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RAPID ANALYSIS AND SPATIALISATION OF RISK

D5.3 – RASOR Flood models and case studies results

RASOR

RAPID ANALYSIS AND SPATIALISATION OF RISK

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RASOR

RAPID ANALYSIS AND SPATIALISATION OF RISK

RASOR Flood models

Contents

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1. Introduction

The RASOR project

Over the past decades, there has been a dramatic rise in disasters, and their impact on human populations. Climate change has brought changing weather patterns, making risks increasingly challenging to predict and changing the ways in which hazards interact with each other. In 2010, disasters left over 300,000 people dead, affected another 220 million and caused over $US120 billion in economic damages. That number reached $US366 billion in 2011. Europe's Copernicus/Global Monitoring for Environment and Security (GMES) Programme is implementing a number of services related to climate change and to emergency management, offering operational mapping products for authorised users on a global basis. There is to date however no tool to integrate these diverse products and existing background data in a single work environment that supports the generation of new risk information.

The project Rapid Analysis and Spatialisation Of Risk (RASOR) aims to develop a platform for multi-hazard risk analysis, including geological and hydrometeorological hazards using the latest EO techniques and data. This includes the new 12m resolution TanDEM-X Digital Elevation Model (DEM) from Airbus/DLR. The platform provides insight into natural hazards through layers of spatial information and a scenario-driven modelling system to project situations into the future and model multi-hazard risk both before and during an event. The project is funded by the EU FP7 SPACE Programme. Activities started in December 2013 and will be finalized in June 2016. More information about the RASOR project can be found on www.rasor-project.eu .

The RASOR platform integrates technology for flood mapping, seismic hazard analysis and risk assessment, offering a single tool for rapid assessment of risk for both international organizations and local and national end users. The tool supports multi-risk analyses and can be used to foster consensus between key stakeholders on risk reduction measures, or to convince international donors of the need to offer assistance, by documenting hazards, identifying risks and simulating the effects of catastrophic events. The advent of globally available high-resolution DTMs and their combination with advanced satellite imagery and socio-economic and demographic information offers disaster managers the opportunity to significantly enhance the accuracy and efficiency of their risk analysis.

The RASOR platform enables to combine hazard, exposure and vulnerability (see Figure 1.1.) for a broad range of hazards including flooding, storm surge, earthquakes, landslides, tsunamis and volcano eruptions. The tool enables to assess specific scenarios, for example for high, medium and low likelihood of occurrence for certain disaster types and to assess the effect of a changing drivers, e.g. climate change or land subsidence.

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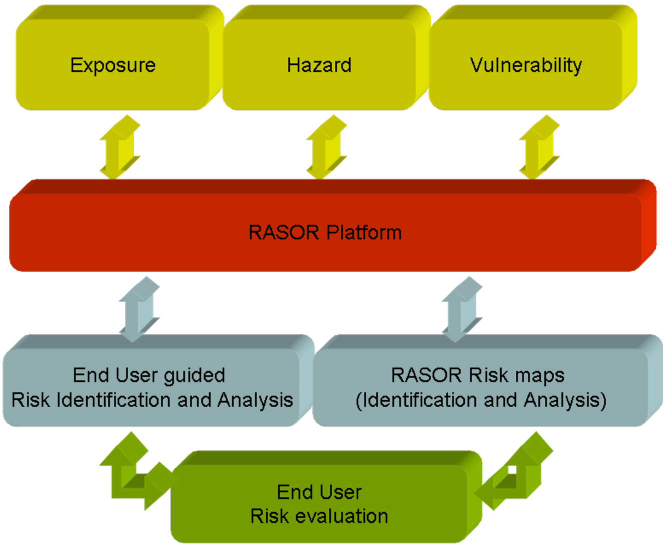

Figure 1.1: Setup of the RASOR platform.

WP5: Flood Risk Assessment

One of the natural hazards covered by RASOR is flooding. Risk and disaster managers can determine the extent of flooding in a given area under various flooding scenarios triggered by intense rainfall, storm surge, tsunami or a combination of hazards. Through the RASOR platform, flood risk managers can review historical events and assess possible future scenarios by running flood models. This allows them to design mitigation or prevention measures.

The aim of RASOR Work Package 5 is to develop models for flood hazard assessment. The flood models produce flood hazard maps (inundation depths and maximum flow velocities) that are delivered to the RASOR platform for visual inspection and overlays with other hazards and geographical information. The RASOR platform enables the user to combine the flood hazard with exposure maps and vulnerability functions to assess the total flood risk (see Figure 1.1). Work Package 5 has developed flood models for case studies in Indonesia, Haiti, the Netherlands, Greece and Italy. Each flood model is designed according to the specific flood hazard in the case study area and according to the needs and the practical constraints/ requirements defined by the end users in each country.

The case studies cover a range of flood hazard types, including inland and coastal flooding, where inland flooding can be further subdivided into embankment overflow or levee breach. Coastal flooding can be caused by a storm surge or tsunami. Each type of flooding requires a specific flood model and some models require additional modules to provide the input. For the final version of the platform (D9.7), delivered in March 2016, seven different types of models or model configurations have been developed. These are:

- Indonesia – Cilacap tsunami runup model
- Indonesia – Bandung fluvial flood model
- Indonesia – Jakarta coastal levee breach
- Greece – Santorini landslide-induced tsunami model
- Haiti – Hurricane storm surge and rainfall runoff flood model

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- Rotterdam – Storm surge and levee breach model
- Italy – Po-Secchia riverine levee breach model

Existing hydraulic simulation software and tools have been used where possible. However, to model the different case studies accurately, it was necessary to enhance or even develop new modules. Existing modeling software included distributed hydrological rainfall-runoff (WFLOW), tsunami runup (FAST), hydrodynamics (Deflt3D) and 2D overland flow (SubGrid) models. Newly developed modules included a model input generator from hurricane tracks (WES and R-CLIPER) and a water level input generator (Rotterdam). All models are driven by meteorological time series and initial conditions that are defined by the user.

This document

This document D5.3: 'RASOR Flood Models' is the final deliverable of RASOR Work Package 5: Flood Risk Assessment. The document describes the flood models that were developed for the RASOR case studies, the underlying model concepts and the procedures for running the models. The report describes the flood models in the RASOR platform as they are implemented in the final version of the platform (D9.7) that is delivered in March 2016. This includes several hydrological and hydraulic models as well as additional modules to prepare input to the models. The procedure to run the models through the 'PIService' (a SOAP protocol that is used for platform-internal communication) is given as an appendix.

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2. Models and software

Software architecture

The flood models have been developed and implemented in a Delft-FEWS environment for convenient handling of input data and running scenarios. Delft-FEWS is a real-time data handling and operational forecasting environment that can also be used for scenario running (Werner et al, 2013).

From the RASOR platform, the models are run as FEWS 'workflows', using the embedded FEWS PI Service that is hosted in a Tomcat service container (see Figure 2.1). This service allows SOAP clients to interact with a FEWS system through the FEWS DataAccessComponent (DAC). With this API the SOAP client can retrieve data from the FEWS system.

In the RASOR platform, the Tomcat runs under the Linux operating system, whilst the FEWS and flood models run under Windows.

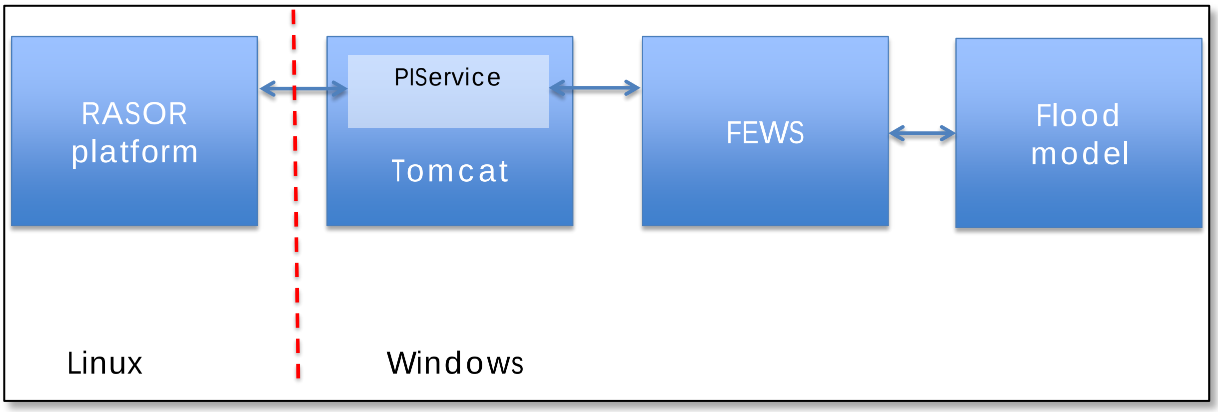

Figure 2.1: Software architecture for flood models within RASOR.

Model software

Several existing hydrological and hydraulic modeling software packages as well as additional modules to prepare input to the models are employed in RASOR. These are briefly introduced below.

WFLOW

The WFlow hydrological model (Schellekens, 2011) is a distributed hydrological model that requires little calibration effort and maximizes the use of available spatial data. It has proven to perform well in data-scarce regions where only global data can be used. WFLOW is part of the OpenStreams initiative, see: http://publicwiki.deltares.nl/display/OpenS/Home.

More information can be found on:
https://publicwiki.deltares.nl/display/OpenS/WFlow+rainfall-runoff+model

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SubGrid – 3Di
The "model engine" used to generate flood hazard maps is Subgrid (Stelling, 2012), part of the 3Di project (http://www.3di.nu/). Subgrid solves full shallow water equations and is especially suited for the simulation of overland-flow, forced by specific runoff and/or discharge/water level boundary conditions. Models are discretized, using a DEM, friction layer and optional a 1 dimensional cross-section layer and/or levee-delineation.

More information about SubGrid can be found on:
http://www.3di.nu/wp/wp-content/uploads/2014/03/Stelling_ice_2012.pdf

Delft3D
Delft3D is an open source modeling suite composed of several modules, grouped around a mutual user interface, while being capable to interact with one another. Delft3D-FLOW is one of these modules. It is a multi-dimensional (2D or 3D) hydrodynamic (and transport) simulation program which calculates non-steady flow and transport phenomena that result from tidal and meteorological forcing on a rectilinear or a curvilinear, boundary fitted grid. For RASOR, only the 2D functionality is used.

More information about the Delft3D modeling suite can be found on:
http://oss.deltares.nl/web/delft3d

WES
A wind field is generated from a user-defined or historical hurricane track by a module called WES. The Wind Enhance Scheme (WES) was initially developed by the UK Met Office following the theory from Holland (1980, 2008). Improvements to the method have been made by Deltares over the last years, making the program more robust and improving the consistency of the results. The output of WES can be used as input for Delft3D-FLOW, i.e. for storm surge simulation.

WES generates a tropical cyclone wind field by computing surface winds and pressure around the specified location of a tropical cyclone center, for a given maximum wind speed. Other cyclone properties that are originally input the WES are either fixed (the radius of maximum wind is set to 75 km) or derived from the maximum wind speed (the pressure drop is related to the wind speed following formula 4 in Matsui et al (2011)). In future RASOR implementations these parameters could also be specified by the user or taken from cyclone forecasts from the Joint Typhoon Warning Center (JTWC).

R-CLIPER
To generate a rainfall field from a hurricane track, a model called R-CLIPER is employed. This model was developed by Robert Tuleya and co-workers from NOAA (Tuleya et al, 2007). The model was implemented by Deltares a separate module that takes the same input as WES. This has the advantage that the same FEWS model adapter can be used for both models. The output is a NetCDF or ASCII grid time series of hourly rainfall on a regular grid. This rainfall is input to the hydrological model WFLOW

FAST
The Flooding ASsessment of Tsunami (FAST) flooding tool developed by Deltares uses relatively simple, empirical expressions that relate tsunami wave height on the coast to the

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run-up onto linearly sloping land (Blaas et al, 2008). The relations have been derived from over 100 numerical simulations on idealized straight channel geometry with Delft3D FLOW.

Rotterdam water levels script

For the Rotterdam case study, a SubGrid model was developed that has three water level boundaries: Maassluis on the sea side of the flood prone area and Dordrecht and Krimpen a/d Lek on the east side. The model requires water level time series at these locations as boundary conditions.

The extreme water levels in this area are mainly determined by storm surges at sea. The required water level time series at the three model boundaries are linked to a reference location at the coast: Hoek van Holland. The extreme sea water levels at this coastal station have been studied in depth and the water level exceedance frequency curve at this location is a reference for most flood studies in the area.

The water level time series at the three SubGrid model boundaries are derived in three steps: The maximum sea water level at Hoek van Holland is entered by the RASOR user. An exceedance frequency curve is available to link this level to a return period (Figure 2.2).
A water level time series at Hoek van Holland is generated by scaling the observed water levels from a November 2007 event to the target maximum level.

The water levels at the three model boundary locations (Maassluis, Dordrecht and Krimpen a/d Lek) are generated from the Hoek van Holland series by a regression model.
The last step involves both a water level height scaling and a time-delay of one to a several hours, depending on the location. The regression of observed values showed that a peak water level at the inland locations typically occurs later than at the coast.

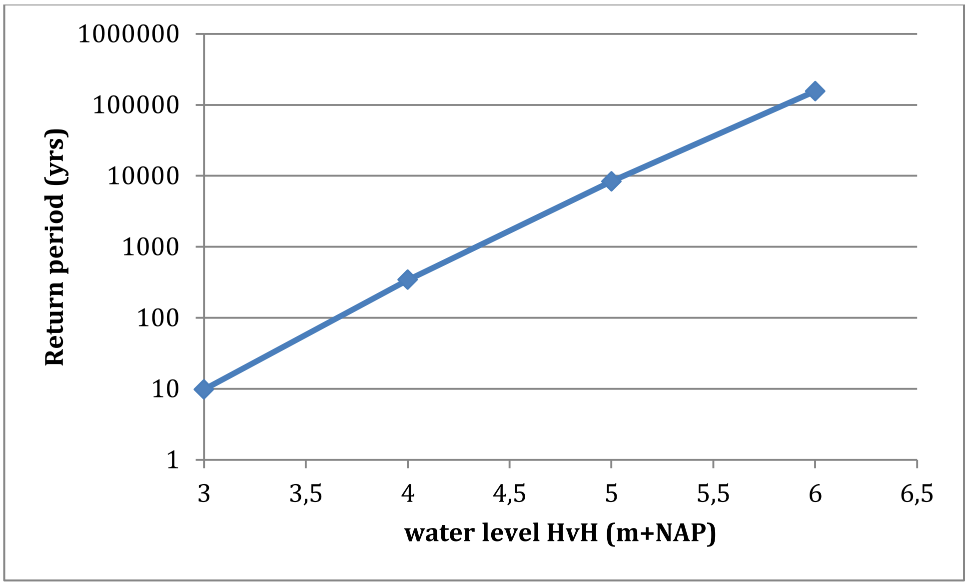

Figure 2.2: Exceedance frequency curve for Hoek van Holland water levels.

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Reliability transformation tool

This module transforms a water level time series at a certain location of the flood defense line into a time series of failure probabilities and – in case of a failure – into a breach development over time. The transformation of water levels to time series of failure probability is done by using a fragility curve (Figure 2.3). The fragility curve expresses the reliability of a structure as a function of a defined dominant stress variable, e.g. water level at a dike section. This transformation is performed for each water level over time $h_w(t)$.

