hazard-vulnerability relationships for different asset types, to determine the impact of individual assets.

5.3 Methodology

5.3.1 Description of the flowchart with all the steps

The analysis of damage assessment include several steps, which are simplified in a single procedure that requires only one operation of the tools. This section will explain the major steps in the analysis. More technical issues can be found in Chen et al. (2016)

- Data conversion

  The input data may have different formats that need to be converted into the same format for joint analysis. For example, both flood maps and land use maps can be in either raster or vector format, depending on the flood model being used and the data sources. The data are converted using Geoprocessing or gdal functions so the information on the same spatial location can be associated to determine the damage. The input for calculating direct flood damage includes **hazard characteristic, components at risk, and hazard-vulnerability functions**.

The hazard characteristic can be (a) flood depth, (b) flood velocity, (c) concentration of contamination, etc. The components at risk describe the layout of assets or properties, but additional attributes are also included to differentiate the impact of flood on non-homogeneous assets. For example (a) building uses, (b) land cover classes from urban growth model, (c) population density, etc.. The hazard-vulnerability or hazard-damage functions can be for (a) depth and damage, (b) velocity and safety, (c) dose and response, etc. These functions are associated to the attributes of components at risk.

Considering possible applications in reality, the tools can take either irregular mesh (polygon) or regular grid (raster) of flood information from hydraulic modelling. For the components at risk, the input could be either the boundaries of assets or zoning (polygons). It can also be raster maps (raster) such as urban growth projection. For the hazard-vulnerability functions, the input is a csv files describing the relationship between hazard condition (e.g. flood depth) and damage. The tools can also consider temporal varied relationships that reflect the exaggerated consequence for a prolonged hazard condition.

- Damage assessment

The input data from multiple sources are overlaid to calculate the damage for all locations within the domain. Figures 5-1 and 5-2 illustrate two types of damage assessment applications that can be done using the tools. The tools also allow iterative simulations to calculate the damage for multiple events with different probabilities, and the expected annual damage (EAD).

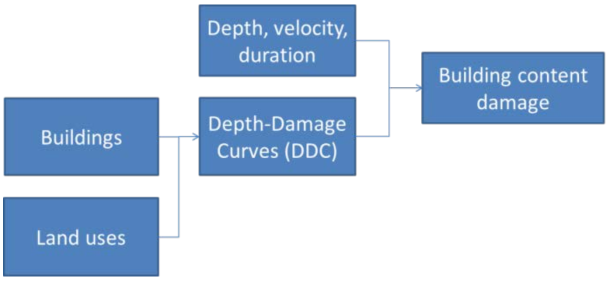

Figure 5-1 The data requirement for building content damage assessment

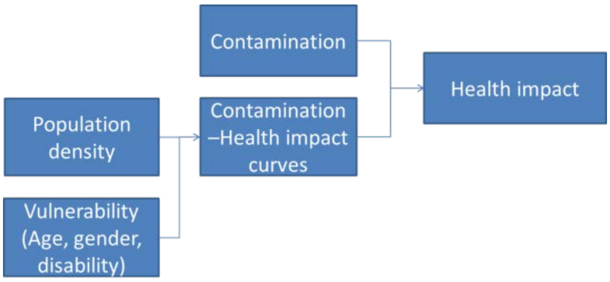

Figure 5-2 The data requirement for health impact assessment

- Data aggregration

For raster data input applications, the damage assessments are done at very fine spatial level (e.g. per raster cell) that need to be integrated into building level to better present the damage information.

5.3.2 *Description of the code, repository, how to install, settings etc.*

The tools are delivered in a zip file. Once the file has been downloaded, extract the file into a folder, which will contain several sub folders. The main folder includes:

- 2017_Dec_PEARL_Tools_v10.tbx, which can be loaded in ArcGIS for running the tools.
- A series of executable files for damage assessment. These executable files are 64-bits version, the Win32 version of same files can be found in “Executables\win32” subfolder. A copy of 64-bit version files is saved in “Executables\x64” subfolder.
- Executable: the executable files for win32 and x64 programmes.
- Scripts: the python scripts to run the analysis in ArcGIS.
- Scripts-QGIS: the python scripts to run the analysis in QGIS.
- Examples: Input and output files of the tutorial cases.

To use the tool, simply copy the files from one of the “Examples\CaseXX” folders (except the “OutputXX” subfolders) to the main folder. Then, open the 2016_April_CaseXX.mxd and run the tool with the parameters shown in the following corresponding figures. The “OutputXX” folders in each “CaseXX” are the only for users references.

The tools will run in either ArcGIS 10.1 or QGIS 2.18 environment. Both require Python 2.7 installed.

The tools are free software and can be redistributed and modified under the terms of GNU General Public License, provided by the Free Software Foundation.

5.4 Using the tool

5.4.1 *Description of the interface steps and menus*

The tools are designed to simplify the process for damage assessment. Users can choice an appropriate tool based on the purpose for analysis and the input data type.

The tools can be executed in Python console in ArcGIS or QGIS, as long as the required parameters are provided, or be trigged throug the dialogue in ArcGIS toolbox or QGIS processing tool. An ArcGIS toolbox and a QGIS processing toolbox, shown in , have been developed to offer the GUI dialogue, shown in Figure 5-4, for users to provide required input data and change some parameters for modelling. Both toolboxes include two categories of tools for applications of different data types (raster and vector) and other tools for data processing.

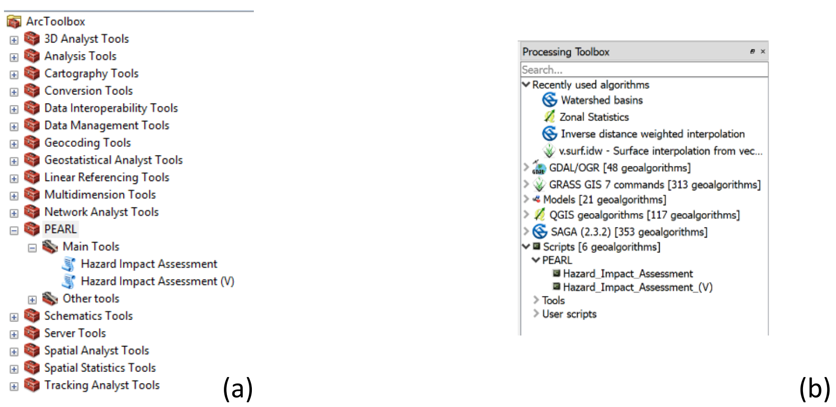

Figure 5-3 *(a)The ArcGIS toolbox and (b) the QGIS toolbox for PEARL damage assessment tools*

