European Geosciences Union General Assembly 2015
Vienna, Austria, 12-17 April 2015
Session NH1.6:Flood risk and uncertainty, Vol. 17, EGU2015-9148-1

Assessing and optimising flood control options along the Arachthos river floodplain (Epirus, Greece)

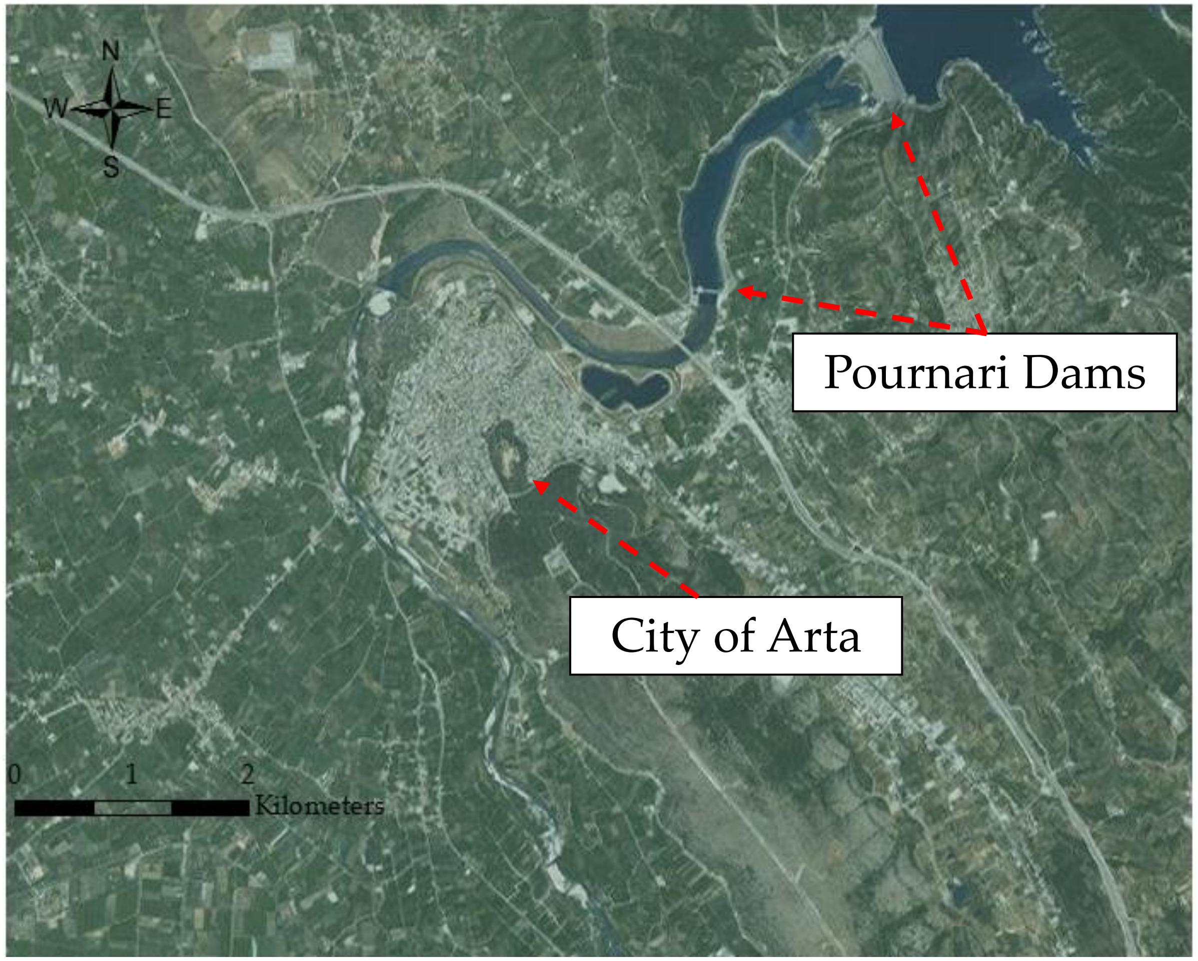
Athina Drosou, Panayiotis Dimitriadis, Archontia Lykou, Panagiotis Kossieris, Ioannis Tsoukalas, Andreas Efstratiadis and Nikos Mamassis

National Technical University of Athens, School of Civil Engineering, Department of Water Resources and Environmental Engineering, Heroon Polytechneiou 5, GR-157 80, Zographou, Greece