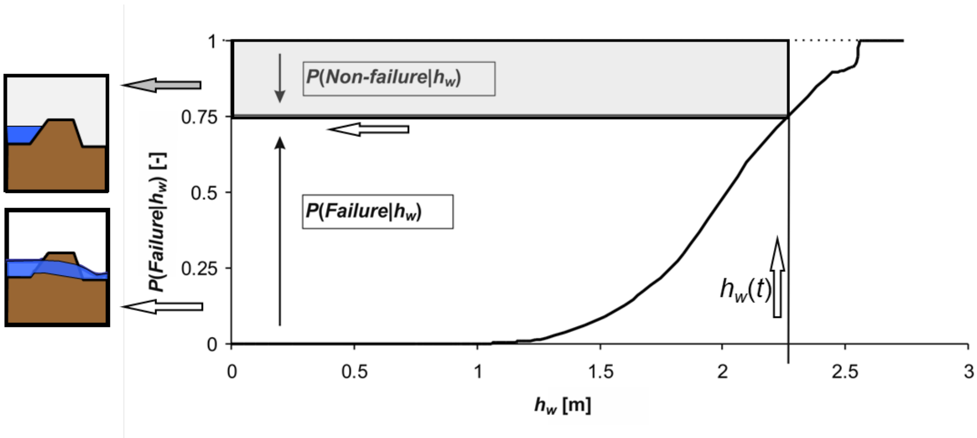

Figure 2.3: Reliability transformation with a fragility curve. The probability of failure increases for increasing water level. The probability of non-failure is 1 minus the probability of failure.

According to the time series of failure probability, the simulated water level time series and a user-defined probability threshold for each dike section a breach development is calculated. By exceeding the defined probability threshold a breach development is started in the dike section. The user can interactively change these thresholds to define different breach locations and starting times (what-if scenarios).

The breach depth development is not modeled; a defined sill height is applied (e.g. adjacent elevation to the dike). For the calculation of the breach width three different approaches are available within the tool (only the first option is used in RASOR at the moment):

- Instantaneous breaching with a defined maximum breach width.
- Linear breaching with a defined maximum breach width and a breach growth rate; if the water level is lower than the defined sill height the breach growth will stop.
- Adapted semi-empirical breach growth model after VERHEIJ with a defined maximum breach width and a critical velocity representing different dike materials.

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3. Case study descriptions

In this chapter, a description is given of the modeling concepts behind each of the RASOR case studies. This information is also accessible via the RASOR platform as modeling background documentation for the RASOR end-users.

Cilacap - tsunami runup model

The town of Cilacap is a sea port on the southern coast of the island of Java. The port is accessible to relatively large ships, making it an important cargo hub. The South coast of Java is prone to tsunami hazard because of the Alpide belt, a seismic active zone that extends along the southern margin of Eurasia, stretching from Java to Sumatra through the Himalayas, the Mediterranean, and out into the Atlantic. The Alpide belt is the second most seismically active zone in the world, with frequent earthquakes, volcanic eruptions and tsunamis in Indonesia and the surrounding areas. Although Cilacap is relatively protected from tsunami impact by the Island of Nusakambangan, the 2004 tsunami took 147 lives, devastated beaches, damaged 435 fishing boats and inflicted material losses amounting to about Rp 86 billion (around $9 million).

The RASOR case study allows the end-user to define a tsunami wave height off the coast and calculate the inundation depths and flow velocities in and around the city of Cilacap. An empirical model called FAST calculates the wave runup over transects that run from offshore to onshore locations (Figure 3.1). From each of the input point a number of transects and their bathymetry/elevation profiles are set. For each of this transect the empirical relation is applied to determine the flood depth based on the bottom gradients. Subsequently, the maximum calculated flood depths at each grid point of the gridded DEM are transferred to a finer resolution (in this case 100 m).

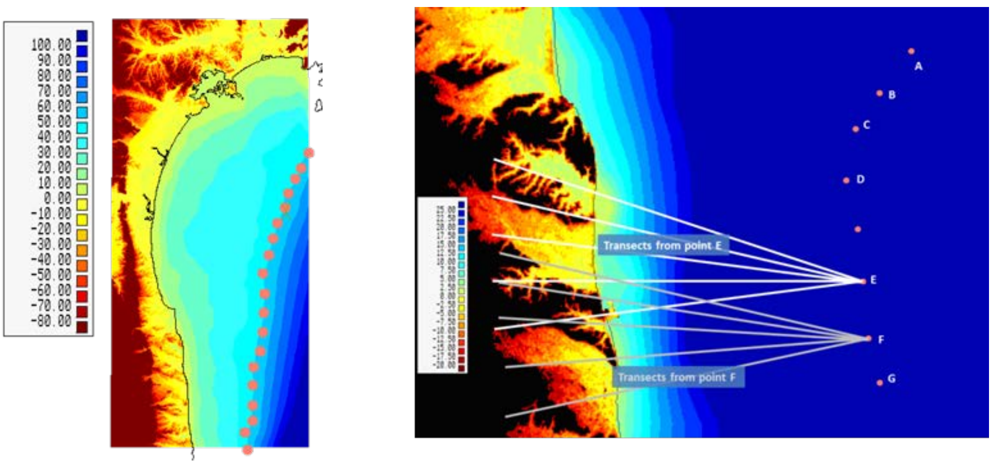

Figure 3.1: FAST model concept of offshore points (left) and wave runup calculated over transects (right).

The Flooding ASsessment of Tsunami (FAST) tool uses relatively simple, empirical expressions that relate tsunami wave height on the coast to the run-up onto linearly sloping land (Blaas et al, 2008). The FAST model requires only the bathymetry and DEM for a given area to run. For Cilacap, the bathymetry was taken from 1km gridded GEBCO2008. Two

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versions of the model were made, one based on SRTM DEM and one on the TanDEM-X intermediate product (see Figure 3.2).

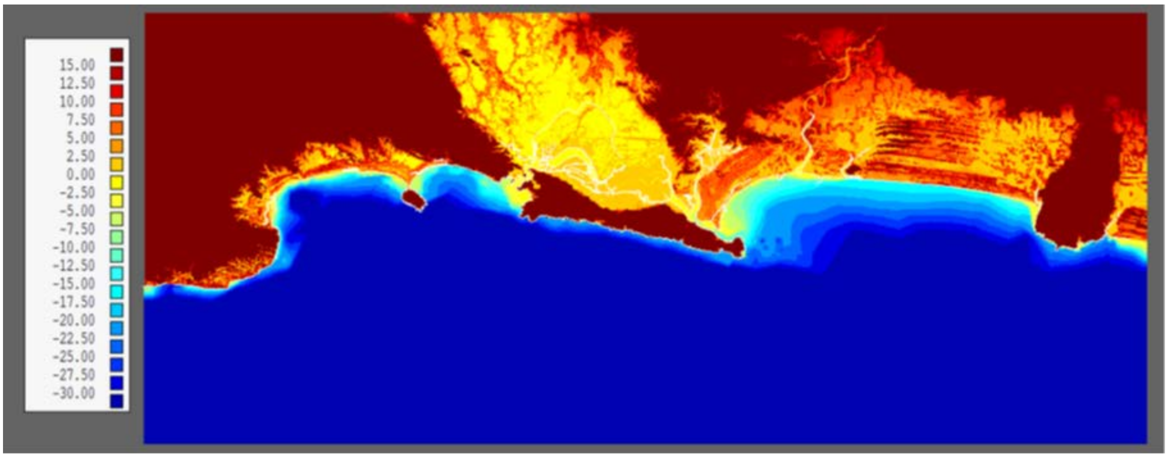

Figure 3.2: Bathymetry and TanDEM-X DEM of the FAST model in Cilacap. Depths are in m.

For the determination of the risk, the (maximum) velocity estimates on land are also required, which is not calculated by the original FAST model. Therefore, a number of methods to estimate the maximum runup velocity from literature were reviewed. The method used by Carrier and Greenspan (1958) and Cousins et al (2007) was found most applicable to narrow bays/channels as the relation is derived using linear approximation of 1D equation (among others) for sine tsunami wave.

Tsunami wave heights for a number of return periods can be found in the table below. An example inundation pattern after a 2.1m tsunami (return period 100 years) is shown in Figure 3.3.

Return period	Wave height (m)
2	0.38
5	0.58
10	0.75
20	1
50	1.5
100	2.1
200	2.7
500	4.5
1000	7

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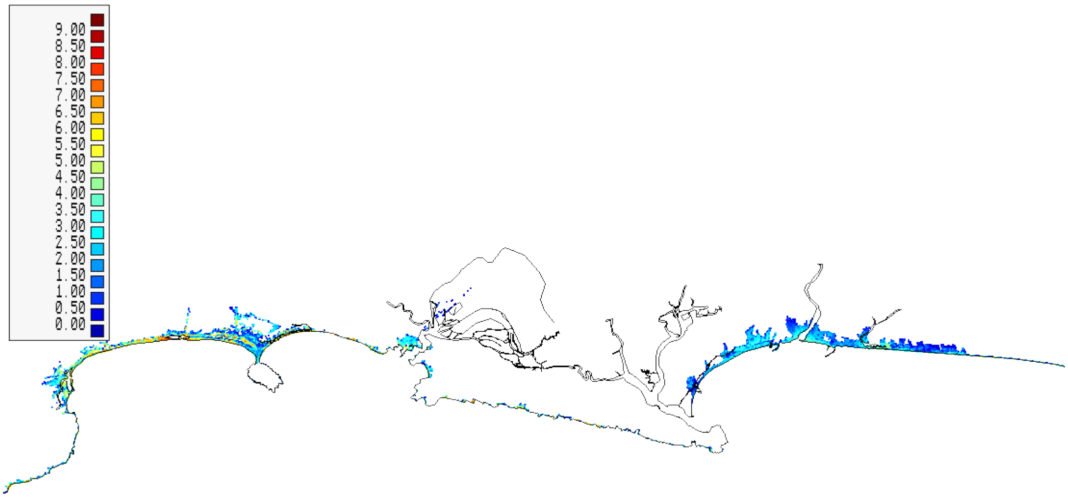

Figure 3.3: Cilacap maximum flood depths for a wave of 2.1m (flood depths in m).

The results from FAST were compared to observed tsunami levels. Tsuji et al. (2005) lists observed run-up and tsunami levels for the 1994 tsunami for several locations. The simulation results show a good overall agreement to these observations (see Figure 3.4), expect for one outlier (20 m water depth) that may have been caused by a local funneling effect. The SRTM and TanDEM-X versions of the model perform more or less equal, with SRTM reproducing the observed inundation depths slightly better for the western locations.

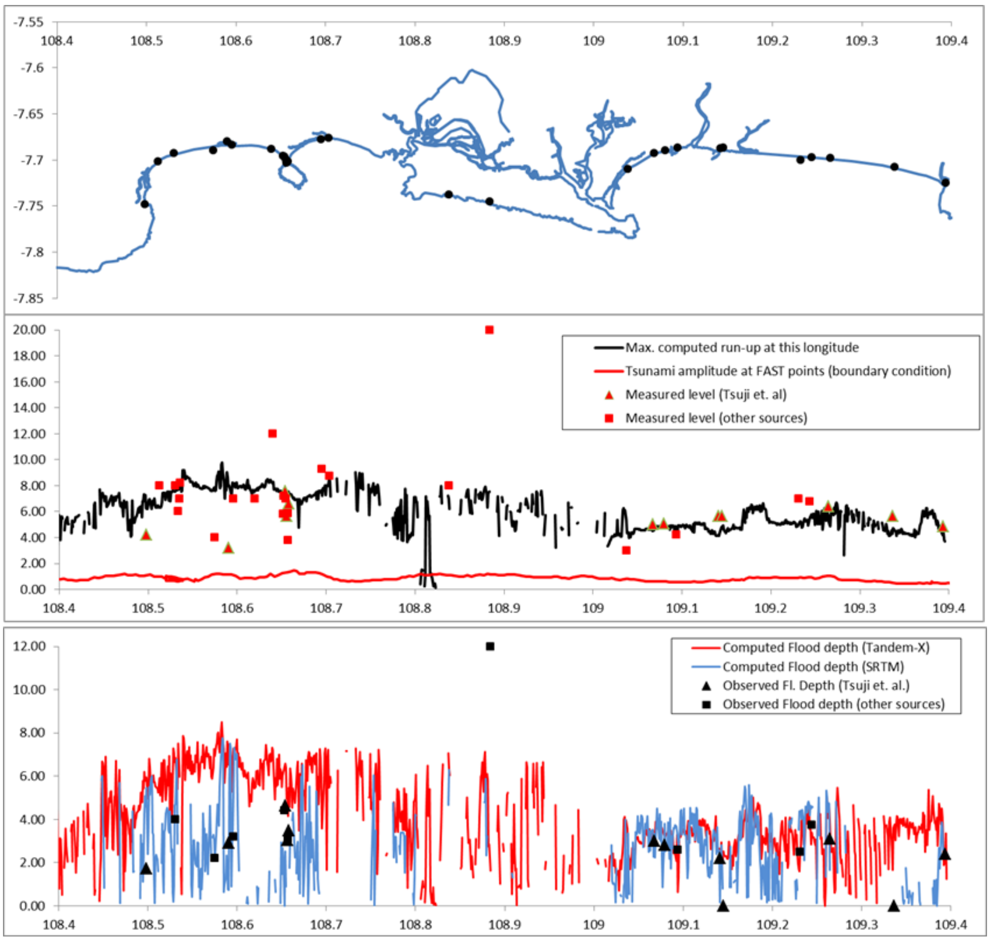

Figure 3.4: Cilacap locations (top), runup distance (middle) and flood depths (bottom). Observed vs simulated.

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Bandung - fluvial flood model

Bandung is the capital of West Java province in Indonesia and Indonesia's third largest city, with a population of 2.4 million. It is located 768 m above sea level and is surrounded by volcanic mountains. Regular flooding in Bandung presents a real and dangerous ongoing problem. The areas south of the city center are most prone to flooding from the Citarum River and its tributaries.

A Wflow hydrologic model at 250 m grid resolution was developed to simulate the rainfall runoff from the mountains that surround Bandung. The DEM for this model was derived from SRTM90 (see Figure 3.5). This runoff is than later used as input to a smaller area SubGrid 2D flood model (see below).

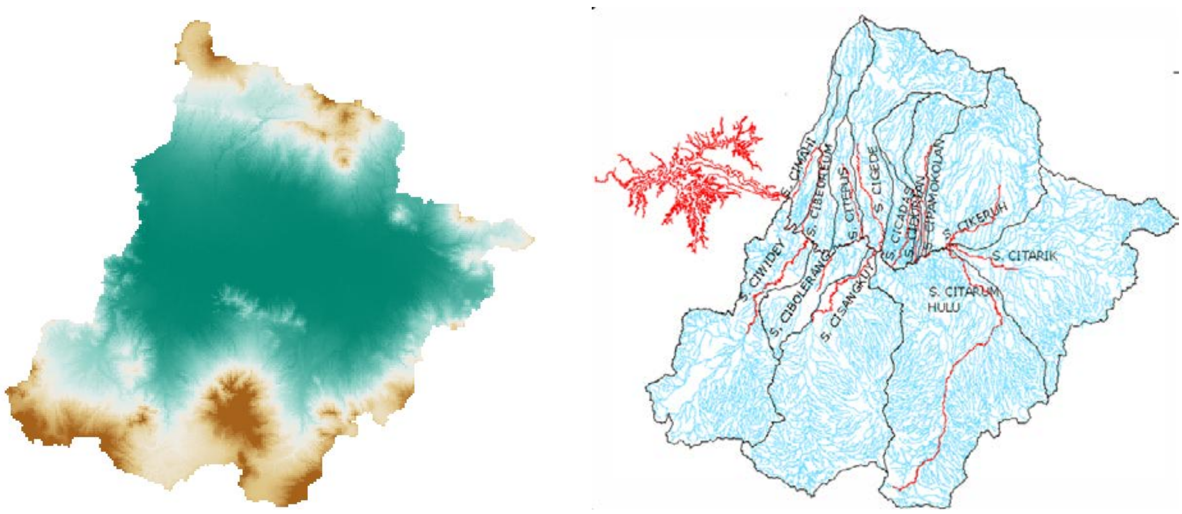

Figure 3.5: Bandung wflow model DEM (left) and river network (right).