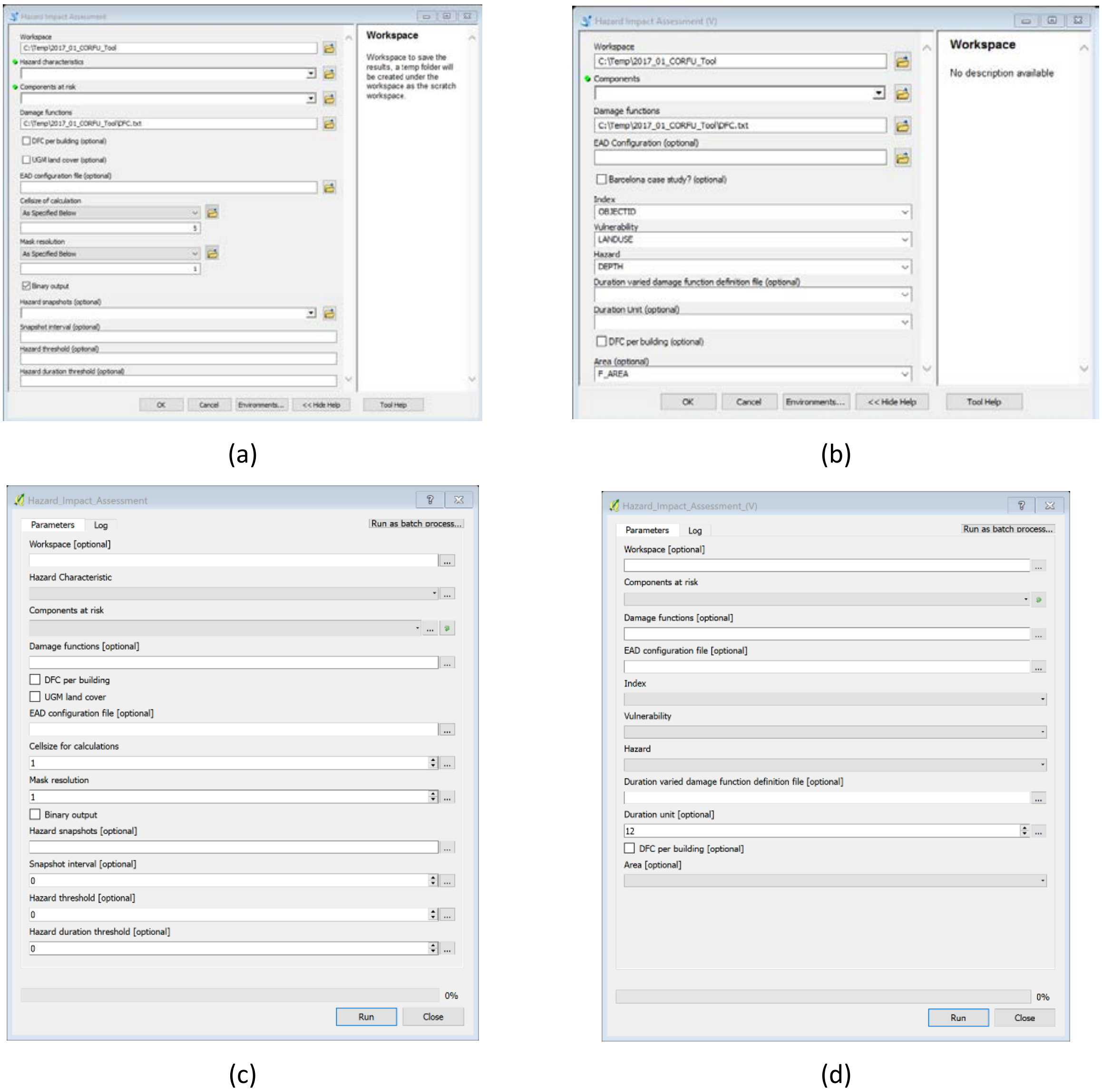

Figure 5-4 The input dialogues for the hazard impact assessment tool (a) ArcGIS raster version; (b) ArcGIS vector version; (c) QGIS raster version; and (d) QGIS verctor version

Figure 5-4 The input dialogues for the hazard impact assessment tool (a) ArcGIS raster version; (b) ArcGIS vector version; (c) QGIS raster version; and (d) QGIS verctor version

5.4.2 Input parameters for raster version

The input parameters for both ArcGIS and QGIS toolboxes are the same. The common parameters for the raster version include:

- Workspace

  The workspace is the folder where scripts and executable programs are saved. All the permanent modelling results will be saved in Workspace as well. A scratch folder “Temp” will be created under the Workspace for saving Intermediate results.

- Hazard characteristic

  The toolbox takes the maximum hazard characteristic information in raster format as the input, which can be taken directly from DHI MIKE Urban modelling results. The hazard characteristic can be flood depth, flood velocity, concentration of contamination, etc. Together with their corresponding damage functions (see below), the damage can be evaluated.

- Components at risk

  The components at risk represent the spatial variation of damage functions. The components can be land use types, land cover types obtained from urban growth model, or population densities of districts, and the data can in either polygon or raster format.

  When a polygon shapefile is used, it should include two fields in the attribute table: “Index” and “Landuse”. The “Index” is a unique value to each polygon that will be used to sum up the damage from computed raster file for cells within the same polygon. The “Landuse” refers to the damage functions to be used for calculation.

  When the raster is used, the raster value should refer to the damage functions to be used for calculation. However, when the land cover classes obtained from the urban growth model are used as the raster, a pre-processing is required to generate the damage functions for different land cover types.

- Damage functions

  The damage functions are required for calculating the flood damage and must be specified in a text file. The details of the file are described as following:

  “*” can be used as comment line indicator. For a set of damage function, it starts with a line that has “DF” at the beginning. The “DF” is followed by the index (Curve_ID, integer), Name and of damage function curve, and comments. The damage function contains a series of hazard-damage data. The Curve_ID should correspond to the index of land use.

  The users can use as many points as needed to define the data. The program will recognise a new set of damage function when it reads a new “DF” indicator. The hazard values of a damage function are suggested to increase monotony. Otherwise, the program will use the first damage value for calculation.

  From the vector version, the unit should be damage per building. If the damage functions are defined in unit area, then the building area is required for calculating the total damage

- DFC per builidng

  The default unit for damage function curves is the damage per square metre. For curves representing the damage per building, it can be specified using the switch.

- UG land cover

  If “UG land cover” is selected, it indicates that the “Components at risk” is the land cover obtained from urban growth model. In this case, the “Reality UGM Correlation” (See 3.6) should be run in advance to get the relationship between land cover and buildings such that new damage functions for UGM land covers will be created and used.

- EAD configuration file

If provided, the tool will calculate the EAD using the events and probability provided in the given configuration file.

The limit of the GUI in the ArcToolbox will result in a complex dialog if all the flood depth files and their corresponding return period are included. Therefore, an external text file (default name: EAD_Configure.txt) will simply the input interface. The EAD configuration text file includes two columns, i.e., the flood depth filename, and its corresponding return period. The return period can be defined in any order, the script and external program will sort out the return period and present the results in ascending order.

- Cellsize for calculations

  The default setting for the analysing cell size is the resolution of hydraulic modelling results (Components at risk). However, if this resolution is too coarse, the results may not reflect the spatial variations in land-use or components. Therefore, the cells for analysing damage can have a finer resolution than that of the hydraulic modelling results, to provide more accurate results. This, however, comes at the cost of increased computer processing time.

  If a cell size value selected is larger than that of the hydraulic model results, this value will only be used to generate the component index and land use rasters. The damage per unit area will be calculated using the resolution of the hydraulic model results to avoid averaging of the flood depths over an analysing cell. This is important as the depth-damage functions are not linear, and averaging of the flood depths could lead to inaccuracies in the results.

  The value of this cell size should be an integer fraction (e.g. 1/5 or 1/4) of the hydraulic modelling results resolution. Otherwise, some of these cells would span adjacent flood depth results cells. This again, leads to the potential for inaccuracies, as a result of averaging, and the inherent loss of information. An alternative solution to this problem would be to generate a finer raster in the “overlapped” sections, but this would lead to increased computer processing times, and so this solution is not favoured.

- Mask resolution

  Larger analysing cell size will result in over-estimation of component area, if a component on occupies a small portion of a cell. The mask is applied to clip out non-component areas from the analysing result to reduce the assessment error.

  The value of this cell size should be an integer fraction (e.g. 1/5 or 1/4) of the hydraulic modelling results resolution. Otherwise, some of these cells would span adjacent flood depth results cells. This again, leads to the potential for inaccuracies, as a result of averaging, and the inherent loss of information.

- Binary Output

  The option allows the users to save the raster data in binary file format to reduce the file size. If unselected, the raster data will be saved in Ascii text format.

- Hazard snapshots (optional)

  Time-series of hazard snapshots from hydraulic modelling results (e.g. dfs2 file). The snapshots are used to determine the duration of hazard which is above the given threshold (L).

