

multi-Risk sciEnce for resilienT commUnities undeR a changiNgclimate

Codice progetto MUR: **PE00000005 D43C22003030002**



Deliverable title: Comprehensive modelling of complex river systems and floodable areas, including sediment transport, vegetation dynamics, levee breaches, river training work, hydraulic infrastructures

Deliverable ID: 1.2.6

Due date: 01.06:2024

Submission date: 01.06.2024

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1. Technical references

Project Acronym	RETURN
Project Title	multi-Risk sciEnce for resilientT commUnities undeR a changiNg climate
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Project Duration	December 2022 – November 2025 (36 months)

Deliverable No.	DV#.1.2.6#
Dissemination level*	
Work Package	WP1.2 - Flood risk under environmental and climatic changes
Task	T1.2 Hazard Model
Lead beneficiary	Partner short name POLITO
Contributing beneficiary/ies	Partner short name, Partner short name, Partner short name, etc.POLITO, UNIPD, CIMA, UNIKORE

* PU = Public

PP = Restricted to other programme participants (including the Commission Services)

RE = Restricted to a group specified by the consortium (including the Commission Services)

CO = Confidential, only for members of the consortium (including the Commission Services)

Document history

Version	Date	Lead contributor	Description
0.1	24.05.2024	Carlo Camporeale POLITO	First draft
0.2	26.05.2024	Lorenzo Alfieri (CIMA)	Critical review and proofreading
0.3	28.05.2024	Marco Borga (UNIPD)	Edits for approval
1.0	31.05.2024	Francesco Ballio (POLIMI)	Final version

2. ABSTRACT

Accurate flood mapping is crucial for enhancing community resilience in the face of flooding. Among the several factors that affect the flood extent, the effect of vegetation dynamics, sediment transport, levee breaches and hydraulic infrastructures is not clearly recognized so far. These factors play an important role in shaping the patterns and magnitudes of water flow and sediment transport in riverine environments, that consequently affect flood extent.

This Deliverable reports on four different contributions from RETURN – SPOKE WATER on this topic, as follows:

- Dynamic modelling of river hydraulics in systems with infrastructures, vegetation, solid transport, Politecnico of Torino;
- Flood forecasting in the terminal stretch of the Po River considering the dynamic estimation of flow resistance, University of Padova;
- Appraising and reducing riverine flood risk: a case study from Central Italy, CIMA;
- Treatment and propagation of uncertainty in flood prediction in urban areas, Kore University Enna

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4. Comprehensive modelling of complex river systems and floodable areas, including sediment transport, vegetation dynamics, levee breaches, river training work, hydraulic infrastructures

4.1 Dynamic modelling of river hydraulics in systems with infrastructures, vegetation, solid transport, Politecnico of Torino

The interaction of river dynamics with bridges and other water infrastructures is extremely important for both the structural stability of the infrastructure and their impact on the surrounding environment (e.g., backwater profile; flood wave due to structure collapse, etc). In this context, two research topics have been carried out at Politecnico of Torino:

1. Simplified hydraulic risk analysis of bridges;
2. Monitoring and modelling bridge scour.

Simplified hydraulic risk analysis of bridges

A recent regulation of the Italian Ministry of Infrastructure and Transport requires a safety evaluation of all existing bridges, including hydraulics aspects. With this Task, we have investigated how simplified hydraulic risk analysis of bridges can be conducted according to Ministry guidelines, and we performed this evaluation at several bridge-river intersections in the Po River basin (Italy). Due to the great variety of bridge geometries and river conditions, different hydrologic-hydraulic simplified approaches may be requested. A particular focus was on the opportunity to use nation-wide hydrological datasets to obtain standardized, although simplified, flood estimates in small river basins.

The research group was also involved in the hydro-geomorphological characterization of the Trebbia River (PC) in support of a preliminary analysis for the removal of an obsolete river barrier. The study involved measurement campaigns conducted using drone flights and 1D unsteady morphodynamic modeling for assessing the characteristic times of erosion and deposition following the removal of the San Salvatore dam. This activity is a synergy with the project “Open Rivers” for the restoration of fluvial connectivity.

Monitoring and modelling bridge scour: a combined approach involving hydrologic, hydraulic and geophysical methods.