The end-user can define uniform rainfall scenarios through the RASOR platform web interface or select a historical period of TRMM rainfall. The user can also select an initial soil moisture condition (dry, medium or wet) that represent respectively typical conditions during the dry season, annual average and conditions during the wet season (December-January).

The river flows in several rivers and larger streams as computed by the Wflow model are ingested into a smaller area SubGrid flood model (Figure 3.6) at a varying grid resolution of 100 to 800 m. The water depths from this model are later downscaled to 50 m based on the TanDEM-X DEM (see Figure 3.7). Several versions of the model were made to represent subsidence scenarios for 2010, 2020, 2050 and 2100. The user can select either of these models through the RASOR web interface to run a simulation for a particular subsidence scenario.

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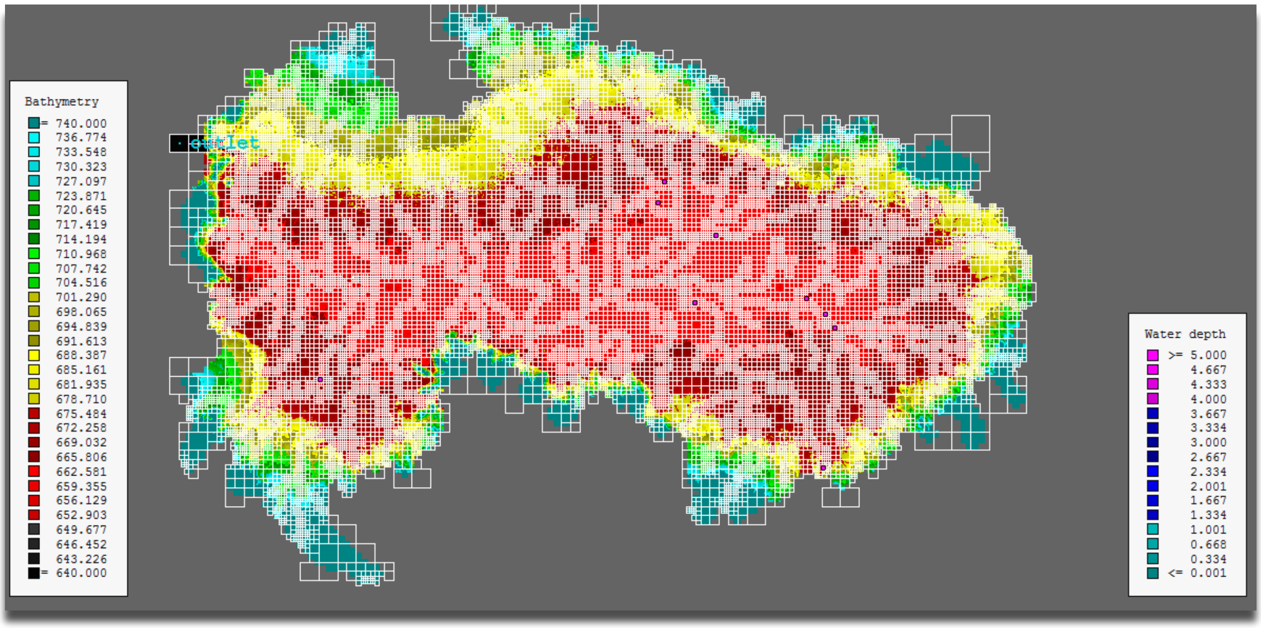

Figure 3.6: Bandung SubGrid model reference DEM (2010) and grid.

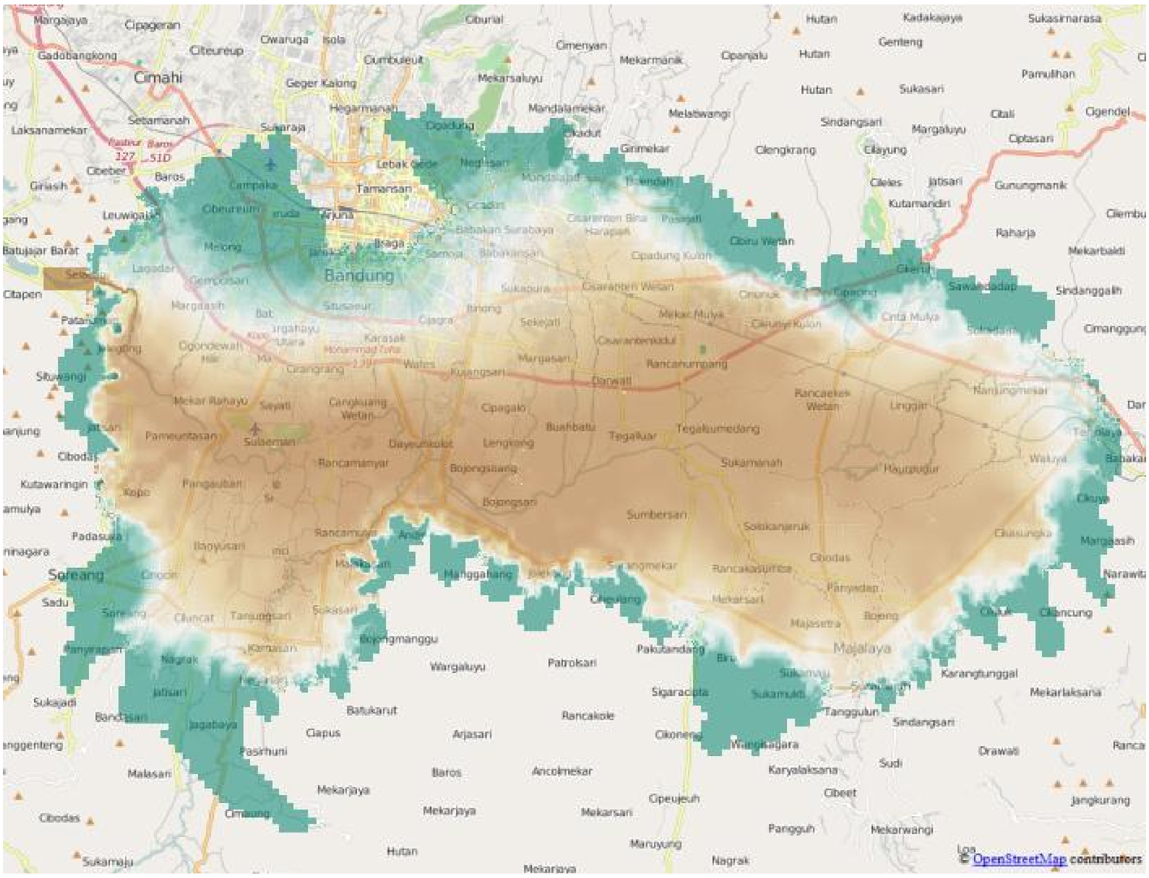

Figure 3.7: Regular grid DEM at 50 m resolution for downscaling of the Bandung SubGrid model water depths.

The Bandung SubGrid model calculates the flood pattern caused by overflow of the Citarum River. Below is an example flood extent map after intense rainfall in December 2014. This flood pattern was confirmed by local flood experts (Mr Oky Subrata from PusAir, personal communication during the RASOR workshop in June 2015).

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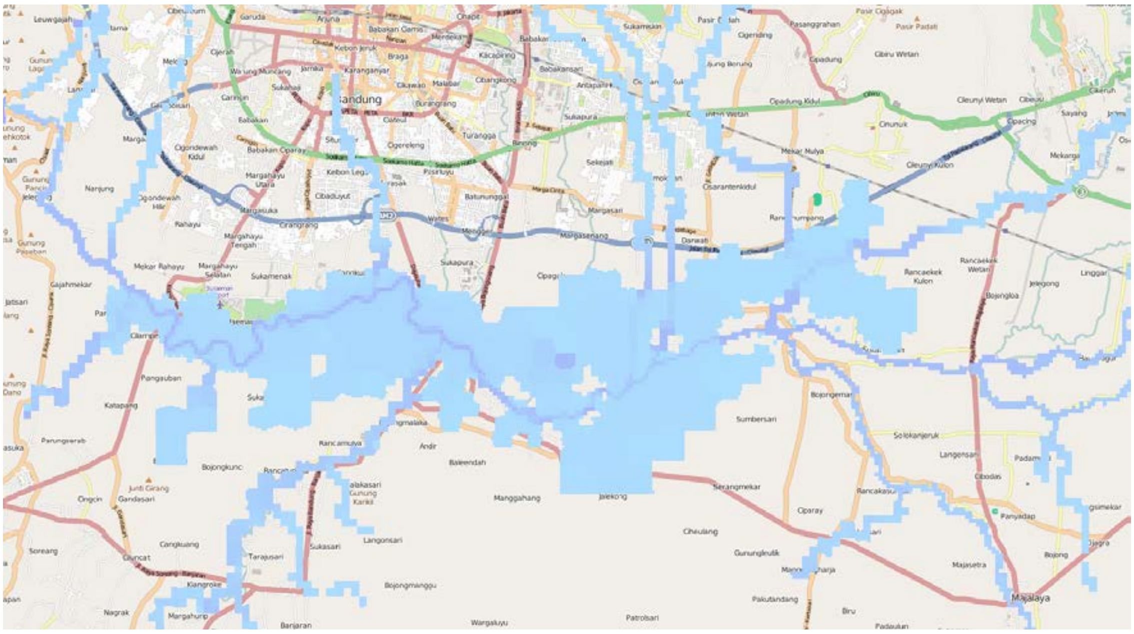

Figure 3.8: Bandung inundation map.

Jakarta - coastal levee breach

Jakarta is the capital and largest city of Indonesia with a population of more than 10 million. It is located on the northwest coast of Java, in a low, flat basin, at elevations between −2 to 50 meters above sea level. About 40% of the city is below sea level and is prone to coastal and fluvial flooding. Moreover, Jakarta is sinking at a rate of 5 to 10 cm annually and even more in the coastal areas. There are plans to build a dike around Jakarta Bay, which will be equipped with a pumping system and retention areas to defend against seawater.

A SubGrid model was developed for a coastal area of Jakarta called Pluit, the northern part shown is in Figure 3.9. The model has a variable grid resolution of 50 to 800 m, but the water depths that are calculated by this model are downscaled to 50 m based on the TanDEM-X DEM (see Figure 3.10). Several versions of the model were made to represent subsidence scenarios for 2010, 2015 and 2030. The RASOR end-user can define a sea water level time series, select a subsidence scenario, run a simulation and view the results or use them in a risk assessment.

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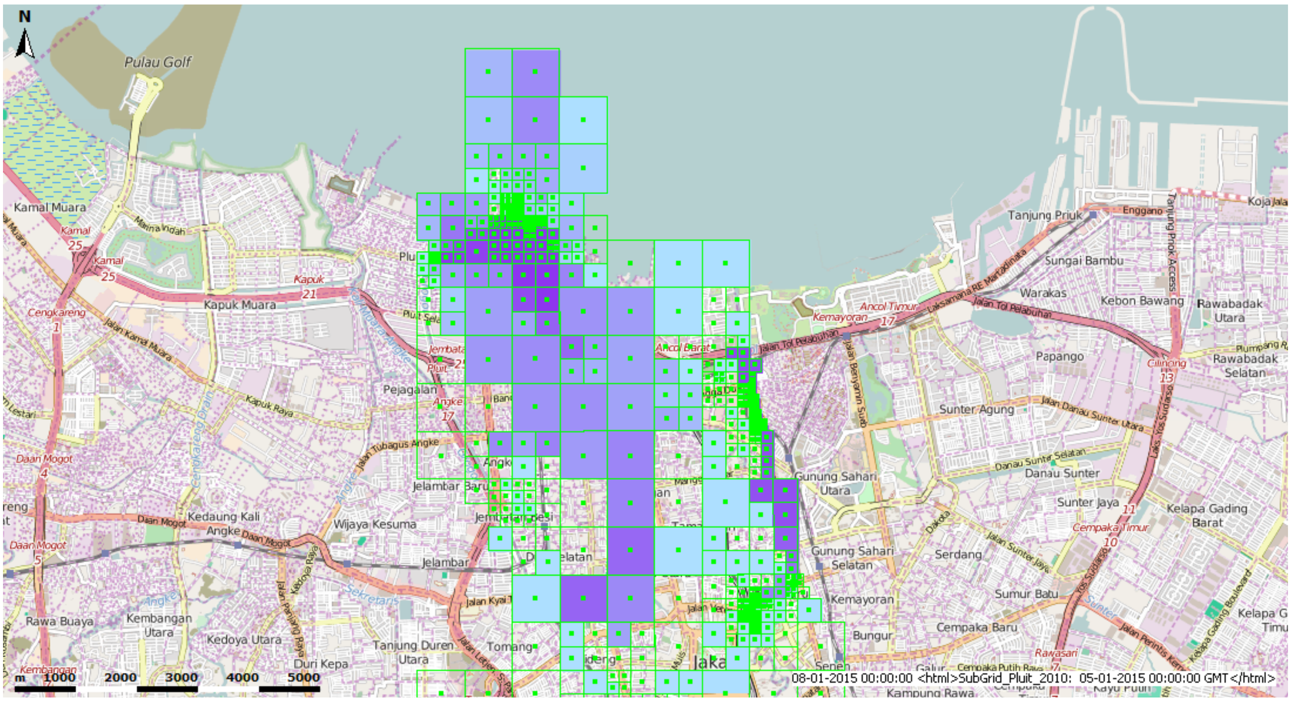

Figure 3.9: Jakarta computational grid at variable resolution, with calculated flood depths.

Figure 3.10: Jakarta DEM at 50 m resolution based on TanDEM-X. Green colours indicate land below mean sea level.

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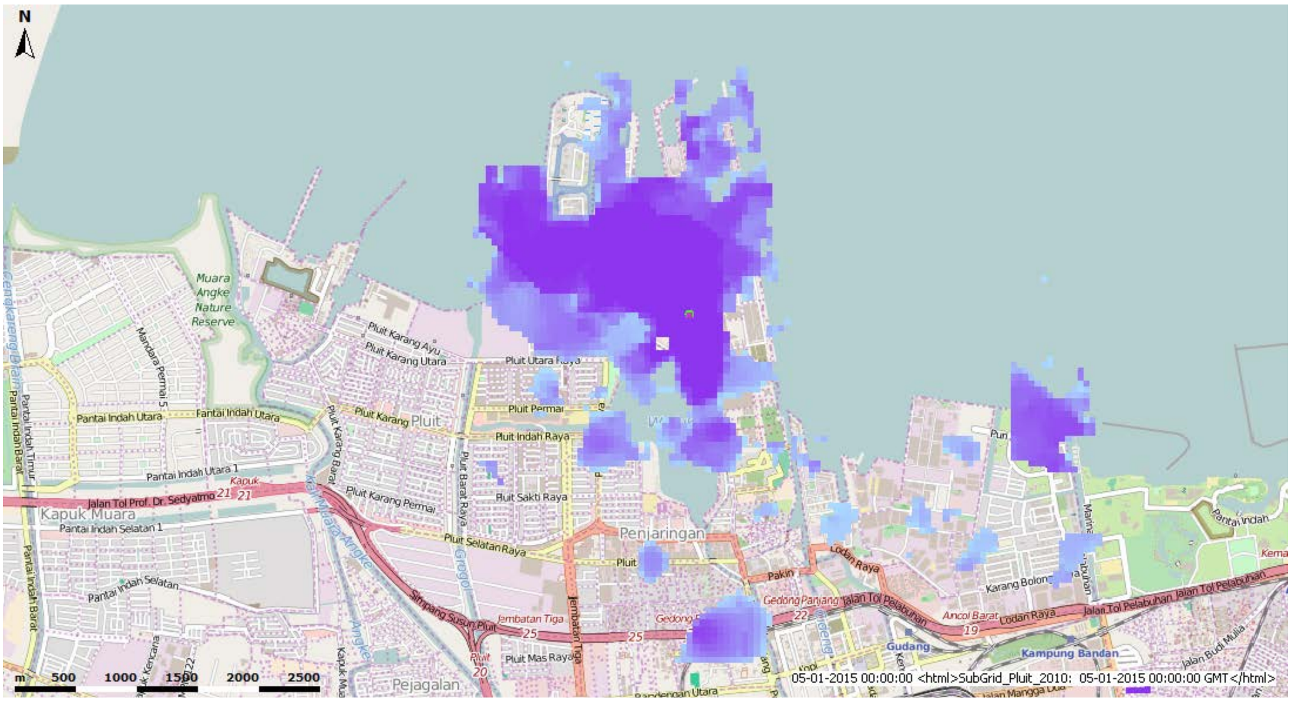

Figure 3.11: Jakarta flood map at 50 m resolution, downscaled result from Figure 3.9.