- Snapshot interval (optional)

The interval between two snapshots (minute).

- Hazard threshold (optional)

  The threshold that a hazard starts to have impact. It is used to determine the calculate the duration of hazard.

- Hazard duration threshold (optional)

  The duration that a hazard lasts long enough to switch to a different damage function (hour), which is defined in a DV_configuration.txt.

5.4.3 Input parameters for vector version

The input parameters for both ArcGIS and QGIS toolboxes are the same. The common parameters for both raster and vector version include:

- Workspace

  Same as the raster version.

- Components at risk

  The components at risk represent the spatial variation of damage functions. For the vector version, the component polygon data should include three attributes: component index, vulnerability (e.g. land use), and hazard characteristic (e.g. depth). The field names can be user-specified but these should be proper mapped via the settings described below. For multiple events, it is assumed that the data are saved in separate shapefiles with the same database structure (field names).

  If the component polygon data do not include land use information, it should be overlapped with land use data to generate the required information. The direct conversion from land use data to raster may include the non- component areas. It will depend on the definition of damage functions.

- Damage functions

  Same as the raster version. For the vector version, the unit should be damage per building. If the damage functions are defined in unit area, then the building area is required for calculating the total damage.

- EAD configuration file

  Same as the raster version.

- Index

  The field in the “Component at risk” as an unique index to identify individual component.

- Vulnerability

  The field in the “Component at risk” refers to the damage functions to be used for calculation.

- Hazard

  The field in the “Component at risk” refers to the hazard characteristic.

- Duration varied damage function definition file (optional)

If the damage functions changes according to the duration of flooding, it should be defined in a separate file such that the tool will use corresponding damage function file for the given flood duration of each building.

- Duration unit (optional)

  It specifies the temporal unit of flood duration.

- Area (optional)

  The field in the "Component at risk" refers to the area of the component.

5.4.4 Outputs

- Component _Damage_Sum.txt

  The file summarises the direct building content damage of each building. If EAD configuration file is given, the Component_Damage_Sum.txt is renamed as Component_Damage_Sum[XXX]y.txt as the damage for [XXX] return period of each building. The Component_EAD.txt that summarises the damage for different return period and the EAD of each building will be also generated.

  For the assessment using land cover type, which doesn't include a shapefile of component, the result will not produce the Component_Damage_Sum.txt.

- Component Damage Shapefile (Component_Damage.shp)

  The "Component_Damage_Sum.txt" is associated with the original building shape file to generate a new shape file "Component_Damage.shp" as the final result of the direct building content damage of each building. The shape file is automatically displayed in the ArcMap using the default legend groups "Component_Damage.lyr".

  If EAD configuration file is given, the "Component_EAD.txt" is associated with the original building shape file to generate a new shape file "Component_EAD.shp" as the final result of the direct building content damage for different return period and the EAD of each building. The shape file is automatically displayed in the ArcMap using the default legend groups "Component_EAD.lyr".

  For the assessment using land cover type, which doesn't include a shapefile of component, the result will not produce the Component_Damage.shp.

- Damage_Category_Summary.txt

  The "Damage_Category_Summary.txt" is, calculated based on 'Component_Damage.shp', the sub-total damage of same land use or land cover type.

5.5 Tutorial / Cases

A seperate document that includes multiple case study examples has been produced to demonstrate the applications of the tools. The input files are saved in subfolders 'Case01', ..,'Case04' inside "Example" subfolder.

5.6 Concluding remarks

In PEARL project, the CORFU damage assessment tools have been improved and enhanced to provide more flexibility and functionality for reality applications. The newly developed QGIS toolbox allow the implementation in Open GIS environment that will benefit the global users in flood risk assessment. The current QGIS toolbox will be further developed as a plugin module that global users can install the toolbox directly in QGIS.

The tools are designed to assess multiple types of flood damage that can be applied to evaluate various elements in the holistic risk assessment to provide better understanding of flood impact.

5.7 References

Chen AS, Hammond MJ, Djordjević S, Butler D, Khan DM, Veerbeek W (2016) From hazard to impact: the flood damage assessment tools for mega cities. Nat. Hazards. 82(2), 857-890. doi:10.1007/s11069-016-2223-2

Naso S, Chen AS, Aronica GT, Djordjević S (2016) A novel approach to flood risk assessment: the Exposure-Vulnerability matrices, 3rd European Conference on Flood Risk Management.

6 Indirect damage assessment tool

6.1 A brief description of the tool

This tool is based on a new methodology that comprises two consecutive steps; a matrix for transforming land uses in business activities, and an econometric regression for quantifying indirect damages. The methodology has been translated into a tool useful for quantifying the indirect damages of several business activities affected by a flood event.

6.2 Introduction to the tool

6.2.1 Description of the components developed

Indirect damages (Cochrane, 2004; Messner *et al.*, 2007; Jonkman *et al.*, 2008; Hammond *et al.*, 2011) can be considered as a cascading effect of direct damages, as they try to assess how direct damages are spread across the closer economic agents. There are several existing methodologies to assess them, but while some of them are very data and resource demanding, others are not accurate enough. A complete state of the art review was done within the project. In this environment, a new methodology to assess indirect damages was considered necessary.

The methodology takes into account not only the indirect damages of the activities directly affected by the flood event (activities that suffer direct damages) but also the indirect damages of the activities that suffer business interruption even though they are not directly affected by the flood event (e.g. business interruptions due to power outage or road closures because of the flood event).

6.3 Methodology

6.3.1 Description of the flowchart with all the steps

This new methodology consists of the following steps (Figure 6-1):

a) The baseline for applying the methodology are the direct damages for land uses.
b) The first step consists in transforming direct damages for land uses in direct damages for business activities (in other words, divide 6 land uses into 10 business activities) as the methodology aims at assessing the damages due to business interruption.
c) The second step allows quantifying indirect damages by using an econometric regression that relates indirect damages with several dependent variables (e.g. direct damages and business activities affected by the flood event).

Figure 6-1. Methodology for Indirect Damages assessment

The typology of land uses considered in this study corresponds to the classification used by the *Consorcio de Compensación de Seguros* (Insurance Compensation Consortium), a public reinsurer

company in Spain. In case of having a different classification of land uses, a previous transformation will be needed to apply this step.

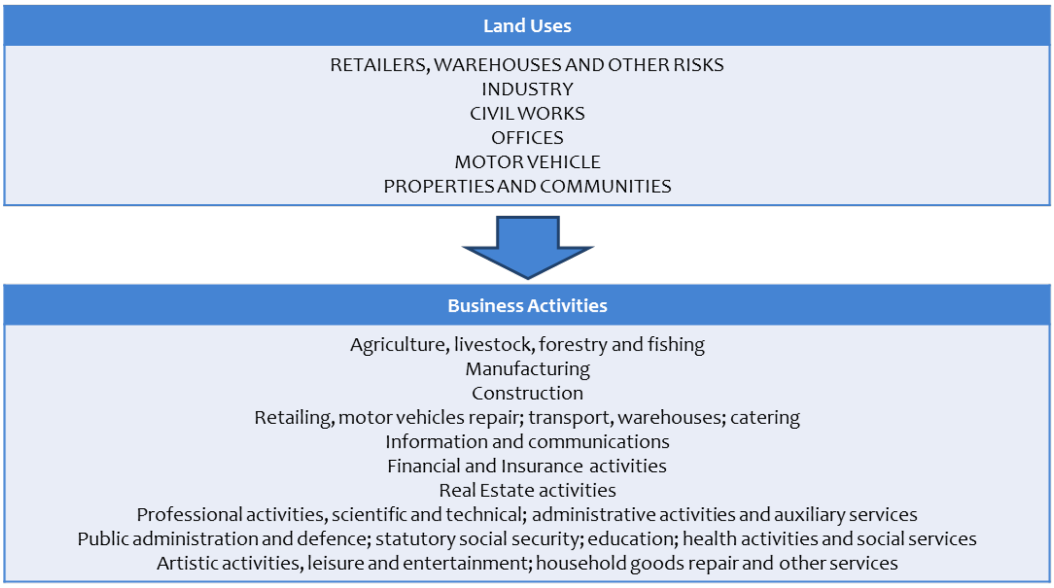

Figure 6-2**.** Land uses and business activities classification

For doing this transformation, a damages transformation matrix was generated, assigning the appropriated relative weights for each business activity (Figure 6-3). Some assumptions were needed (e.g. direct damages in properties and communities have no indirect damages associated and hence this land use does not impact on any business activity).