The Task includes two projects:

Project 1: Scour is known to be one, if not the most relevant cause for bridge collapse and damage during floods. Current hydraulic design and assessment techniques are based on empirical methods that are based mainly on laboratory data, whose representativeness of field conditions is however debatable due to well known difficulties in achieving full similarity. Field data would complement and fine-tune laboratory-based empirical models, but they are extremely difficult to gather as they require the installation of delicate and often expensive equipment in bridge piers and abutment, which, when a flood comes, are exposed to high risk of damage associated with the violent flow of water and the impact of floating debris. Post flood surveys are often meaningless because most of the times, scour holes are refilled with sediment which hides erosion features and do not allow for a thorough assessment of the scour severity.

In this project we aim at overcoming these difficulties by taking a different approach. We intend to identify, further develop and test geophysical methods for shallow underground exploration to capture after-flood scour signatures around bridge foundations. Hydrologic and hydraulic modelling will be then used to associate the gathered scour features with specific hydraulic conditions. This will serve to calibrate/develop scour modelling formulae for the online and offline assessment of the hydraulic vulnerability of bridges.

To fulfil this goal, research activities will involve the following steps (i) identifying the most suitable geophysical method for shallow underground detection of scour features; (ii) exploring the performance of the chosen technique by means of numerical simulations; (iii) testing the chosen techniques in large scale laboratory settings where scour holes will be naturally developed around bridge pier models; (iv) testing of the chosen methodology to field conditions; (v) interpretation of field measurements by means of hydrological and hydraulic modelling.

Project 1: Results from research activities have not been published yet, however electrical resistivity profiling has been identified as the most promising technique (part i) and tested by means of 2-D numerical simulations (part ii). The flume that will be used for large scale laboratory tests for both Project 1 and 2 is currently being designed by means of CFD with particular emphasis on the inlet to allow for well controlled flow development. Depending on the results from CFD simulations and a cost-benefit analysis, the flume test section will be about 10-15m long, 1.5-2.0 m wide and 1 m deep. This size will allow to host large scale laboratory experiments where bridge pier and abutment models will be nicely replicated.

Project 2: In parallel to this, the project will also delve deeper into the issue of scour worsening caused by debris accumulation with a view to improve methods to quantify bridge vulnerability to flood events. The Research plan is to carry out a series of laboratory experiments to gather an extensive data set of hydrodynamic and erosion features using bridge pier and debris accumulation models covering a wide range of relevant size and geometries. Results from the experiments will be used to improve a method developed at PoliTO that combines turbulence theory with sediment transport theory to predict scour depths.

4.2 Flood forecasting in the terminal stretch of the Po River considering the dynamic estimation of flow resistance, University of Padova

The aim of the Task is performing advanced real-time flood forecasting in the terminal stretch of the Po River including the possible flooding of the adjacent, low-lying areas. The case study is of particular interest from both the scientific and applicative point of view: i) flood-prone areas are very large and below the sea level, entailing disastrous scenarios in case of flooding events (as for example in the catastrophic flood of 1951); ii) flood prediction is difficult because, as highlighted by the last severe flood events, a significant reduction of flow resistance occurs for the highest flow regimes, which causes classical hydrodynamic models to overestimate the peak water level by over 1.5 m; iii) in case of levee failures, predicting how the flooding extent proceeds in time with a lead time of some days is fundamental to undertake prompt actions of civil protection.

The novel aspects of the study include:

- 1) the use of an efficient two-dimensional Finite Element model, which solves the full Shallow Water Equations, to perform real-time flood forecasting;
- 2) the dynamic estimation of the flow resistance caused by hydro-morphodynamic processes;
- 3) the possibility of simulating possible levee failures, either at user-defined locations or triggered by overflowing, so as to track the ensuing flooding of external adjacent areas in real-time.

In this framework, we setup a numerical model of the terminal stretch of the Po River, from Borgoforte to the Adriatic Sea (~180 km). An accurate calibration against flowrate and level data recorded in the two last severe flood events (2002 and 2014) confirmed the reduction of flow resistance (i.e., increased conveyance) occurring for flow discharges larger than 6.000 m³/s, which becomes more evident while getting closer to the Po delta.

We then analyzed the hydro-morphodynamic processes that may cause this conveyance shift. The analysis suggested that this is not determined by the increase of wet section resulting from bed erosion. Indeed, a characterization of the sediment transport excluded the chance of a transient and generalized scour occurring only at the peak of major floods and promptly refilled during their receding phase. Rather, by accounting for the change of bedforms with the flattening of river dunes during discharge extremes, the model produced a realistic reduction in flow resistance.