Santorini - landslide-induced tsunami model

The island of Santorini in the Aegean Sea is subject to seismic hazards from several submarine faults in the caldera and surrounding sea bed and from volcanic activity. An earthquake can cause direct damage to buildings and indirect damage from tsunamis that are caused by landslides from the cliffs of the caldera rim. The tsunami waves travel across the caldera and can propagate even to the outer shores of the island. This forms a flood hazard to the population of the low-lying areas and to cruise ships that are often moored in the Caldera. The travelling time of the tsunami wave to the most vulnerable locations is a few minutes, which probably too short to issue a warning. This case study can help to improve risk awareness and support contingency planning.

To accurately model the process of a landslide causing a tsunami wave requires sophisticated numerical models connected in a complex way. An example is given by Tinti et al (2006) who simulate a submarine landslide and tsunami near Stromboli (It). To develop such a model for Santorini is beyond the scope of this RASOR case study and would require too much computing time for rapid risk assessments. Instead, we have adopted a simplified approach for the tsunami source by making a few assumptions on the wave shape, length and height of the tsunami approximately 60 seconds after the slide impact (see figures below from Tinti, 2006). We assume the initial wave to be radially symmetrical from the source point specified. In this approach it is assumed that the tsunami wave can be treated as long wave.

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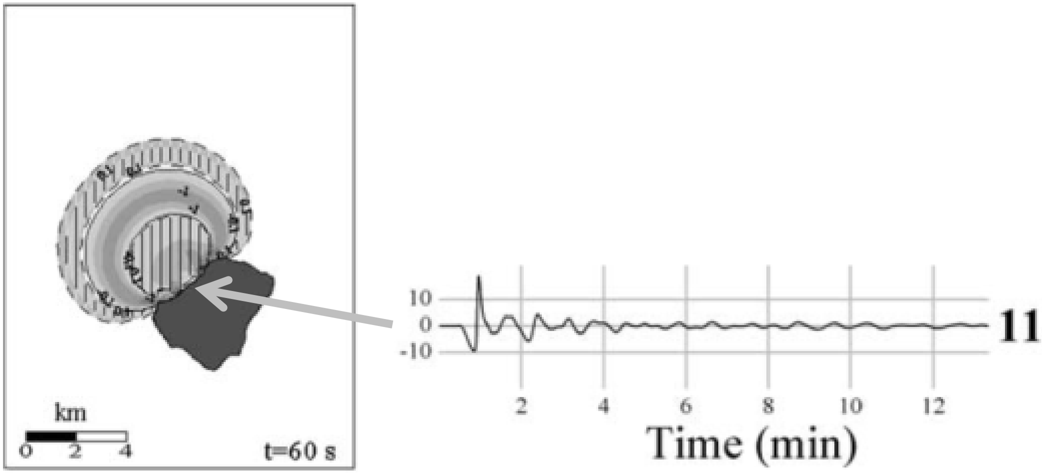

Figure 3.12: Tsunami wave pattern and N-wave shape 60 seconds after slide (from Tinti et al, 2006).

To simulate the tsunami wave propagation in the waters in and around the Santorini caldera we apply Delft3D-FLOW, which is a hydrostatic non-linear shallow water solver that calculates non-steady flow and transport phenomena that result from tidal and meteorological forcing on a rectilinear or a curvilinear, boundary fitted grid. For RASOR, only the 2D functionality is used. The model area is about 50 by 60 km. A grid resolution of approximately 75 m is used.

Bathymetry information near the main islands has been obtained from the Greek Institute of Geodynamics. Missing data in this map near the Santorini coastline (see Figure 3.13, left) were filled with a minimum depth value of 20m and interpolated using the available data. Outside the area of data coverage, the existing data is interpolated towards the freely available global SRTM data. The final bathymetry applied in the model is shown in Figure 3.13 (right).

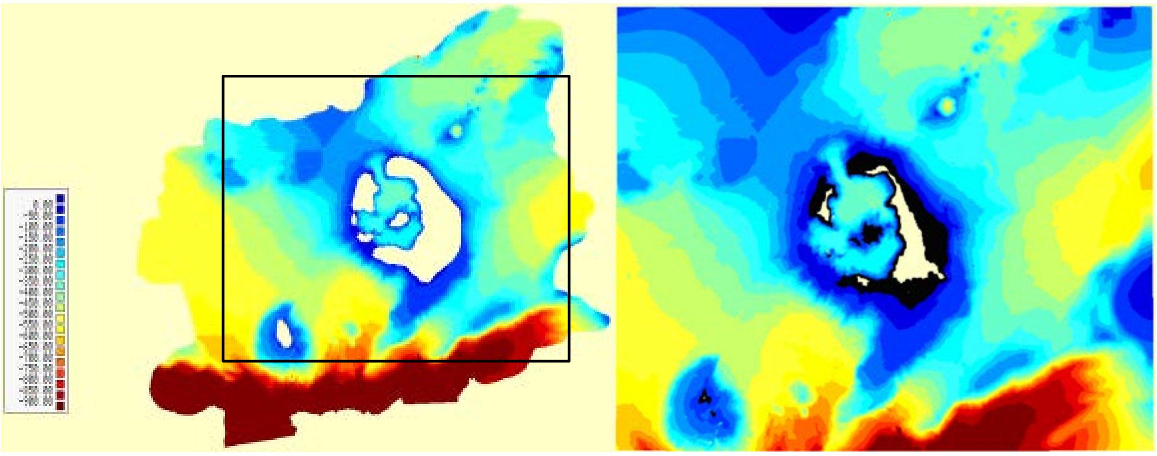
Figure 3.13: Bathymetry of the area (source: Institute of Geodynamics) and the Delft3D model bathymetry.

In general, a tsunami wave generated by a slide will contain smaller wave lengths, i.e. wave lengths that are in the same order of magnitude to the local depth value. The dynamics of these waves will not be represented properly on the coarse grid that we are using and not solved properly by a hydrostatic, non-linear shallow water solver. This would require a very high resolution model that has the capability to resolve the wave dispersion (i.e. either a code that is capable of handling non-hydrostatic terms or a Boussinesq model). The tsunami wave

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(heights) as computed in our case study will slightly be overestimated. Given the objectives of this study, i.e. rapid risk assessment, this is deemed acceptable.

The model was implemented into the RASOR platform. Through the RASOR web interface, the user can select an arbitrary landslide location and initial water perturbation.

To set a realistic initial water perturbation, a literature search was done to find a relationship between landslide characteristics and initial wave parameters. Several (related) studies were found that use a general parameter P to characterize sub aerial landslide tsunamis (Fritz et al, 2003; Fritz and Hager, 2010; Heller and Hager, 2014). This approach is simple and straightforward and is therefore very convenient for this study. However, it should be mentioned that many other equations exist that relate landslide characteristics to tsunamis (e.g. Law and Brebner, 1968; Papadopoulos and Kortekaas, 2003; McAdoo and Watts, 2004). This highlights the fact that the process is complicated and a simple and universal expression for landslide tsunamis is not readily available. Moreover, the parameter P was derived from landslide observations which were much larger than the one listed in the example here (e.g. the Lituya Bay landslide of 1958, which had an estimated mass of $8.26 \cdot 10^{10}$ kg). This could mean that this equation is not particularly suitable for smaller landslides, which in turn could explain the relatively small value that was found for the wave period in the example above. It is important to stress that the user is not bound by the results of the equation and is free to enter other values describing the initial wave for the model.
The parameter P for subaerial landslide tsunamis is defined as follows:

$$P = V_s \cdot g^{-1/2} \cdot h^{-3/2} \cdot s^{1/2} \cdot \left(\frac{m_s}{\rho_w \cdot b_s}\right)^{1/4} \cdot \left[\cos\left(\frac{6}{7} \cdot \alpha\right)\right]^{1/2}$$

Where:

V_s	Slide impact velocity	$[m/s]$
m_s	Slide mass	$[kg]$
b_s	Slide width	$[m]$
s	Slide thickness	$[m]$
α	Hill slope angle	$[°]$
h	Still water depth	$[m]$
ρ_w	Water density	$[kg/m^3]$
g	Gravitational	$[m/s^2]$

From this parameter P all relevant wave parameters can be calculated:

$$a_M = (4/9)P^{4/5}h$$
$$H_M = (5/9)P^{4/5}h$$
$$T_M = 9P^{1/2}(h/g)^{1/2}$$

With a_M being the maximum amplitude $[m]$, H_M the corresponding height $[m]$ and T_M the corresponding period $[s]$, as shown in Figure 3.14.

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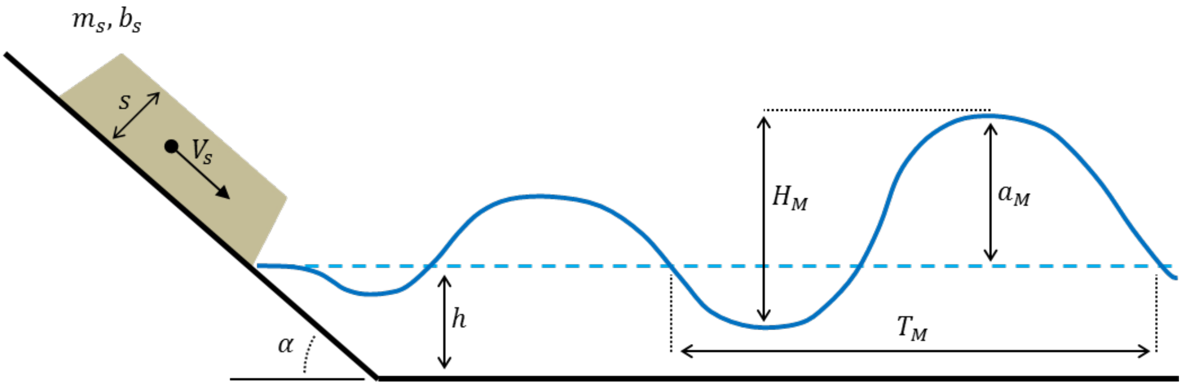

Figure 3.14: Schematization of a subaerial landslide tsunami with all relevant parameters.

An example scenario was created for a landslide near Imerovigli, which is the highest point on the caldera rim. The landslide properties are:

V_s	50	$[m/s]$
m_s	$1 \cdot 10^6$	$[kg]$
b_s	20	$[m]$
s	10	$[m]$
α	45	$[°]$
h	100	$[m]$

These values lead to an impulse product parameter of $P = 0.12$. The initial wave amplitude and period are respectively 8 meters and 10 seconds. This initial wave was entered as a starting condition for a Delft3D-FLOW simulation (see Figure 3.15).

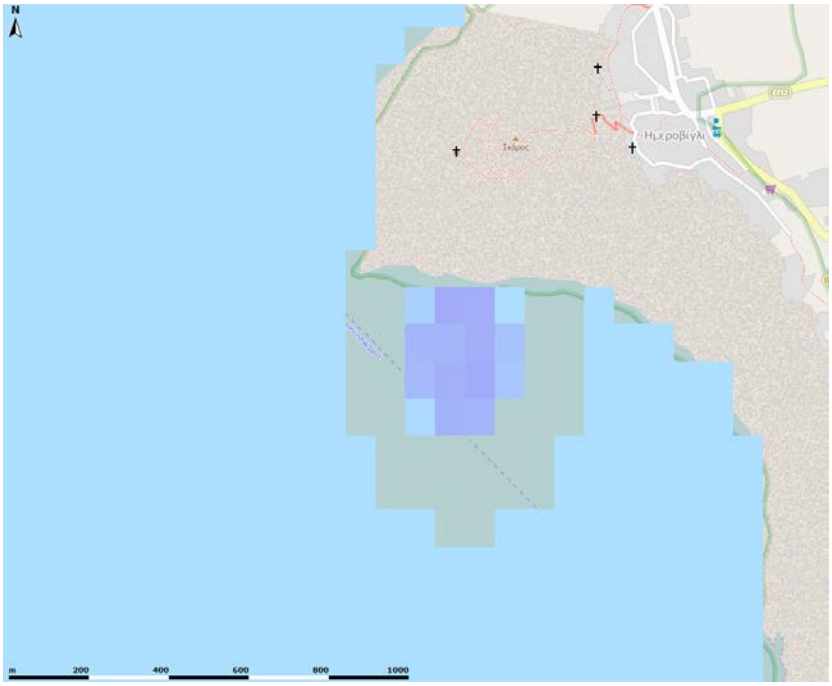

Figure 3.15: Initial water level perturbation, invoked by a landslide near Imerovigli.

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The wave propagation was simulated for 20 minutes. The computing time is about 30 minutes. Figure 3.16 (left) is an example of the wave pattern two minutes after the landslide. The wave height increases to 1 m or more in small inlets of the coastline that act as funnels. The right hand side of Figure 3.16 shows the first wave arrival times in minutes from the landslide. Within the caldera, the arrival time at any locations is below 3 minutes. This leaves hardly any room for early warning or evacuation.

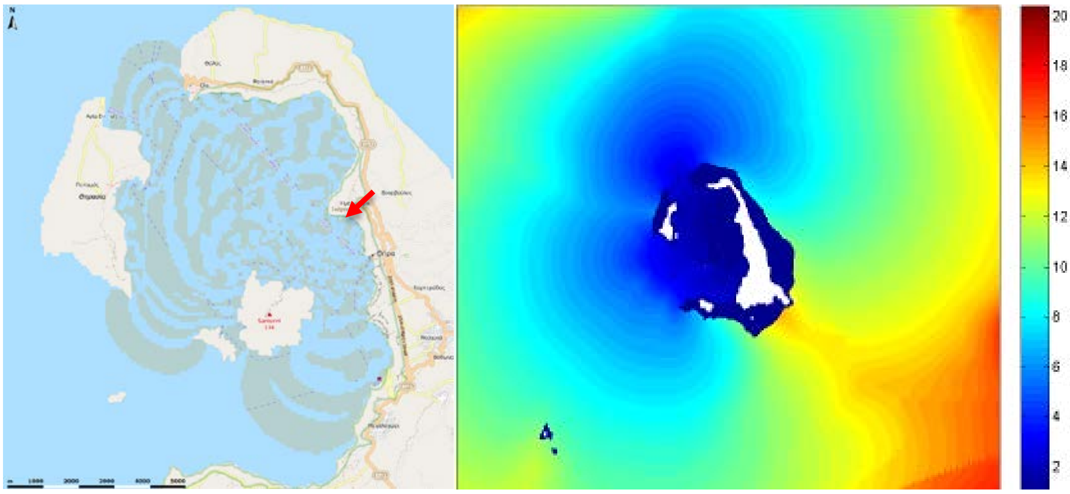

Figure 3.16: Santorini wave pattern about 2 minutes after the landslide (left) and wave arrival times in minutes (right). The location of the landslide is indicated by a red arrow.