Damages transformation matrix

	Agriculture, livestock, forestry and fishing	Manufacturing	Construction	Retailing, motor vehicles repair; transport, warehouses; catering	Information and communications	Financial and Insurance activities	Real Estate activities	Professional activities, scientific and technical; administrative activities and auxiliary services	Public administration and defence; statutory social security; education; health activities and social services	Artistic activities, leisure and entertainment; household goods repair and other services
RETAILERS, WAREHOUSES AND OTHER RISKS	0.05	0.05	0.05	0.55	0.05	0.05	0.05	0.05	0.05	0.05
INDUSTRY	0	1	0	0	0	0	0	0	0	0
CIVIL WORKS	0	0.2	0.7	0.1	0	0	0	0	0	0
OFFICES	0	0.05	0.05	0	0.15	0.15	0.15	0.15	0.15	0.15
MOTOR VEHICLE	0.05	0.05	0.05	0.55	0.05	0.05	0.05	0.05	0.05	0.05
PROPERTIES AND COMMUNITIES	0	0	0	0	0	0	0	0	0	0

Figure 6-3. Damages transformation matrix

Prior to estimating the econometric regression, a database creation was needed. The data base comprises information with about 60 real flood events in Marbella. For each event, information is provided on direct damages associated, unemployment rate, season of the year, and business activities affected.

Since no specific indirect damages data for the Marbella case study were available, the Input-Output (I/O) methodology was used for generating these particular data. I/O methodology was chosen because the high level of accuracy that it provides.

An econometric model was estimated which relates indirect damages with direct damages, unemployment, dummies for the season of the year and dummies for the business activity. Results of the estimates suggest a clear and strong positive relationship between the direct and indirect damages, as it could be expected. Furthermore, indirect damages are higher when unemployment

is lower (unemployment can be understood as an indicator of economic activity). Evidence also suggests that summer is the season with the lowest indirect damages, while spring is the season with the highest indirect damages. In addition, indirect damages seem to be relatively higher for agriculture and relatively lower for manufacturing, construction and retailing. Results of the econometric regression are summarised in the following Figure 6-4.

Explanatory variables	Influence found	Interpretation
Direct Damages	+	Clear and strong positive relationship between direct and indirect damages
Unemployment	-	Indirect damages are higher when unemployment is lower
Season of year	?	Summer is the season with the lowest indirect damages, while Spring is the season with highest indirect damages
Business Activities	?	Indirect damages seem to be relatively higher for Agriculture and relatively lower for Manufacturing, Construction and Retailing.

Figure 6-4. Interpretation of the model coefficients

6.3.2 Description of the code, repository, how to install, settings etc.

This tool was created with the purpose of facilitating the use of the methodology in a quick and efficient way. It consists in an Excel file with two sheets, as the use of this software is open and widespread[11]. Therefore, there is no need of installation and any setting is required. This methodology is expected to be patented so a certain protection should be given and guaranteed to this excel file to ensure that such foreground, as far as the methodology and formulation behind it is concerned, is not used and disseminated. However, the excel file can be publicly shared and used as an input-output tool.

As indicated in the Article II.30.2 of the EC-GA, “Dissemination activities shall be compatible with the protection of intellectual property rights, confidentiality obligations and the legitimate interests of the owner(s) of the foreground”.

6.4 Using the tool

6.4.1 Description of the interface steps and menus

6.4.2 Input data set

The first sheet encompasses the direct damages matrix transformation. Thus, it allows transforming damages for land uses in damages for business activities. The first text box represents the different land uses, and the direct damages corresponding to each land use can be typed (cells in green).

[11] The estimation of the econometric regression was done using Stata, a statistical software package widely used in the field of economics, among others. Stata requires a specific level of knowledge for being able to use its commands.

Direct damages introduced are automatically distributed among business activities in the box below. A graphic representation of both land uses (in blue colour) and business activities (in orange colour) complements the study (Figure 6-5).

Damage Land Use	
RETAILERS, WAREHOUSES AND OTHER F	500.000,00
INDUSTRY	100.000,00
CIVIL WORKS	100.000,00
OFFICES	37.500,00
MOTOR VEHICLE	192.000,00
PROPERTIES AND COMMUNITIES	460.100,00
	1.389.600,00

Damage Business Activity	
Agriculture, livestock, forestry and fishin	34.600,00
Manufacturing	156.475,00
Construction	106.475,00
Retailing, motor vehicles repair; transpo	390.600,00
Information and communications	40.225,00
Financial and Insurance activities	40.225,00
Real Estate activities	40.225,00
Professional activities, scientific and tec	40.225,00
Public administration and defence; statu	40.225,00
Artistic activities, leisure and entertainm	40.225,00
Total Damage	929.500,00
PROPERTIES AND COMMUNITIES	460.100,00
	1.389.600,00

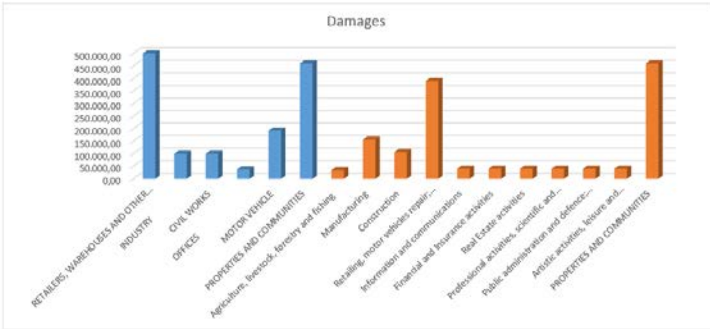

Figure 6-5 Toolbox direct damages transformation sheet

The second sheet allows quantifying the total indirect damage. For doing so, a single box must be filled with the following needed inputs:

a) Direct damage associated with each business activity. In this sense, Direct Damage 1 represents the direct damage related with the Business Activity 1, and so on.

b) Unemployment rate of the flooded area.

c) Season of the year that the flood has taken place must be selected.

d) Up to 10 Business Activities affected by the event can be selected. In this sense, Business Activity 1 must be in consonance with Direct Damage 1, and so on.

A graphic representation of the numeric inputs is provided for complementing the study.

6.4.3 Outputs

Figure 6-6 shows the simulation of a flood event that takes place in winter in an area with an unemployment rate of 10% and that causes 1 million euros of direct damages to agriculture and 0.5 million euros of direct damages to manufacturing. In this particular case, the total indirect damage due to business interruption in this area would amount to nearly 2 million euros.