The next steps concern the improvement of the dynamic estimation of the flow resistance ascribed to changes in bedforms and the implementation of a comprehensive model including both the Po River and the flood-prone external areas, to be used as the core of the real-time flood forecasting system.

4.3 Appraising and reducing riverine flood risk: a case study from Central Italy, CIMA

On 15 September 2022 a catastrophic flood event hit the Misa, Esino and Cesano river basins in Central Italy. The town of Senigallia on the Adriatic coast was heavily affected as were smaller communities upstream. With high rainfall intensities and steep slopes in the upper catchments, this flood event led to more than ten casualties, transported large amounts of debris, caused widespread erosion, landslides, and destroyed infrastructures. The most affected areas were within the Marche region of Italy in the provinces of Ancona and Pesaro e Urbino, while a small area within the region of Umbria in the province of Perugia was also affected.

The magnitude of the event (intensity of precipitation, river discharge, debris and sediment transport) and the subsequent impacts were far more severe and extended than previous flood events in the same area, thus calling for a radical change in current practices of flood risk management.

In this Task, we carried out a comprehensive study which aims at 1) providing a comprehensive assessment of flood risk for the Misa river basin, and 2) evaluating and designing appropriate risk reduction measures at river basin scale.

With this aim, we reconstructed the September 2022 event by integrating in-field surveys, hydrological data, hydraulic models, observations of the event (e.g. flood extent maps) and historical data of past flood events, taking into account the incompleteness and uncertainty of both models and observations, including detailed reconstructions of some bridges along the river network and their effect on the inundation patterns. The outcomes of these activities were used to explore different alternatives for flood risk reduction, in agreement with local authorities and stakeholders. We evaluated a range of structural measures (strengthening of dike systems, detention areas, river diversions) and non-structural measures (land-use planning, relocation, flood-proofing measures), considering existing risk management plans and proposing additional solutions for risk reduction (Mennino et al., 2024).

4.4 Treatment and propagation of uncertainty in flood prediction in urban areas, Kore University Enna

The activity aims to perform a comprehensive uncertainty analysis of the factors influencing the magnitude, frequency, and expected damage of urban flooding.

When dealing with urban areas and urban drainage systems (considering the ordinary underground drainage system, the street system on the surface, and the set of protection channels and underground facilities to cope with urban flooding), a large number of uncertainties have usually to be handled regarding urban rainfall, initial

and subsequent conditions of the urban catchment, and the geometry, capacity, and hydraulic functionality of the drainage system.

Uncertainty related to urban hydrologic parameters and catchment initial status is the most discussed in the literature, and it is often handled with common formal and non-formal methods based on model parameter variation. Investigations about rainfall, urban drainage functionality, and damage estimation are less present in the literature, mainly due to the lack of data. This kind of integration is the outcome of the activity trying to compare different sources of uncertainty with the final aim to guide future monitoring and data collection.

The basis for the present analysis was given by a case of use: Palermo City Centre Catchment (Italy).

The “Centro Storico” of Palermo (Italy) is the oldest part of the city, strongly urbanised and with a very old drainage system, which receives both storm and wastewater also from upstream less urbanized watersheds; local surface flooding due to the system insufficiency often occurs even for high-frequency rainfalls. The case study was continuously kept under monitoring since the nineties, and a large amount of data is available concerning rainfall temporal and spatial resolution, hydraulic functionality and characteristics of the urban drainage system flooding damage data.

The “Centro Storico” catchment is about 2.5 km², with about 88% of impervious areas, mainly roofs and roads. The whole catchment has been divided into 262 subcatchments, and the model runs under the hypothesis that each subcatchment is connected to a single inlet manhole. Simulations have been carried out using 12 historical rainfall events (recorded since 1993 at the Palermo-Parco d’Orléans rain gage located in the analysed area and in other locations inside the city slightly outside of the analysed catchment) during which network surcharge and local flooding have been observed.

The implementation of a Bayesian statistical approach helps in the evaluation of statistically valid confidence and prediction intervals that can then be considered to represent the uncertainty in the parameters, individual model structure and input data. Namely, all Bayesian techniques start from prior knowledge regarding the modelling and input data error and parameter distribution thus updating them according to available data by means of Bayes’ theorem application. Additionally, this approach allows for separating different sources of uncertainty and to evaluate the impact of additional data once they are collected in order to obtain a robust analysis tool.

The novel aspects of the study include:

- 1) the integration of several uncertainty sources in a single comprehensive framework in urban areas;
- 2) the use of formal and robust approaches that can be updatable once new data is received;