The Santorini model provides an insight into the flood risk from tsunami waves caused by landslides that can occur on the inner slopes of the caldera. The model is able to estimate the location of the high waves and the arrival time with respect to the location of the landslide. It has a potential for early warning and emergency applications. However, given the extremely short arrival times for locations inside the caldera, the possibilities for early warning are limited.

Gonaïves, Haiti - Hurricane storm surge and rainfall runoff flood model

The city of Gonaïves is the capital of the Artibonite department of Haiti. It has a population of about 300,000 people. It is situated on a flat plain on the coast, with a small river La Quinte running past it (see Figure 3.17). During most of the year, all the water in this river is used for irrigation. However, after heavy rainfall, the small La Quinte stream can swell and overflow its banks to run through the surrounding lands including the city of Gonaïves. Moreover, if at the same time, the sea water level is high, the water accumulates near the coast and the city is severely flooded. In September 2004, Hurricane Jeanne caused major flooding and mudslides in the city. Four years later, the city was again devastated by another storm, Hurricane Hanna, which again flooded parts of the city and killed 529 people.

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Figure 3.17: Gonaïves and surroundings. The La Quinte River runs from the mountains on the top left past the city and past Nan Piguel before it flows into the Baie des Gonaïves on the far right of this picture. Source: Google Earth.

A modelling chain (see Figure 3.18) was developed to simulate storm surge, rainfall runoff and flooding of the city of Gonaïves, as a result of a hurricane storm passing by. The end user defines a hurricane track by a series of coordinates of the eye of the storm and a maximum wind velocity. This information is transformed into a time dependent wind field by WES and into a rainfall field by the R-CLIPER module. The wind field is input to a Delft-3D storm surge model of about 1500 by 1500 km (resolution of 5 to 6 km, bathymetry from GEBCO2008). The rainfall field is input to a Wflow hydrologic model, which covers the watershed of the La Quinte River and neighbouring streams at a resolution of 100 m (Figure 3.19). The DEM for this model was derived from TanDEM-X.

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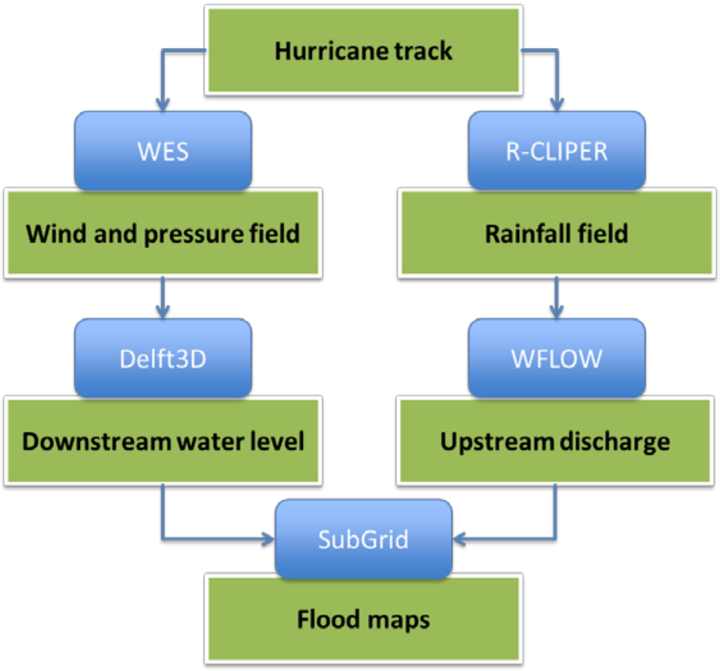

Figure 3.18: Gonaïves modelling chain.

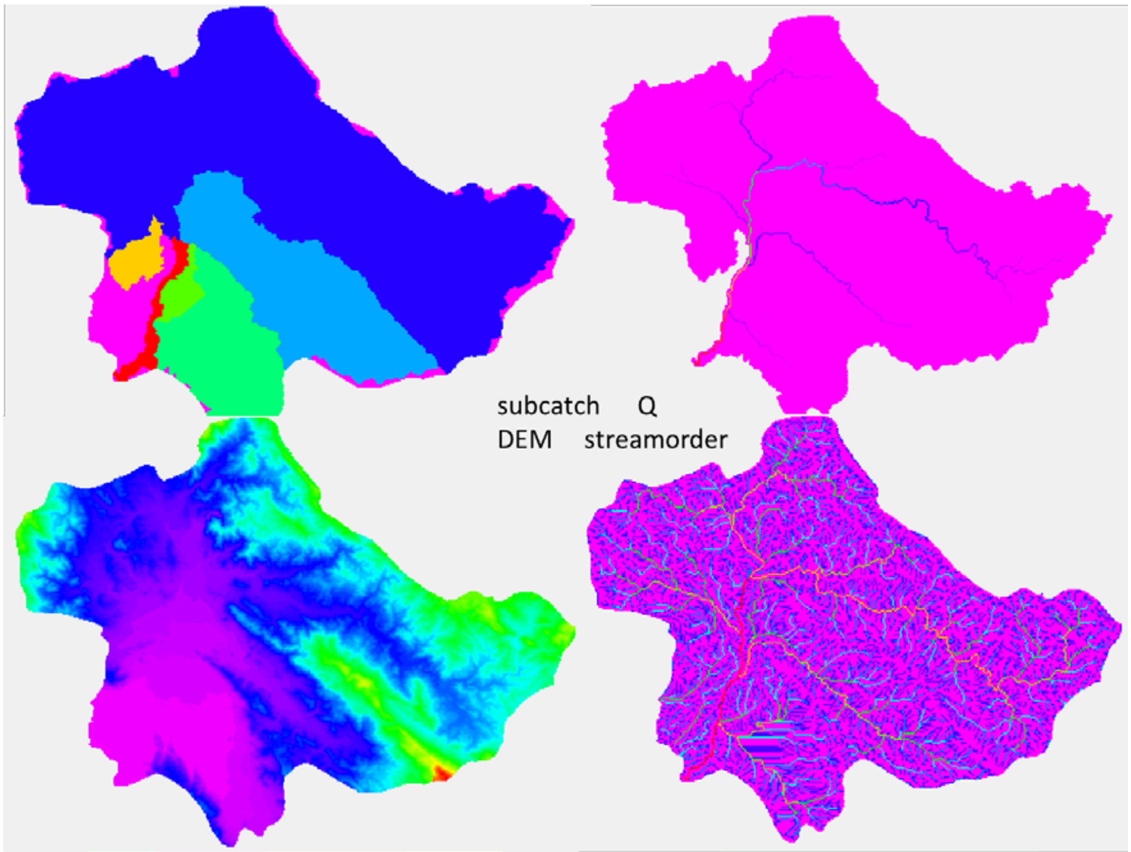

Figure 3.19: Gonaïves Wflow model maps at (from top left, clockwise): Wflow subcatchments, surface flow, streamorder and DEM.

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A SubGrid model was developed for the city of Gonaïves and its surroundings (Figure 3.20) to simulate overland flow and flooding of the city. The discharge in the La Quinte River and some smaller inflows as calculated by the Wflow hydrologic model are the upstream boundary of this model. The sea water level time series from the Delft-3D storm surge model is the downstream boundary condition. The computational cells of the SubGrid model are between 25 and 800 m. A higher resolution is used for the flood prone urban areas and a lower resolution is used elsewhere for computational speed.

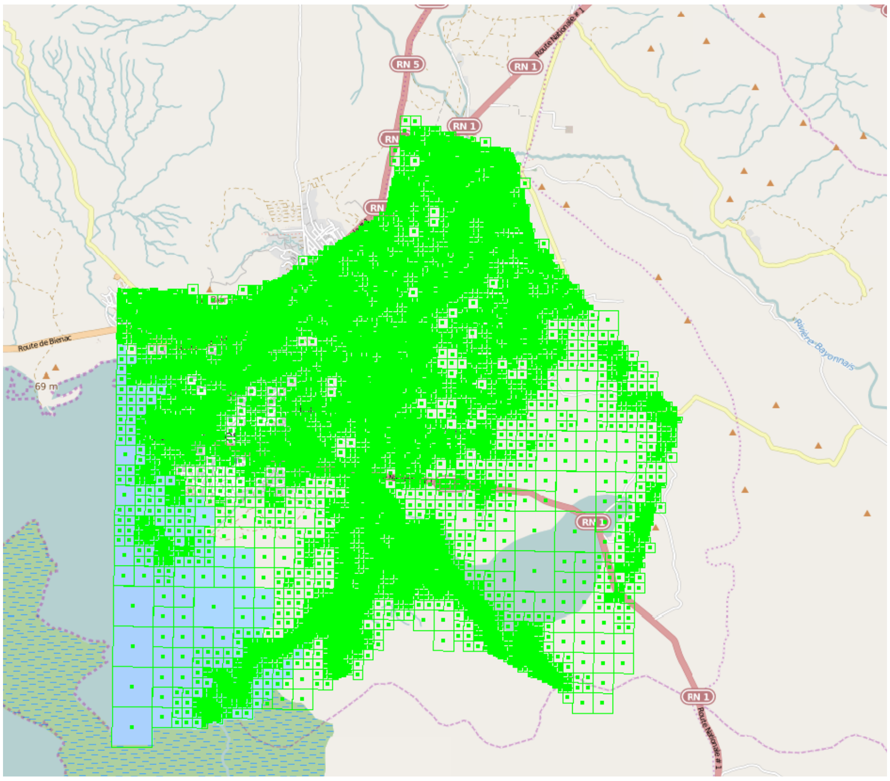

Figure 3.20: Gonaïves SubGrid model for simulation of 2D overland flow. The cell size varies between 25 and 800 m.

The Haiti model chain calculates the flood pattern after a hurricane whose track and intensity are defined by the user. Below is an example of a flood pattern in Les Gonaives after a hurricane that followed the same track as Jeanne in 2004. However, it is important to note that the wind and rainfall fields derived from this track are not the same as the observed wind and rainfall during the 2004 event. The WES and R-CLIPER models generate a realistic but strongly simplified hurricane model. A real storm will always deviate from this idealized storm. Nevertheless, the flood pattern as computed by the modeling chain (Figure 3.21) agrees with the SPOT image (Figure 3.22). The La Quinte River overflows on the west bank and flows in South-West direction through the city.

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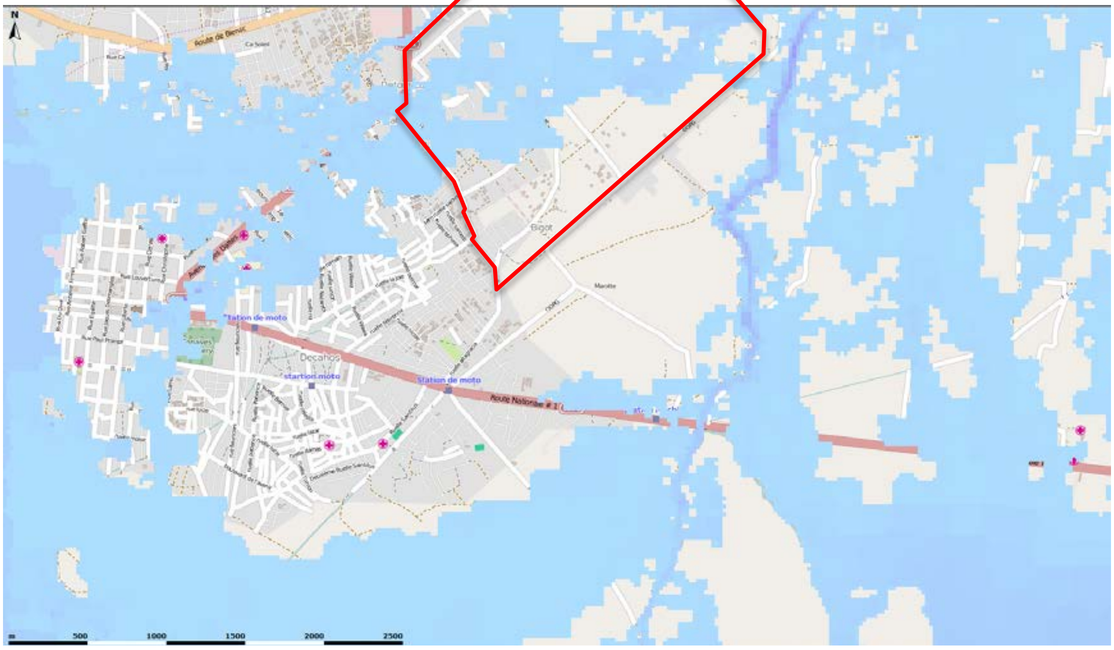

Figure 3.21: Les Gonaives inundation map. The La Quinte River runs from North to South just right of the centre of the map. The coastline is on the left. The red polygon corresponds to the polygon in Figure 3.22.

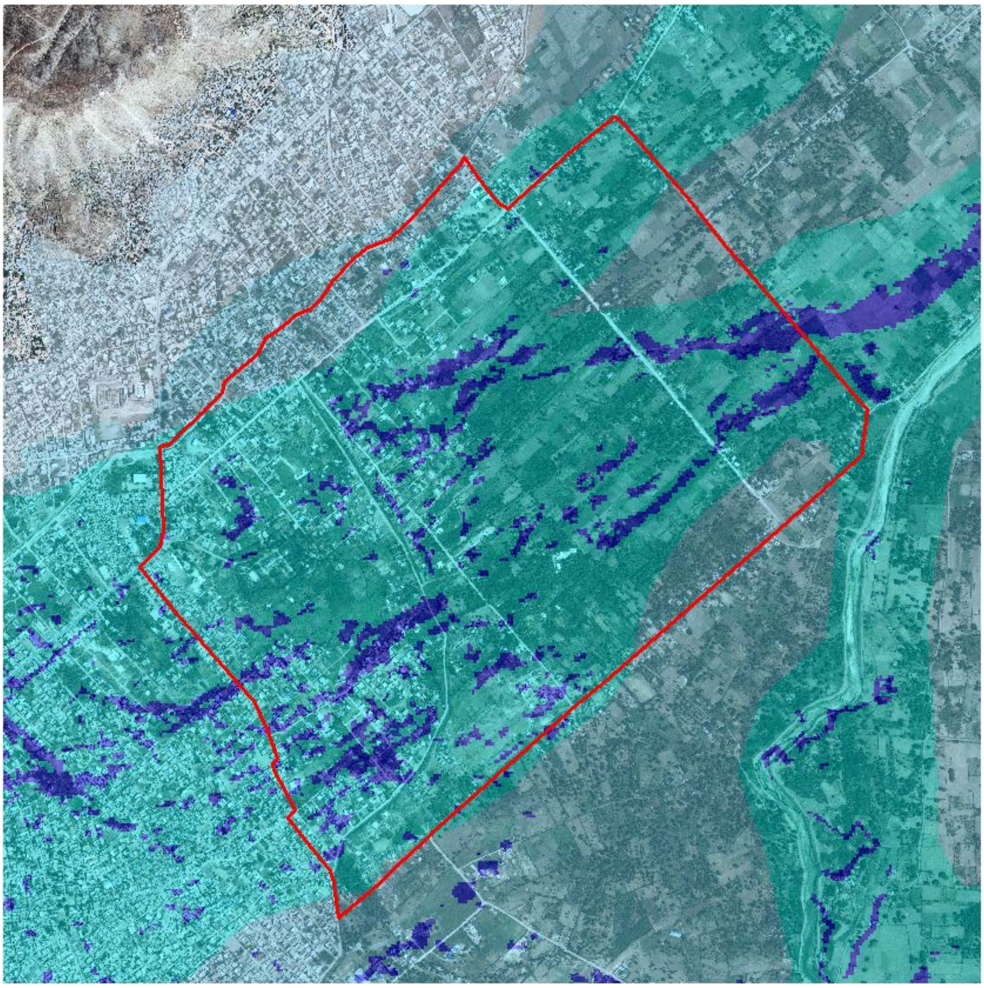

Figure 3.22: Les Gonaives inundation map from SPOT imagery. The La Quinte River runs on the right side.