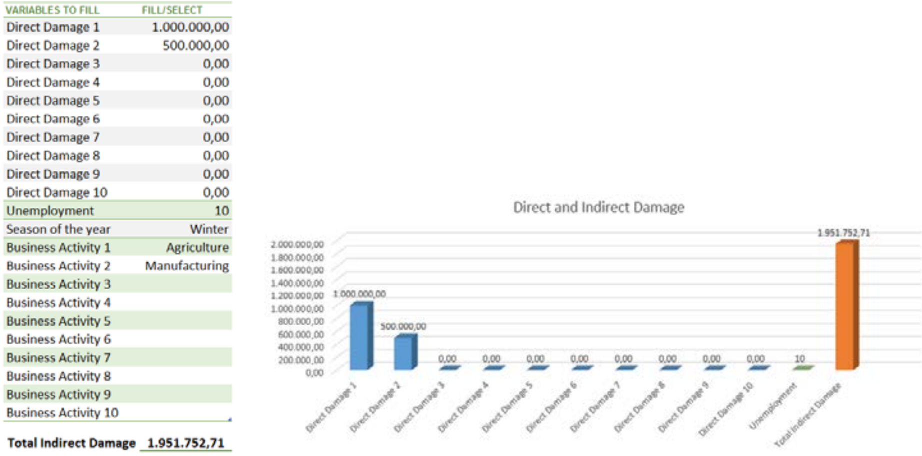

Figure 6-6 Toolbox indirect damage quantification sheet

6.5 Tutorial / Cases

6.5.1 Description of the application of the tool in a case study

This new methodology has been successfully tested using as a baseline the direct damages for land uses of design storms for three return periods (1, 10, 100 years) without and with the implementation of adaptation measures.

First, damages for land uses were transformed in damages for business activities using the damages transformation matrix, and then indirect damages were estimated using the econometric regression.

The following Figure 6-7 shows the aggregated direct damages for each return period (T1, T10 and T100) without and with adaptation measures.

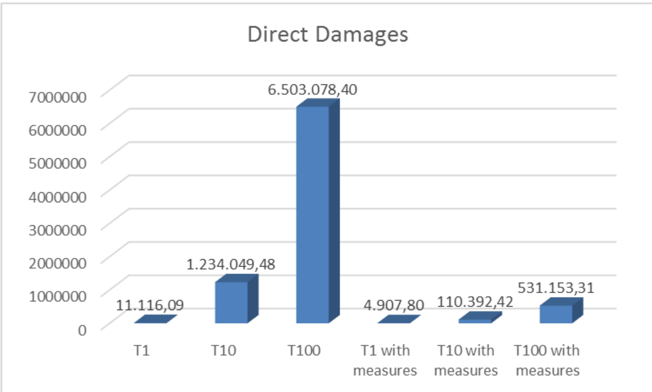

Figure 6-7**.** Aggregated Direct Damages

As expected, direct damages for T1 are lower than T10, which in turn are lower than T100. And with the implementation of measures all direct damages decrease.

6.5.2 Outputs from the case study

Indirect damages were estimated under two scenarios; a first scenario assuming a relatively low unemployment rate (8%) and a second scenario assuming a higher unemployment rate (18%) (Figure 6-8 and Figure 6-9).

In both simulations indirect damages are shown again for each return period (T1, T10, T100) without and with adaptation measures. Damages are disaggregated for seasons of the year. Thus, indirect damages in *spring* assume that all flood events happened during spring season, and the same assumption is done for the rest of the seasons.

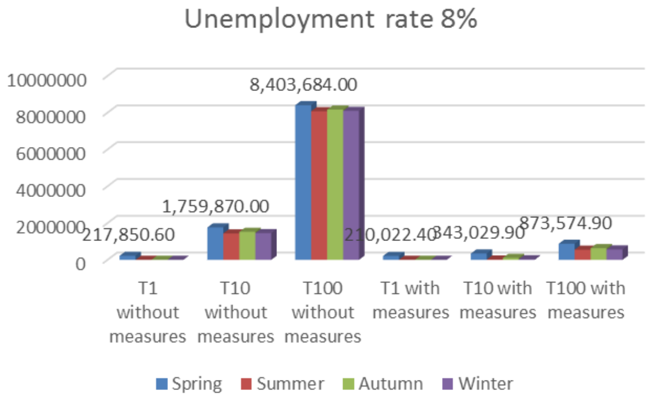

Figure 6-8. Indirect Damages results with low unemployment rate

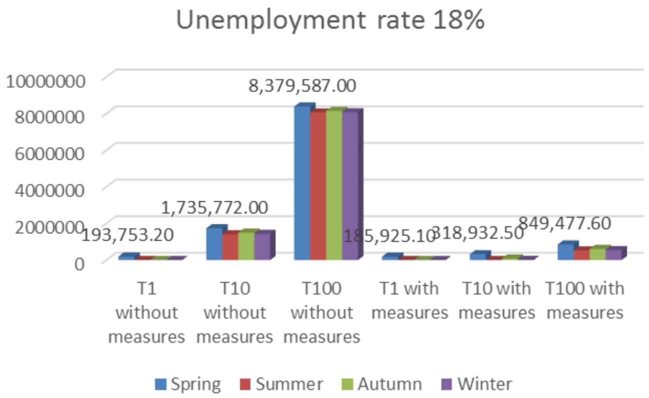

Figure 6-9. Indirect Damages results with high unemployment rate

As expected, indirect damages for T1 are lower than T10, which in turn are lower than T100. And with the implementation of measures all indirect damages decrease. Indirect damages are higher in the scenario of lower unemployment rate, and they are also higher in spring (damages quantification is shown for this season of the year).

6.6 Concluding remarks

The tool developed simplifies a relatively complex methodology in a user-friendly Excel tool and hence, any user can benefit from it without having specific knowledge on damage assessment techniques or econometric models. The toolbox allows assessing indirect damages due to business interruption in an easy way, with little information required as inputs.

The toolbox presents multiple advantages in addition to the abovementioned. It can be applied to any site of interest and it allows doing simulations and predictions. However, it should be taken into account that results will be more robust in sites with similar rainfall characteristics as Marbella.

In addition, the toolbox could be improved by adding additional relevant inputs (e.g. rainfall intensity, existence of measures for avoiding entrance of water, etc.) which could help improving the accuracy.

6.7 References

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Hammond, M.J., Chen, A.S., Djordjević, S., Butler, D., Mark, O. (2015). Urban flood impact assessment: A state-of-the-art review. Urban Water Journal 12(1), 14–29. doi:10.1080/1573062X.2013.857421

Jonkman, S. N., Bočkarjova, M., Kok, M., and Bernardini, P. (2008). Integrated hydrodynamic and economic modelling of flood damage in the Netherlands. Ecological economics, 66(1), 77-90.

Messner, F. (2007). Evaluating flood damages: guidance and recommendations on principles and methods. T09-06-01.

7 Other tools

7.1 PEARL ABM SAS: The PEARL institutional ABM simulating authorities' decision making for the selection of resilience strategies

7.1.1 *A brief description of the tool*

PEARL ABM SAS is a another Agent Based Model developed under the PEARL project. The PEARL ABM SAS simulates how authorities prepare against flood risk and aims to support the exploration of alternative intervention options under different socio-economic conditions and different flood event scenarios that are comprised by series of flood occurrences of differing intensities.

The ABM simulates the authorities' decision-making process for the selection of resilience strategies and assesses the performance of the case area under different socio-economic and flood events scenarios. Additionally, and most importantly, the developed PEARL ABM SAS provides a useful and a tangible way for authorities to examine and explore all decisive factors which affect the actual implementation of measure, after the selection as well as the decision of implementing a measure has been made. Such factors are related to the available funding, the level of authorities' collaboration, etc.

The developed PEARL ABM SAS has been applied to the case study of Rethymno, Crete. The LAA of Rethymno was involved in the development of the tool and was also able to use it, during a training session in October 2017.

The tool is linked to an online user interface available from the PEARL toolbox and integrated into the PEARL Web Learning and Planning platform. The tool is also linked with the PEARL Knowledge Base.

This tool was developed in WP5: Task 5.4 and documented in detail in Deliverable 5.4 “A toolbox of methods and tools supporting selection of resilience strategies”.

Nevertheless, to ensure completeness of this deliverable, a summary of the PEARL ABM SAS is given in the following sections.