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Rotterdam - Storm surge and levee breach model

The area of Rotterdam is located in the western part of the Netherlands. Approximately 1.3 million people live in the greater Rotterdam area with an average population density of about 3000 Inhabitants/km^2. Housing, industrial and agricultural purposes are the predominant land use. Rotterdam is situated at the delta of the Rhine and Maas rivers, about 35 km from the North Sea. Due to this location in a deltaic area and an average elevation of about MSL, Rotterdam is a highly flood prone area with a very high flood impact potential. Coastal and riverine floods or combined events are probable. However, large flood protection structures, like the Maeslant Barrier which protects the Rhine Meuse Delta from the North Sea in case of extreme surges and the high protection standards for the Dutch dike rings (up to a 10.000 yearly flood event), reduce the flood risk to a low level in this area.

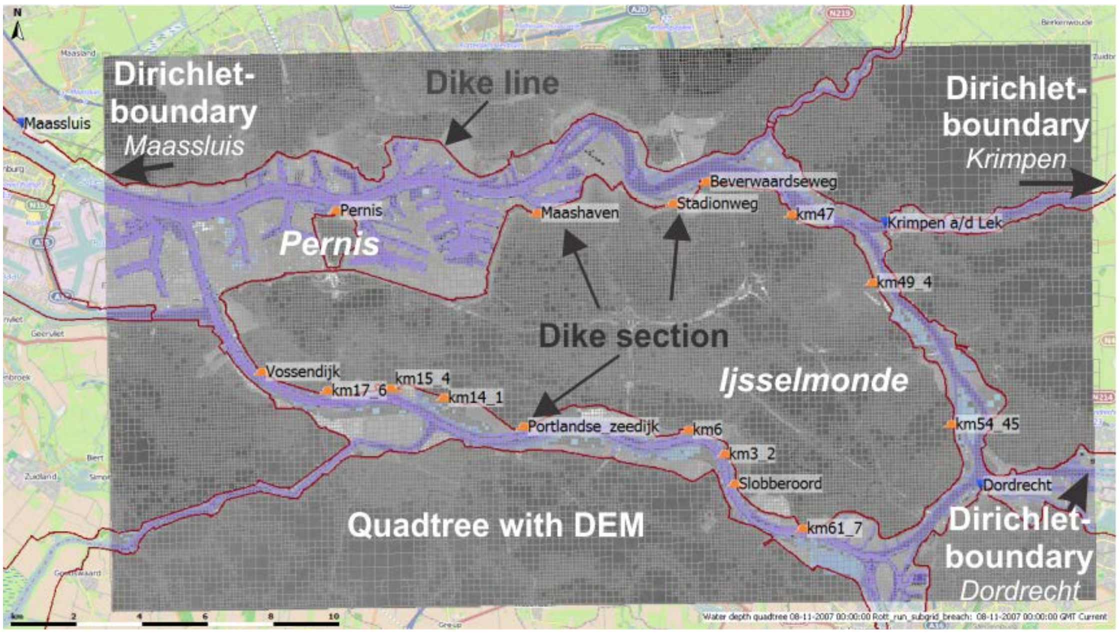

Figure 3.23: Model set-up of the Rotterdam test case.

Within the Rotterdam case study, the following model software is applied (see Chapter 2):

- a Rotterdam water levels script to determine the required boundary condition,
- the reliability transformation tool to determine the location and point in time of breaching at potential breach locations and
- the 3D-subgrid software for the two-dimensional hydrodynamic calculations.

Within the dike rings of Pernis and IJsselmonde, 15 dike sections are selected as potential breach locations (see Figure 3.23). The two-dimensional model domain for the hydrodynamic model covers about 500 km^2. The resolution of the SubGrid computational elements ranges between 100 and 400 m, according to the local variability of the DEM. The underlying DEM has a resolution of 25 x 25 m. The dike rings of Pernis and IJsselmonde are covered by the model domain. To include also the surrounding rivers of the dike rings (see Figure 3.23) the model the area is extended beyond the dike rings. Thus, interactions (e.g. back water effects) between rivers and floodplains are represented in the hydrodynamic model.

The end-user of the RASOR platform can set the maximum sea water level at Hoek van Holland and the breach locations. He can also set the functioning of the Maeslant barrier to

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either 'functional' (will close when the water reaches a level of 3.6m at Rotterdam) or 'non-functional' (barrier will not close). The Hoek van Holland water levels for a range of return periods are given in the table below:

return period (years)	water level (m+MSL)
10	3.0
20	3.2
50	3.4
100	3.6
200	3.8
500	4.1
1000	4.3
2000	4.5
5000	4.8
10000	5.1

Figure 3.24 is an example flood pattern after a 4.5m storm surge (T=2000 yrs), a failure of the storm surge barrier and a double levee breach. Breach locations are indicated by arrows.

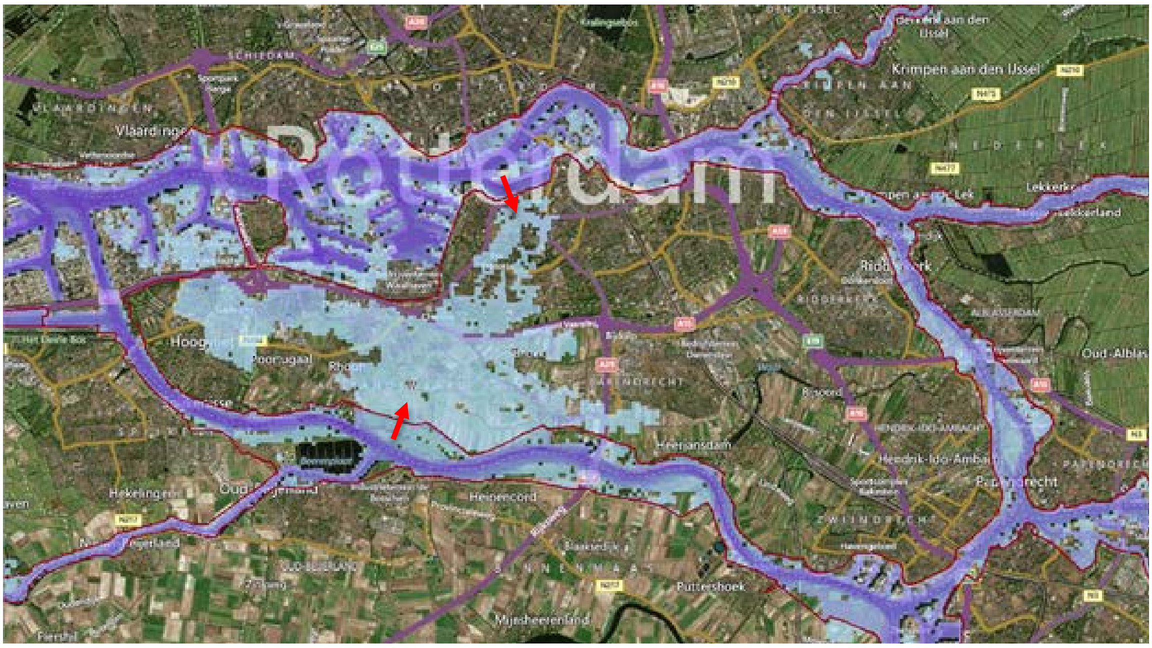

Figure 3.24: Rotterdam inundation map. Dikes are indicated as red lines, breach locations by arrows.

Because of the high standards for flood protection, no flood has occurred in this area in the past 50 years. The 1953 flood did breach some of the dikes on the South side of IJsselmonde, but the inundation pattern of that flood is not known in great detail. Moreover, the area has changed a lot since 1953 (urbanisation, flood protection). It was therefore not considered useful to validate the model on the 1953 data. The inundation patterns look realistic to experts from the local Water Board and the RASOR end-user WMCN – Rijkswaterstaat.

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Po-Secchia - riverine levee breach model

This case study area is located in the north eastern part of Italy at the Po river between the cities of Mantua and Ferrara. Agricultural purposes are the predominant land use. The average population density is about 100 Inhabitants/km^2. The average height in the area varies from about 17 m.a.s.l. at the western boundary to 5 m.a.s.l. at the eastern part. Dikes with heights of up to 10 m along the Po river protect the adjacent area against flooding from the river. Additionally, several storage areas between the main river channel and main dike line are available for a reduction of the water level in case of a flood event.

Within the Po river case study, the following model software was applied:

- the reliability transformation tool to determine the location and point in time of breaching at potential breach locations and
- the 3D-subgrid software for the two-dimensional hydrodynamic calculations.

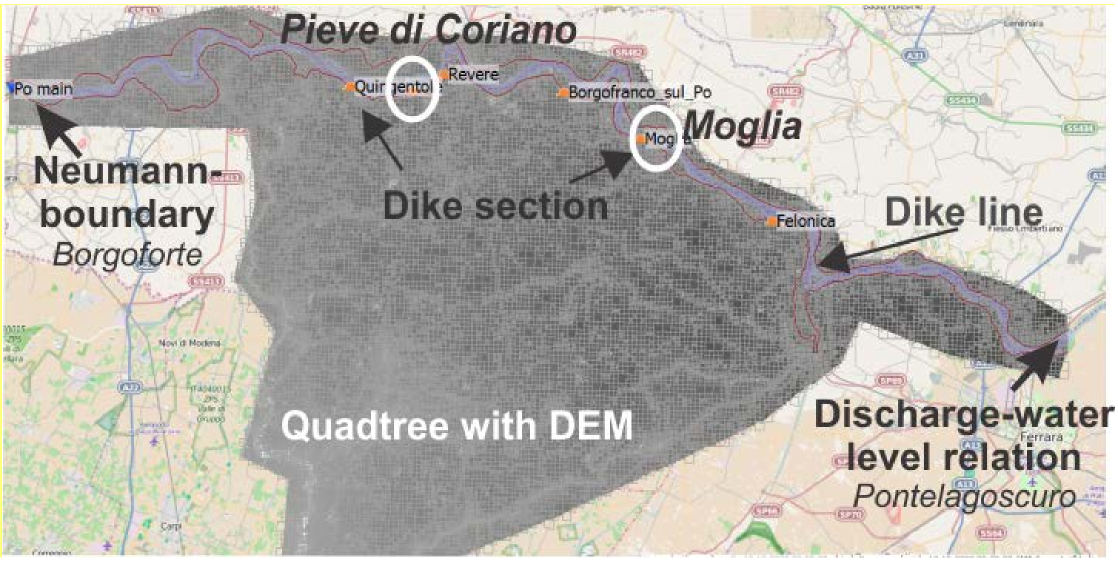

Figure 3.25: Model set-up of the Po river test case. The orange bullets indicate potential breach locations. Dike sections and dike lines are indicated by arrows.

Six dike sections were selected as potential breach locations (see Figure 3.25). They are all located at the right bank of the river (in flow direction) in the middle part of the model area. The two-dimensional model domain covers about 1.300 km^2. It includes about 85 km of the Po river as well as the adjacent area located in the South of the river. The resolution of the SubGrid computational elements varies between 144 and 576 m, according to the variability of the local variations in the DEM. The underlying subgrid raster has a resolution of 12 x 12 m and is based on TanDEM-X data.

The end-user of the RASOR platform can set the boundary conditions as a maximum discharge or a time series at Borgoforte and the breach locations. The downstream boundary condition is calculated automatically by a stage-discharge relationship. Below is an example flood pattern after a dike breach at Pieve di Coriano. The breach location is indicated by an arrow.

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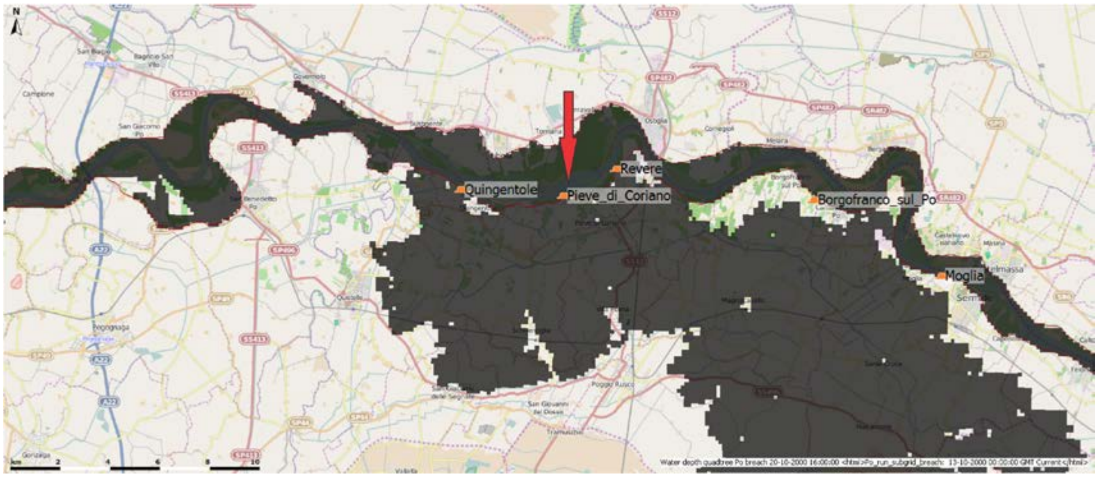

Figure 3.26: Po river inundation map. Dikes are indicated as red lines, breach location by an arrow.

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4. Conclusions and future work

Conclusions

The aim of RASOR Work Package 5 was to develop models that allow to assess the flood hazard for a given study area. For all RASOR case study areas, flood models have been developed and implemented in the RASOR platform. The flood models have produced flood hazard maps (inundation depths and maximum flow velocities) that are delivered to the RASOR platform for visual inspection and usage in a flood risk assessment.

This document describes the models and the user-interface in terms of defining flooding scenarios and model inputs. Depending on the case study, a scenario is defined by a rainfall or water level time series, a levee breach, tsunami wave height or a hurricane track. After the scenario has been defined, the user activates the models and the results can be viewed in the geographical interfaces provided by the platform and used for risk assessment.

For all case studies, model results are described for an example scenario, but many more scenarios can be generated by the end-user. Where possible, the example scenario results have been validated with local data or EO imagery. In general, the model results are remarkably good, given that most flood models were based on global data only and no or very little calibration was done. This shows that reasonable flood hazard maps can be generated from global data. Results can only improve by calibrating the models to local data.

The workflows take between a few seconds up to 45 minutes to complete, depending on the length of the type of model and simulation period. The flood hazard maps (maximum water depth and flow velocity) vary between 3 and 10 MB, depending on the size of the area and the resolution of the maps.

Future work

After delivering the D9.7 final version of the platform, we hope that the RASOR platform will be used by risk managers around the world and that more case studies and models will be added to the platform in 2016 and further.

The first post-FP7 case study for northern Malawi was commissioned by the World Bank in 2015 and is currently being implemented. The setup of the Malawi case study is slightly different from the case studies described in this document. In addition to a WFLOW hydrological model, there are three 2D flood models for hotspot areas, based on the Deflt3D-FM software package. However, the generic setup of the platform ensures that the end-user will experience the same 'look and feel' for this new case study.

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Appendix A: FEWS PI service – interface to the models

The models running within Delft-FEWS are accessed through workflows that are activated through the PI Service. The user typically first sets an input time series and then runs one or several so-called workflows that perform tasks such as importing data, running a model simulation, transforming output data into another format and writing results to file. The procedures for running the models for each of the case studies are described in detail below. This description is can be used as a reference for platform developers.