7.1.2 *Introduction to the tool*

7.1.2.1 Description of the components developed

The PEARL ABM SAS aim is to simulate how authorities prepare against flood risk. The model consists of agents representing: the central authorities, the local authorities (region, municipality), critical infrastructure owners (water utility company) and stakeholders (construction companies, general public).

The following *Figure 7-1* gives a conceptual framework of the PEARL ABM SAS. The agents that represent the local authorities cooperate with the agents that represent the stakeholders in order to make decisions based on the available funds and the perceived annual flood risk, regarding the implementation of preparedness actions and new resilience measures. The outcome of the PEARL ABM SAS is a qualitative measurement of the performance of the area in respect to the flood events that occurred during the simulation year.

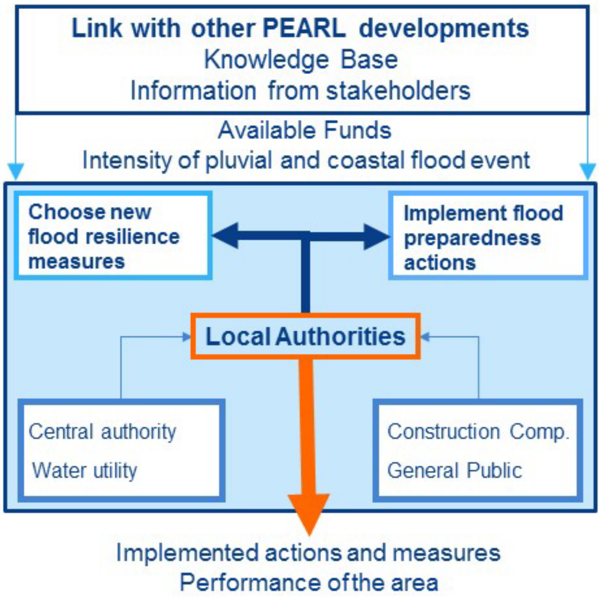

Figure 7-1: Conceptual framework of the PEARL ABM SAS

The agents representing the authorities are presented with two different sets of resilience strategies: flood preparedness actions and flood protection measures. The first set consists of actions that a city needs to undertake every year to prepare for flood events, while the second set of measures includes strategies that strengthen its resilience. This model assumes that authorities are well informed regarding the characteristics of the resilience strategies. It aims to simulate the behaviour of authorities in changing socio-economic and environmental conditions and how this behaviour may affect the city's resilience.

These agents have preferences and interests regarding the city's flood protection. They follow specific rules that allow them to get information regarding the available funding and the characteristics of the resilient strategies, interact with the stakeholders to prepare the city for flooding events and implement actions, decide to implement new measures of flood protection, inspect existing flood protection measures and maintain them.

7.1.3 Methodology

7.1.3.1 Description of the flowchart with all the steps

The local authorities' agents have preferences and interests regarding the city's flood protection. It is assumed that the decision-makers' behaviour will be influenced by the available funding sources, their preferences and the political will generally for urban water management system and defined by specific rules of conduct. The intelligent agents will interact to implement actions for flood preparedness and will decide on the implementation of new measures in response to external pressures such as flooding events. Additionally, the interaction of intelligent agents will simulate the cooperation between the different services, and follow basic principles of game theory (such as the prisoner's dilemma, etc.) which allows for greater realism in modelling collaborations, since it may

reflect a lack of cooperation phenomena even when the cooperative behaviour appears more beneficial for all parties (Madani, 2010).

The agents follow specific rules that allow them to get information regarding the available funding and the characteristics of the resilience strategies, interact with the stakeholders to prepare the city for flooding events and implement actions, decide to implement new flood resilience measures, inspect existing flood resilience measures and maintain them.

The procedures that the decision making agents follow are described in detail in Deliverable 5.4. Nevertheless, a summary of the procedures is given in Figure 7-2.

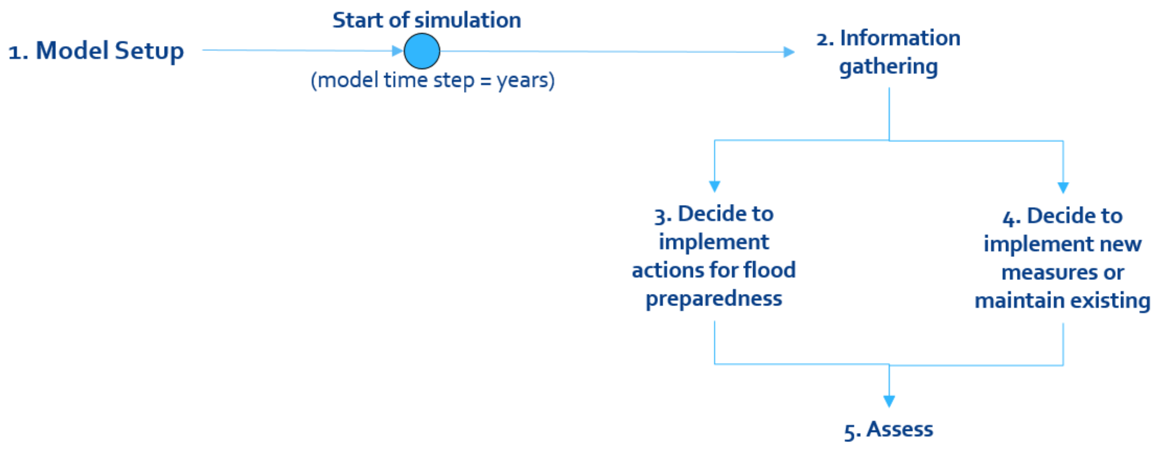

Figure 7-2: Core procedure of the PEARL ABM SAS

7.1.3.2 Description of the code, repository, how to install, settings etc.

PEARL ABM SAS was developed using NetLogo, an open modelling platform. The variables were set using either the NetLogo interface or CSV files to import tabulated information into the model (*Figure 7-3*).

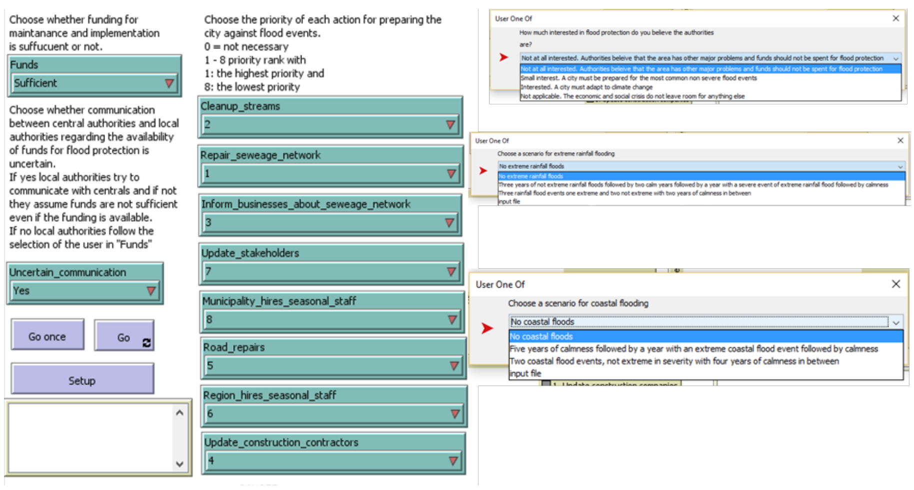

Figure 7-3: Inserting external data through the original interface (NetLogo's interface) of the PEARL ABM SAS

As said earlier, a web based interface was designed and developed aiming to make the developed tool more user-friendly and available to decision makers for use. The back-end developments are described in detail in Deliverable 5.4. This interface is available through the PEARL WebLP platform.