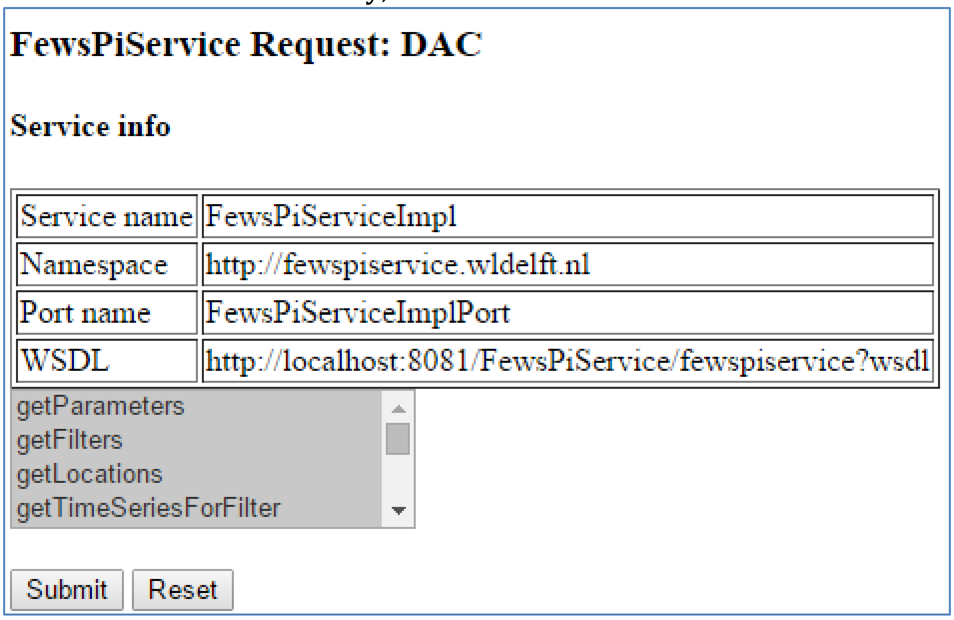
Starting Tomcat

To be able to run models the Tomcat must first be started. This can be done by running the script startup.bat in ~\Tomcat 7.0 rasor\bin\

The bat script opens a DOS screen with log messages, where the last message reads:
'INFO: Server startup in *** ms'

Next, the SOAP commands can be sent to Tomcat. This can be tested by opening a test web site in a standard web browser: http://localhost:8081/FewsPiService/

If the Tomcat runs correctly, the web browser should show the following:



Cilacap tsunami

The FAST tsunami model for Cilacap is run by giving the following SOAP commands:

RunTask **SetCilacapDefaultWaveHeight**
This sets the offshore wave height to a default value of 4 m. The user can change this value by using putTimeSeries with the following input:

```
<TimeSeries xmlns="http://www.wldelft.nl/fews/PI" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://www.wldelft.nl/fews/PI http://fews.wldelft.nl/schemas/version1.0/pi-
schemas/pi_timeseries.xsd" version="1.9">
  <timeZone>0.0</timeZone>
  <series>
    <header>
      <type>instantaneous</type>
      <locationId>Cilacap_offshore</locationId>
      <parameterId>H_mean</parameterId>
      <timeStep unit="second" multiplier="60"/>
      <startDate date="2015-01-01" time="00:00:00"/>
      <endDate date="2015-01-01" time="00:00:00"/>
      <missVal>-999.0</missVal>
      <stationName>Cilacap offshore</stationName>
      <lat>-7.8</lat>
      <lon>108.5</lon>
      <x>108.5</x>
      <y>-7.8</y>
      <z>0.0</z>
      <units>m</units>
    </header>
    <event date="2015-01-01" time="00:00:00" value="3" flag="2"/>
  </series>
</TimeSeries>
```

Make sure the time of the wave height value is identical to the Forecast time of the next workflow, which runs the FAST model. Formally, there is no time in this model (FAST is a static model), but FEWS needs a time. It is easiest to always use the same Forecast time, Start time and End time (all identical), for example 2015-01-01 00:00.

Runtask **Run_FAST**
    Forecast time = 2015-01-01 00:00

The current implementation copies the NetCDF output from Run_FAST directly to the export folder. Check the results in export folder 'Cilacap'

Therefore, the workflow Cilacap_export is not necessary (it will even give an error message because there are no files to export). Do not use it. It is mentioned for completeness here.

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Bandung Uniform rainfall (user defined time series)

To prepare input time series for the Bandung model, do the following:
Copy ~\RASOR_SA\ImportBackup\Citarum_ET_ts* to ~\RASOR_SA\Import\.
Copy ~\RASOR_SA\ImportBackup\Citarum_P_ts* to ~\RASOR_SA\Import\.

Runtask **Citarum_ImportP_ET_ts**
Imports rainfall and evaporation time series: evaporation from 1/1/1980 to 1/1/2016, rainfall from 1/1/1986 to 1/1/2005, with missing data in 2000.
The forecast, start or end time of this workflow are irrelevant.

You can check the result by getTimeSeriesForFilter, Parameter ID = “P.obs”. The P.obs time series for the period of interest can be changed by the used by using putTimeSeries. Make sure that ET and P data are available for the period that will be simulated.

Next, the hydrological (WFLOW) and hydraulic (SubGrid) models are run:

Runtask **WFLOW_Cita_historical**
Set start and forecast time to the start of the simulation period, end time defines the length of the simulation. For example:
Forecast time = 2004-09-30 00:00
End time = 2004-10-02 00:00
Start time = 2004-09-30 00:00
Use the same time settings for the next workflows.

Set cold state by entering: “default”, “wet” or “dry”

You can check the discharges from the WFLOW model by getTimeSeriesForFilter
For example: Parameter ID = “Q.sim” Location ID = “WFLOW_CITA_65”
The user can change these time series by putTimeSeries

Check the Task status by getTaskRunStatus:
R = running
C = completed successfully
A = approved (=completed successfully)
D = completed with errors
F = failed

Runtask **SubGrid_Citarum**
Forecast time = 2004-09-30 00:00, Start time 2004-09-30 00:00, End time 2004-10-02 00:00

Runtask **SubGrid_Cita_export**
Forecast time = 2004-09-30 00:00, Start time 2004-09-30 00:00, End time 2004-10-02 00:00
Check the results in export folder ‘Bandung’

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Bandung TRMM rainfall

To prepare input time series for a Bandung model run with TRMM rainfall input, do the following:
Copy ~\RASOR_SA\ImportBackup\Citarum_TRMM_3B42RT* to ~\RASOR_SA\Import\.

RunTask **Citarum_TRMM_Import**
Imports bias-corrected TRMM rainfall from 01-Jan-2007 to 03-May-2015
The forecast, start or end time of this workflow are irrelevant

If the Evaporation time series is not already defined, do the following:
Copy ~\RASOR_SA\ImportBackup\Citarum_ET_ts* to ~\RASOR_SA\Import\Citarum_ET_ts\.

Runtask **Citarum_ImportP_ET_ts**
Imports evaporation from 1/1/1980 to 1/1/2016.
The forecast, start or end time of this workflow are irrelevant

Next, the hydrological (WFLOW) and hydraulic (SubGrid) models are run:

Runtask **WFLOW_Cita_historical_TRMM**
Set start and forecast time to the start of the simulation, end time defines the length.
Use the same time settings for the next workflows.
Set cold state by entering: “default”, “wet” or “dry”

Runtask **SubGrid_Citarum_TRMM**

Runtask **SubGrid_Cita_export_TRMM**
Check the results in export folder ‘Bandung’

Jakarta sea wall breach

To run flood simulations for Jakarta, Indonesia, the user first needs to define a sea level time series. This time series is passed to FEWS by using the putTimeSeries command. An example of this PI-XML input is given below.

```
<?xml version="1.0" encoding="UTF-8"?>
<TimeSeries xmlns="http://www.wldelft.nl/fews/PI" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://www.wldelft.nl/fews/PI http://fews.wldelft.nl/schemas/version1.0/pi-
schemas/pi_timeseries.xsd" version="1.14">
  <timeZone>0.0</timeZone>
  <series>
    <header>
      <type>instantaneous</type>
      <locationId>WL_Jakarta</locationId>
      <parameterId>H.obs</parameterId>
      <timeStep unit="second" multiplier="1800"/>
      <startDate date="2015-01-01" time="00:00:00"/>
      <endDate date="2015-01-01" time="23:30:00"/>
      <missVal>NaN</missVal>
      <stationName>WL_Jakarta</stationName>
      <lat>-6.091507</lat>
      <lon>106.798023</lon>
      <x>106.798023</x>
```


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```
        <y>-6.091507</y>
        <z>NaN</z>
        <units>m</units>
      </header>
      <event date="2015-01-01" time="00:00:00" value="0.0" flag="0"/>
      <event date="2015-01-01" time="00:30:00" value="0.08" flag="0"/>
      <event date="2015-01-01" time="01:00:00" value="0.16" flag="0"/>
      <event date="2015-01-01" time="01:30:00" value="0.23" flag="0"/>
      <event date="2015-01-01" time="02:00:00" value="0.3" flag="0"/>
      <event date="2015-01-01" time="02:30:00" value="0.37" flag="0"/>
      <event date="2015-01-01" time="03:00:00" value="0.42" flag="0"/>
      <event date="2015-01-01" time="03:30:00" value="0.48" flag="0"/>
        …
      <event date="2015-01-01" time="22:30:00" value="-0.23" flag="0"/>
      <event date="2015-01-01" time="23:00:00" value="-0.16" flag="0"/>
      <event date="2015-01-01" time="23:30:00" value="-0.08" flag="0"/>
   </series>
</TimeSeries>
```


Next, the following workflows should be run:
SubGrid_Pluit_XXXX, where XXXX can be 1975, 2000, 2010, 2015 or 2030
Jakarta_SubGrid_export
The start and end times should be defined at full hours. They can be any day after 1-1-2015.

A breach is automatically induced at the sea wall that protects the Pluit polder from flooding by the sea. The model takes a few minutes of computing time per day of simulation.

Santorini landslide

The Santorini landslide-tsunami model is run by a single workflow, requiring only initial wave input (see below). The forecast time in this model is irrelevant, but FEWS needs a forecast time so we set one. The forecast time must be after 8-8-2014, so any date in 2015 is fine. A simulation length of 20 minutes is standard. Make sure to set a description (can be anything) because Tomcat expects one.

runTask **WF_D3D_Santorini**

Forecast time	2015-01-01 00:00
Start time	2015-01-01 00:00
End time	2015-01-01 00:20
Workflow ID	WF_D3D_Santorini
Description	my_test_run

The initial wave that is generated by the landslide is characterized by a wave period (in seconds) and amplitude (in meters). The location (lat, lon) and these variables can be set in the Pi XML content of the workflow.

Pi XML Content:


```
<parameters xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xmlns="http://www.wldelft.nl/fews/PI"
xsi:schemaLocation="http://www.wldelft.nl/fews/PI http://fews.wldelft.nl/schemas/version1.0/pi-
schemas/pi_modelparameters.xsd" version="1.5">
   <group id="Santorini" name="Santorini" readonly="false" modified="false">
      <parameter id="Latitude" name="Latitude">
```


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```xml
            <description>Latitude of landslide</description>
            <dblValue>36.5</dblValue>
        </parameter>
        <parameter id="Longitude" name="Longitude">
            <description>Longitude of landslide</description>
            <dblValue>25.4</dblValue>
        </parameter>
        <parameter id="Wave.period" name="Wave.period">
            <description>Initial Wave period (s)</description>
            <dblValue>50.0</dblValue>
        </parameter>
        <parameter id="Wave.amplitude" name="Wave.amplitude">
             <description>Initial Wave amplitude (m)</description>
            <dblValue>8.0</dblValue>
        </parameter>
    </group>
</parameters>
```


The computation time for a 20 min simulation is around 40 min on an i5 Laptop.

runTask **WF_Export_D3D_Santorini**
Workflow ID WF_Export_D3D_Santorini
Forecast time 2015-01-01 00:00
Exports the results to ~Export\Santorini\
Results are gridded water level time series and water level time series at specified locations. Wave arrival times are disabled for the moment.

Rotterdam levee breach

To run this simulation, we first need to generate water level time series at three model boundaries (Maassluis, Dordrecht and Krimpen a/d Lek). These time series must be defined for the simulation period, i.e. from start to end time of the SubGrid workflows. You can generate the model boundary time series in several ways:
By using the Excel file provided by Deltares. Export the time series to csv, put it in the import\Rotterdam\import directory and run 'Rott_import_waterlevel'
By using the python script provided by Deltares. Put the output of the script in the import\Rotterdam\import directory and run 'Rott_import_waterlevel'
By uploading the time series in PI XML format directly through the PIService. Use 'putTimeSeriesForFilter' with the time series data in PI XML format (see end of this memo for an example). Do the same for locations 'Krimpen a/d Lek' and 'Dordrecht'.

After setting these time series, run the following workflows. The example below is for a simulation of a single day: November 9, 2007.

NB The start and forecast time should be 00:00

runTask **Rott_run_subgrid**

Forecast time 2007-11-09 00:00
Start time 2007-11-09 00:00
End time 2007-11-10 00:00
Workflow ID Rott_run_subgrid

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This workflow runs the simulation without breaches. It takes about 15 minutes per day of simulation.

runTask **Rott_probability**

Forecast time	2007-11-09 00:00
Start time	2007-11-09 00:00
End time	2007-11-10 00:00
Workflow ID	Rott_probability

This workflow calculates breach probabilities from water levels (previous workflow) and fragility curves at 16 locations. It takes about 1 minute.

You can trigger a levee breach by modifying the fragility curve for one or more of the potential breach locations. Below is an example where the levee at location Maashaven is set to breach at a water level higher than 2 m. The fragility curve is defined at the end (<parameter id="frc">). You can edit this table at will and enter other probabilities, but the typical end-user will want to set a breach level. In the example below, the breach probability is set to zero for water level up to 2m and breach probability is 1 for water level 2.01m (or higher). Rerun the task Rott_probability with this Pi XML content and a description.

Description	my_test

Pi XML Content:

```
<parameters xmlns="http://www.wldelft.nl/fews/PI" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://www.wldelft.nl/fews/PI http://fews.wldelft.nl/schemas/version1.0/pi-
schemas/pi_modelparameters.xsd" version="1.5">
	<group id="0">
		<!-- general paramete r-->
		<locationId>frc_Maashaven</locationId>
		<parameter id="name_section">
			<description>Name of the fpl-section</description>
			<stringValue>frc_Maashaven</stringValue>
		</parameter>
		<!-- overflow parameter-->
		<parameter id="section_height">
			<description>Height of the fpl-section [mNN]</description>
			<dblValue>5.3</dblValue>
		</parameter>
		<parameter id="poleni_fac_overflow">
			<description>Poleni factor applied for overflow of the section [-]</description>
			<dblValue>0.65</dblValue>
		</parameter>
		<parameter id="section_width">
			<description>Width of the section applied for overflow [m]</description>
			<dblValue>600</dblValue>
			<!-- breach parameter-->
		</parameter>
		<parameter id="breach_type">
			<description>Type for breach development</description>
			<intValue>1</intValue>
		</parameter>
		<parameter id="break_prob">
			<description>Probability of failure when a breach starts</description>
			<dblValue>0.5</dblValue>
		</parameter>
		<parameter id="max_breach_width">
```


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```
                <description>Maximum breach width which can be reached [m]</description>
                <dblValue>100</dblValue>
            </parameter>
            <parameter id="breach_level">
                <description>The height of the breach sill [mNN]</description>
                <dblValue>3</dblValue>
            </parameter>
            <!-- breach development parameter-->
            <parameter id="poleni_factor_breach">
                <description>Poleni factor for breach flow of the section</description>
                <dblValue>0.65</dblValue>
            </parameter>
            <parameter id="growth_rate">
                <description>Growth rate of the breach [m/s] </description>
                <dblValue>0.005</dblValue>
            </parameter>
            <!-- hydraulic parameter-->
            <parameter id="name_gauge">
                <description>Name of the gauge</description>
                <stringValue>frc_Maashaven</stringValue>
            </parameter>
            <parameter id="gauge_height">
                <description>Height of the gauge [mNN]</description>
                <dblValue>0</dblValue>
            </parameter>
            <!--Total fragility curve astable-->
            <parameter id="frc">
                <table>
                    <columnIds A="waterlevel" B="probability"/>
                    <columnTypes A="double" B="double"/>
                    <row A="0" B="0"/>
                    <row A="2.0" B="0"/>
                    <row A="2.01" B="1"/>
                </table>
            </parameter>
        </group>
</parameters>
```

Check the result using getTimeSeries,

Parameter ID = Prob.total, Location ID = frc_Maashaven

runTask **Rott_run_subgrid_breach**

Forecast time	2007-11-09 00:00
Start time	2007-11-09 00:00
End time	2007-11-10 00:00
Workflow ID	Rott_run_subgrid_breach

This workflow runs the simulation with breaches. It takes about 15 minutes per day.

runTask **Rott_subGrid_export**

Forecast time	2007-11-09 00:00
Start time	2007-11-09 00:00

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End time 2007-11-10 00:00
Workflow ID Rott_run_subGrid
This workflow exports the results in NetCDF regular grid format to Export\Rotterdam\
Water depth and absolute flow velocities are exported. The export takes two minutes to complete.

Example of PI XML water level time series for Maassluis, 2007, Nov 9.