7.1.4 Using the tool

7.1.4.1 Description of the interface steps and menus

To setup the PEARL ABM SAS model you need to:

- Access the tool through the WebLP, under the tab Generic / Simulation of Decision and Resilience
- Go to Saved sets and press on the Create a new set button
- Go to Parameters and fill in the model's social, economic, technical and environmental conditions under which you wish to run the simulation.
- Run the PEARL ABM SAS model simulating the authorities' decision making for the selection of resilient strategies.
- Explore the results of the simulations with the higher and lower performance. Plots are produced presenting the annual implementation of preparedness actions and flood resilience measures, spending of funds, cooperation of authorities and performance in respect to flood events.
- Repeat to explore different conditions.

7.1.4.2 Input data set

In order to start a simulation, the user has to specify the input parameters first by clicking on Input parameters from the ABM PEARL SAS menu.

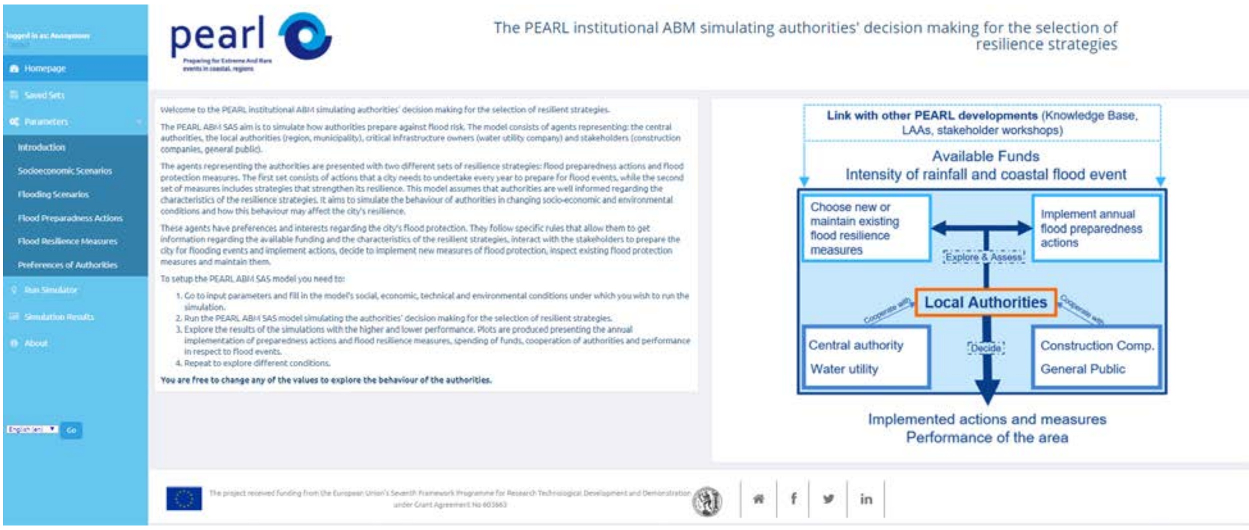

Figure 7-4: Parameters menu bar

This procedure has been adequately described in Deliverable 5.4. An example is given below regarding the input of dataset required so as to use the PEARL ABM SAS.

Flood scenarios may be selected by either choosing one of the pre-set scenarios or creating a new scenario, using the menu Flood scenarios (*Figure 7-5*). Flood scenarios require information regarding the order of occurrence and the qualitative intensity of extreme rainfall flooding events that occur within a ten-year span.

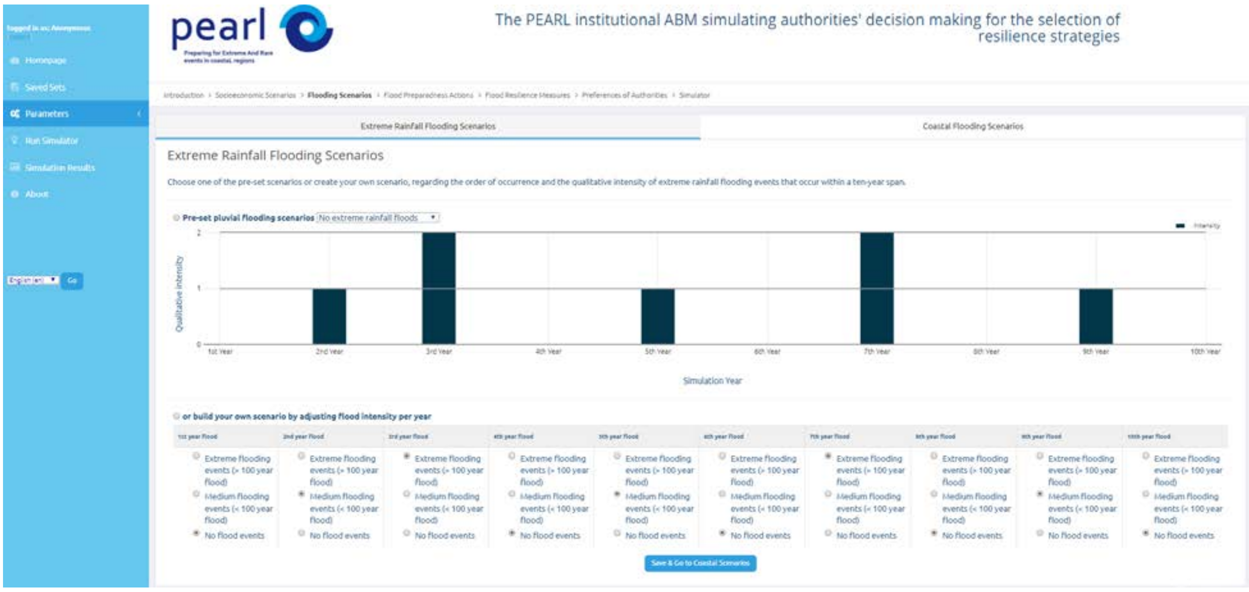

Figure 7-5: Define flood scenarios

Using the online interface the user is able to run the PEARL ABM SAS without having any prior knowledge on how to use ABMs.

7.1.4.3 Outputs

The user is able to save and retrieve previous runs by importing saved sets of parameters using the menu Saved sets. The user is able to run the simulation using the Run Simulator menu (*Figure 7-6*) and obtain results through the Simulation results menu.

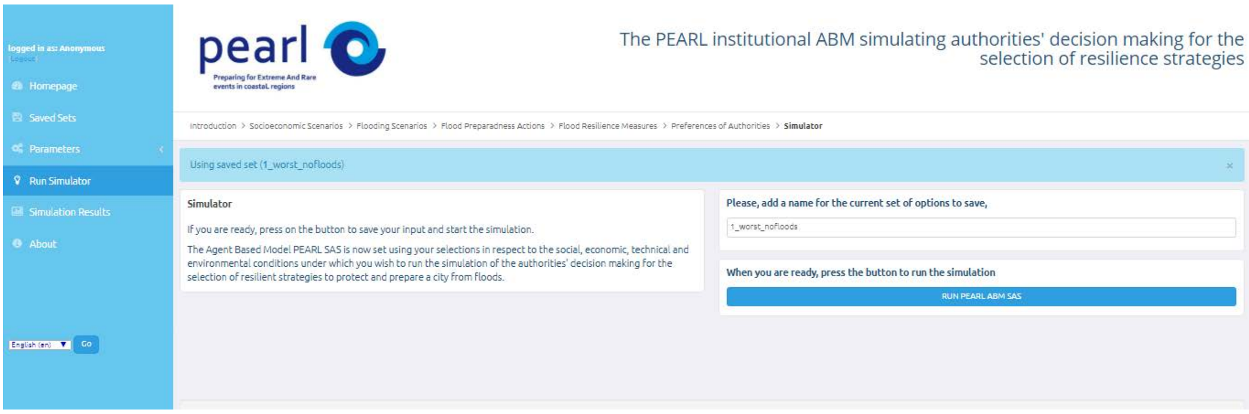

Figure 7-6: Run simulator

By the end of the PEARL ABM SAS simulation, the simulation output is automatically produced. The last output is also saved together with the saved parameter set to be able to trace back the results of different saved parameter sets.

The simulation output presents two selected simulation results, those with the higher and lowest performance in respect to the preparation and protection of the city against the flooding scenarios given the selected social, economic, technical and environmental conditions.

Since this procedure has been adequately described in Deliverable 5.4, an example of the outputs of the PEARL ABM SAS is given below regarding the implementation of preparedness actions. The following *Figure 7-7* pressents the implemented preparedness actions during the 10-year simulation. If an action is implemented during a year the box is coloured green and if it is not the box is coloured grey.

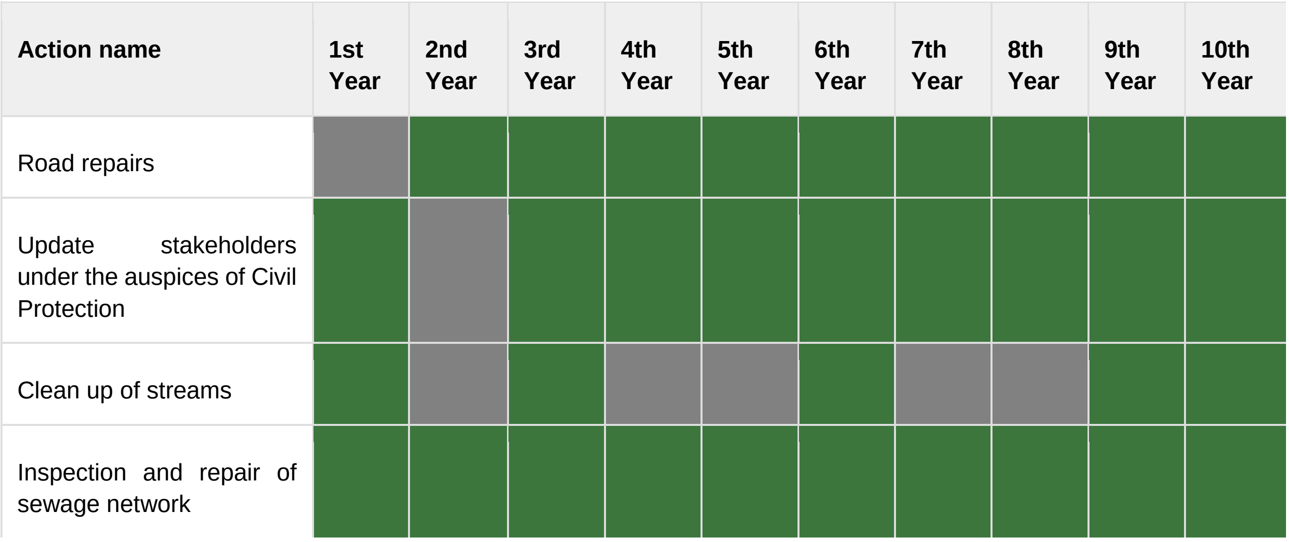

Figure 7-7: Implemented actions during the 10-year simulation (implemented – green, not-implemented – grey)

7.1.5 Tutorial / Cases

7.1.5.1 Description of the application of the tool in a case study

The developed PEARL ABM SAS has been applied to the case study of Rethymno, Crete. The participants of the LAA workshop of Rethymno have been introduced to the notion of Agent Based Modelling in LAA workshops and they have been involved in the design of the PEARL ABM SAS.

Finally, the participants of the LAA workshop held in October 2017, were able to use the PEARL ABM SAS and discuss its usability and applicability in supporting their decisions.

7.1.5.2 Outputs from the case study

The participants of the 3rd LAA workshop of Rethymno were very interested in the PEARL ABM SAS. Upon the completion of the exercise the participants and the researchers were involved in a long discussion regarding the usability of the tool by policy makers. During the discussions many participants were using the tool to explore different socio-economic or flood scenarios on their own,

without any further assistance and discussing the results and their meaning with the researchers. The stakeholders provided many ideas for further development of the tool that will allow its use in strategic planning.

7.1.6 Concluding remarks

PEARL ABM SAS was developed by NTUA team to allow the simulation of the authorities' decision making under different socioeconomic and flood risk scenarios. This tool is part of the PEARL Toolbox, as described in Deliverable 5.4., which aims at identifying the most appropriate flood resilience measures and strategies, using a concise methodology (Figure 7-8), which is divided in the following discrete stages:

1. Flood resilience measures: Use of the PEARL Knowledge Base and/or other relevant tools to select a list of flood resilience measures that fit the flood risk problem and the specifics of the area under study.
2. Algorithms: Use of optimisation and multi-criteria decision analysis algorithms (see, Reed et al., 2013; Maier et al., 2014 for recent reviews) to define specific attributes of the selected resilience strategies that offer a minimised cost and a maximised protection from extreme events.
3. Agent based modelling: Use of the PEARL ABM SAS to simulate the authorities' decision-making process for the selection of resilience strategies and assess the performance of the case study area under different socio-economic and flood events scenarios.

The main aim of the proposed methodology is to be able to transfer scientific knowledge to decision makers by exploring the response of the city to the flood management decisions under different flood event scenarios and socio-economic conditions.

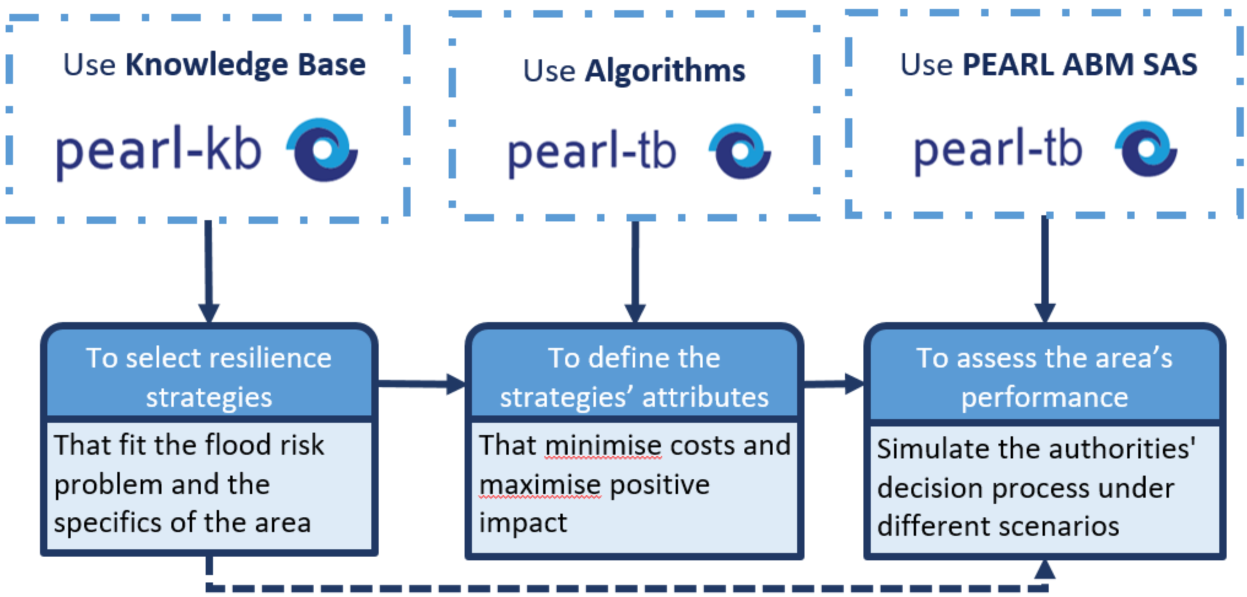

Figure 7-8: PEARL Toolbox methodology

pearl
Preparing for Extreme And Rare events in coastal regions