```xml
<TimeSeries xmlns="http://www.wldelft.nl/fews/PI" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://www.wldelft.nl/fews/PI http://fews.wldelft.nl/schemas/version1.0/pi-
schemas/pi_timeseries.xsd" version="1.9">
  <timeZone>0.0</timeZone>
  <series>
    <header>
      <type>instantaneous</type>
      <locationId>Maassluis</locationId>
      <parameterId>H.obs</parameterId>
      <timeStep unit="second" multiplier="600"/>
      <startDate date="2007-11-09" time="00:00:00"/>
      <endDate date="2007-11-10" time="00:00:00"/>
      <missVal>-999.0</missVal>
      <stationName>Maassluis</stationName>
      <lat>51.91750713023151</lat>
      <lon>4.2497886958255</lon>
      <x>76750.0</x>
      <y>437170.0</y>
      <z>NaN</z>
      <units>m</units>
    </header>
    <event date="2007-11-09" time="00:00:00" value="0.96" flag="0"/>
    <event date="2007-11-09" time="00:10:00" value="1.02" flag="0"/>
    <event date="2007-11-09" time="00:20:00" value="1.15" flag="0"/>
    <event date="2007-11-09" time="00:30:00" value="1.24" flag="0"/>
    <event date="2007-11-09" time="00:40:00" value="1.32" flag="0"/>
   …
    <event date="2007-11-09" time="23:30:00" value="0.6" flag="0"/>
    <event date="2007-11-09" time="23:40:00" value="0.57" flag="0"/>
    <event date="2007-11-09" time="23:50:00" value="0.57" flag="0"/>
    <event date="2007-11-10" time="00:00:00" value="0.56" flag="0"/>
  </series>
</TimeSeries>
```


Haiti hurricane

To run flood simulations for Gonaives, Haiti, the user first needs to define a hurricane track (lat, lon) and a maximum wind speed V_{max} as a function of time. These time series are passed to FEWS by using the putTimeSeries command. An example of PI-XML input is given below. Note that lat, lon are in degrees and V_{max} is in knots. The time series of the hurricane track should cover the simulation period (start and end time) of the subsequent workflows.

The model that generates a wind field needs three more variables: Method, P_{drop} and R_{max}. These are automatically set:
Method is an identifier for the method to use to generate the wind field. It is set to 4.
P_{drop} is the air pressure drop over the hurricane centre.
It is derived from V_{max} using Matsui et al (2011): $P_{drop} = 0.735\ V_{max} + 0.0126\ V_{max}{}^2$

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R_{max} is the radius of the hurricane wind field. It is fixed to 40 NM = 75 km.

After having defined the hurricane track, the following workflows should be run:

WF_WES_Haiti_Preprocess
gnvs_raintrack – takes about 30 sec to run per day of simulation
gnvs_wflow – takes a few minutes to run
Set WFLOW cold state by entering: "default", "wet" or "dry"

WF_WES_Haiti – takes about a minute to run
WF_D3D_Haiti – takes around 15 minutes per day of simulation

gnvs_run_subgrid – takes around 15 minutes per day of simulation
gnvs_subgrid_export – takes about a minute

The result (NetCDF waterdepth and flow velocity) are exported to ~Export\Gonaives\

Below is an example of PI-XML input to putTimeSeries for setting the storm track. Note that lat and lon must be between -180 and +180 deg.


```xml
<TimeSeries xmlns="http://www.wldelft.nl/fews/PI" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://www.wldelft.nl/fews/PI http://fews.wldelft.nl/schemas/version1.0/pi-
schemas/pi_timeseries.xsd" version="1.7">
   <timeZone>0.0</timeZone>
   <series>
      <header>
         <type>instantaneous</type>
         <locationId>Haiti_storm_track</locationId>
         <parameterId>lat</parameterId>
         <timeStep unit="nonequidistant"/>
         <startDate date="2015-01-01" time="00:00:00"/>
         <endDate date="2015-01-10" time="00:00:00"/>
         <missVal>-999.0</missVal>
         <units>degrees</units>
      </header>
      <event date="2015-01-01" time= "00:00:00 " value="15.9" flag="0"/>
      <event date="2015-01-01" time= "06:00:00 " value="16" flag="0"/>
      <event date="2015-01-01" time= "12:00:00 " value="16.2" flag="0"/>
      <event date="2015-01-01" time= "18:00:00 " value="16.3" flag="0"/>
      <event date="2015-01-02" time= "00:00:00 " value="16.4" flag="0"/>
      <event date="2015-01-02" time= "06:00:00 " value="16.7" flag="0"/>
      <event date="2015-01-02" time= "12:00:00 " value="17.1" flag="0"/>
      <event date="2015-01-02" time= "18:00:00 " value="17.2" flag="0"/>
         …
      <event date="2015-01-09" time= "06:00:00 " value="27.6" flag="0"/>
      <event date="2015-01-09" time= "12:00:00 " value="27.6" flag="0"/>
      <event date="2015-01-09" time= "18:00:00 " value="27.4" flag="0"/>
      <event date="2015-01-10" time= "00:00:00 " value="27.2" flag="0"/>
   </series>
   <series>
      <header>
         <type>instantaneous</type>
         <locationId>Haiti_storm_track</locationId>
         <parameterId>lon </parameterId>
```


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```xml
        <timeStep unit="nonequidistant"/>
        <startDate date="2015-01-01" time="00:00:00"/>
        <endDate date="2015-01-10" time="00:00:00"/>
        <missVal>-999.0</missVal>
        <units>degrees</units>
      </header>
      <event date="2015-01-01" time= "00:00:00 " value="-60" flag="0"/>
      <event date="2015-01-01" time= "06:00:00 " value="-60.7" flag="0"/>
      <event date="2015-01-01" time= "12:00:00 " value="-61.3" flag="0"/>
      <event date="2015-01-01" time= "18:00:00 " value="-61.5" flag="0"/>
      <event date="2015-01-02" time= "00:00:00 " value="-62.6" flag="0"/>
      <event date="2015-01-02" time= "06:00:00 " value="-63.5" flag="0"/>
        …
      <event date="2015-01-08" time= "00:00:00 " value="-72.1" flag="0"/>
      <event date="2015-01-08" time= "06:00:00 " value="-72" flag="0"/>
      <event date="2015-01-08" time= "12:00:00 " value="-71.7" flag="0"/>
      <event date="2015-01-08" time= "18:00:00 " value="-71.4" flag="0"/>
      <event date="2015-01-09" time= "00:00:00 " value="-70.8" flag="0"/>
      <event date="2015-01-09" time= "06:00:00 " value="-70.2" flag="0"/>
      <event date="2015-01-09" time= "12:00:00 " value="-69.5" flag="0"/>
      <event date="2015-01-09" time= "18:00:00 " value="-69.2" flag="0"/>
      <event date="2015-01-10" time= "00:00:00 " value="-68.9" flag="0"/>
    </series>
    <series>
      <header>
        <type>instantaneous</type>
        <locationId>Haiti_storm_track</locationId>
        <parameterId>Vmax</parameterId>
        <timeStep unit="nonequidistant"/>
        <startDate date="2015-01-01" time="00:00:00"/>
        <endDate date="2015-01-10" time="00:00:00"/>
        <missVal>-999.0</missVal>
        <units>knots</units>
      </header>
      <event date="2015-01-01" time= "00:00:00 " value="25" flag="0"/>
      <event date="2015-01-01" time= "06:00:00 " value="25" flag="0"/>
      <event date="2015-01-01" time= "12:00:00 " value="30" flag="0"/>
      <event date="2015-01-01" time= "18:00:00 " value="30" flag="0"/>
      <event date="2015-01-02" time= "00:00:00 " value="35" flag="0"/>
      <event date="2015-01-02" time= "06:00:00 " value="50" flag="0"/>
      <event date="2015-01-02" time= "12:00:00 " value="55" flag="0"/>
      <event date="2015-01-02" time= "18:00:00 " value="55" flag="0"/>
      <event date="2015-01-03" time= "00:00:00 " value="60" flag="0"/>
      <event date="2015-01-03" time= "06:00:00 " value="60" flag="0"/>
      <event date="2015-01-03" time= "12:00:00 " value="60" flag="0"/>
        …
      <event date="2015-01-09" time= "18:00:00 " value="75" flag="0"/>
      <event date="2015-01-10" time= "00:00:00 " value="80" flag="0"/>
    </series>
</TimeSeries>
```


Po-Secchia flooding

To run flood simulations for the Po flooding test area in Italy, the user needs to define the upstream discharge boundary and the probability of breaching at a number of levees along the south bank of the Po.

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The discharge time series is passed to FEWS by using the putTimeSeries command. An example of this PI-XML input is given below.

```
<?xml version="1.0" encoding="UTF-8"?>
<TimeSeries xmlns="http://www.wldelft.nl/fews/PI" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://www.wldelft.nl/fews/PI http://fews.wldelft.nl/schemas/version1.0/pi-
schemas/pi_timeseries.xsd" version="1.14">
  <timeZone>0.0</timeZone>
  <series>
    <header>
      <type>instantaneous</type>
      <locationId>Po main</locationId>
      <parameterId>Q.obs</parameterId>
      <timeStep unit="second" multiplier="3600"/>
      <startDate date="2000-10-17" time="00:00:00"/>
      <endDate date="2000-10-31" time="23:00:00"/>
      <missVal>NaN</missVal>
      <stationName>Po main</stationName>
      <lat>45.04414853885275</lat>
      <lon>10.7515139340957</lon>
      <x>637940.0</x>
      <y>4989347.0</y>
      <z>NaN</z>
      <units>m3/s</units>
    </header>
    <event date="2000-10-17" time="00:00:00" value="2409.97" flag="0"/>
    <event date="2000-10-17" time="01:00:00" value="3000.0" flag="0"/>
    <event date="2000-10-17" time="02:00:00" value="4000.0" flag="0"/>
    <event date="2000-10-17" time="03:00:00" value="4500.0" flag="0"/>
    <event date="2000-10-17" time="04:00:00" value="5000.0" flag="0"/>
    <event date="2000-10-17" time="05:00:00" value="5500.0" flag="0"/>
    <event date="2000-10-17" time="06:00:00" value="6000.0" flag="0"/>
    <event date="2000-10-17" time="07:00:00" value="6500.0" flag="0"/>
      ...
    <event date="2000-10-31" time="22:00:00" value="2565.17" flag="0"/>
    <event date="2000-10-31" time="23:00:00" value="2559.79" flag="0"/>
  </series>
</TimeSeries>
```

Next, the following workflows need to be run. The start and end times should be 00:00 and the input time series should be defined between start and end time.

Po_run_subgrid
This workflow runs the simulation without breaches. It takes about 15 minutes per day of simulation.
Po_probability
This workflow calculates breach probabilities from water levels (previous workflow) and fragility curves at predefined locations. It takes about 1 minute.
Po_run_subgrid_breach
This workflow runs the simulation with breaches. It takes about 15 minutes per day of simulation.
Po_subGrid_export
Exports the water level and velocity time series to NetCDF.
As for the Rotterdam model, the breaches in the Po model need to be invoked by the user by adding XML content to the workflow Po_run_subgrid_breach. Below is an example where the levee at location

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Quingentole is set to breach between water levels 21.5 m. The fragility curve is defined at the end (<parameter id="frc">). Note that a description of the content (can be anything) is mandatory.

Description my_test
Pi XML Content:


```
<?xml version="1.0" encoding="utf-8"?>
<!-- edited with XMLSpy v2014 rel. 2 sp1 (http://www.altova.com) by Afdeling ICT (Stichting Deltares) -->
<parameters xmlns="http://www.wldelft.nl/fews/PI" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://www.wldelft.nl/fews/PI http://fews.wldelft.nl/schemas/version1.0/pi-
schemas/pi_modelparameters.xsd" version="1.5">
	<group id="1">
		<!-- general paramete r-->
		<locationId>frc_Quingentole</locationId>
		<parameter id="name_section">
			<description>Name of the fpl-section</description>
			<stringValue>frc_Quingentole</stringValue>
		</parameter>
		<!-- overflow parameter-->
		<parameter id="section_height">
			<description>Height of the fpl-section [mNN]</description>
			<dblValue>22.5</dblValue>
		</parameter>
		<parameter id="poleni_fac_overflow">
			<description>Poleni factor applied for overflow of the section [-]</description>
			<dblValue>0.65</dblValue>
		</parameter>
		<parameter id="section_width">
			<description>Width of the section applied for overflow [m]</description>
			<dblValue>1200</dblValue>
		</parameter>
		<parameter id="breach_type">
			<description>Breach growth model: 0:=inst,1:=linear,2:=Verheijh </description>
			<intValue>1</intValue>
		</parameter>
		<parameter id="break_prob">
			<description>Probability when failure occurs [-]</description>
			<dblValue>0.5</dblValue>
		</parameter>
		<parameter id="max_breach_width">
			<description>Maximum breach width [m]</description>
			<dblValue>100</dblValue>
		</parameter>
		<parameter id="breach_level">
			<description>The height of the breach sill [mNN]</description>
			<dblValue>16.5</dblValue>
		</parameter>
		<!-- breach development parameter-->
		<parameter id="poleni_factor_breach">
			<description>Poleni factor </description>
			<dblValue>0.65</dblValue>
		</parameter>
		<parameter id="growth_rate">
			<description>Growth rate of the breach</description>
			<dblValue>0.005</dblValue>
		</parameter>
		<!-- hydraulic parameter-->
```


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```
		<parameter id="name_gauge">
			<description>Name of the gauge</description>
			<stringValue>frc_Quingentole</stringValue>
		</parameter>
		<parameter id="gauge_height">
			<description>Height of the gauge</description>
			<dblValue>0</dblValue>
		</parameter>
		<!--Total fragility curve astable-->
		<parameter id="frc">
			<table>
				<columnIds A="waterlevel" B="probability"/>
				<columnTypes A="double" B="double"/>
				<row A="0" B="0"/>
				<row A="18.5" B="0.01"/>
				<row A="19" B="0.02"/>
				<row A="21.5" B="0.5"/>
				<row A="22.5" B="1.0"/>
			</table>
		</parameter>
	</group>
</parameters>
```


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