1. Abstract

We present a multi-criteria **simulation-optimization framework** for the **optimal design and setting of flood protection structures** along river banks. The methodology is tested in the lower course of the Arachthos River (Epirus, Greece), downstream of the hydroelectric dam of Pournari. The entire study area is very sensitive, particularly because the river crosses the urban area of Arta, which is located just after the dam. Moreover, extended agricultural areas that are crucial for the local economy are prone to floods. In the proposed methodology we investigate two conflicting criteria, i.e. the **minimization of flood hazards** (due to damages to urban infrastructures, crops, etc.) and the **minimization of construction costs** of the essential hydraulic structures (e.g. dikes). For the hydraulic simulation we examine two flood routing models, named **1D HEC-RAS** and **quasi-2D LISFLOOD**, whereas the optimization is carried out through the **Surrogate-Enhanced Evolutionary Annealing-Simplex** (SEEAS) algorithm that couples the strengths of surrogate modeling with the effectiveness and efficiency of the EAS method.

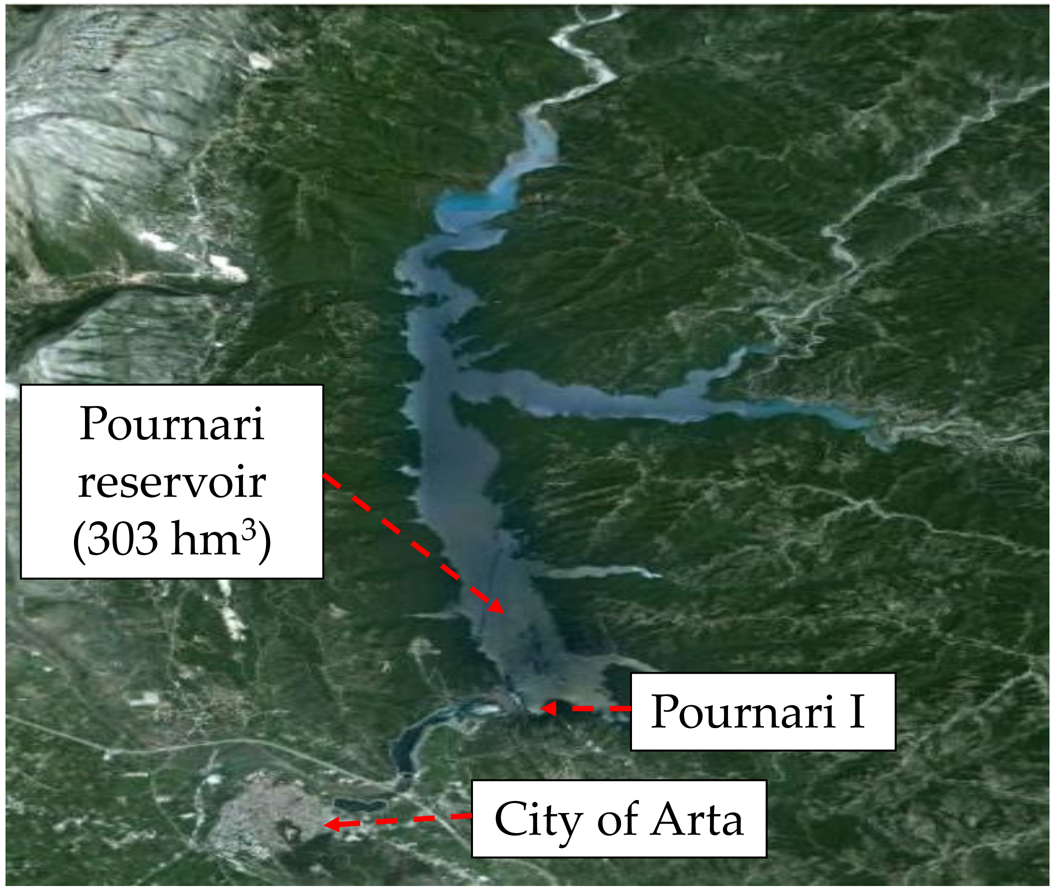
2. Problem statement

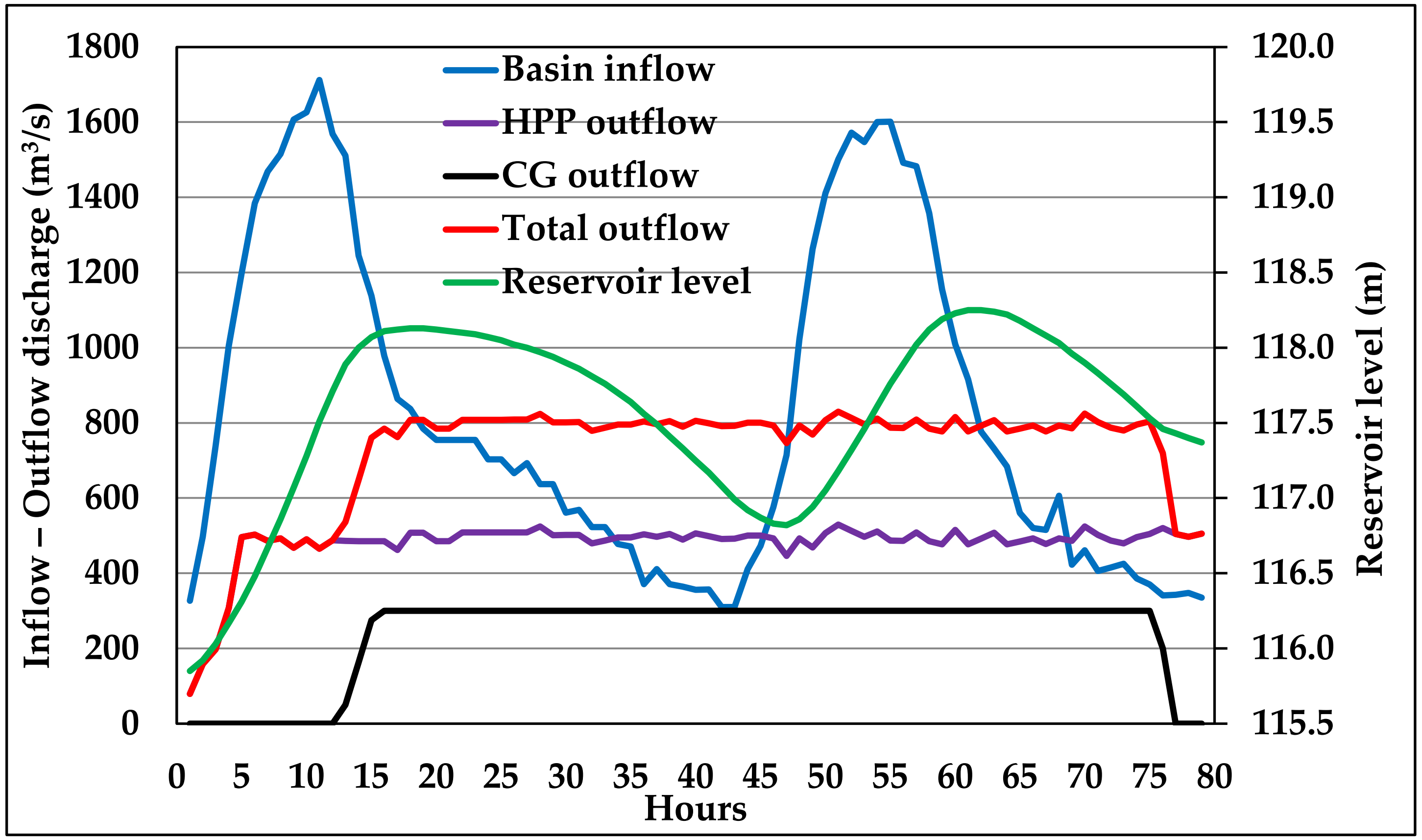


- The area of interest is the lower course of river Arachthos (Epirus, Western Greece), particularly the first 11 km downstream of the hydroelectric dam of Pournari.
- The upstream basin extends over 1794 km^2 and its mean annual flow exceeds 300 m^3/s.
- The river crosses the city of Arta that is prone to significant flood risk, since it is located just downstream of the dam.
- During the flood event of 28 to 31/12/2005, the total water release through the penstoke and the spillway was up to 800 m^3/s and caused major damages in the study area.
- Our objective is to evaluate two well-known hydraulic simulation models, i.e. HEC-RAS and quasi-2D LISFLOOD, under steady-state flow conditions (for Q = 640, 800, 1710 and 2200 m^3/s) against two key characteristics of floods, namely the spatial distribution of water depths and the extent of inundated areas.
- In order to improve the resilience of the urban area we couple the most suitable of the above modelling approaches with robust optimization techniques for ensuring an optimal placement of the essential flood protection structures (embankments).

3. The flood event of 28-31/12/05

- During the first storm event (maximum basin inflow, 1600 m^3/s), the operators (Greek PPC) released in total 800 m^3/s to prevent a possible exceedance of the maximum reservoir level (120 m) facing the upcoming second peak.
- We generate several management scenarios, in terms of total water release, by varying the lag between the time of advent of the first peak and the initialization of the control gates (CG).

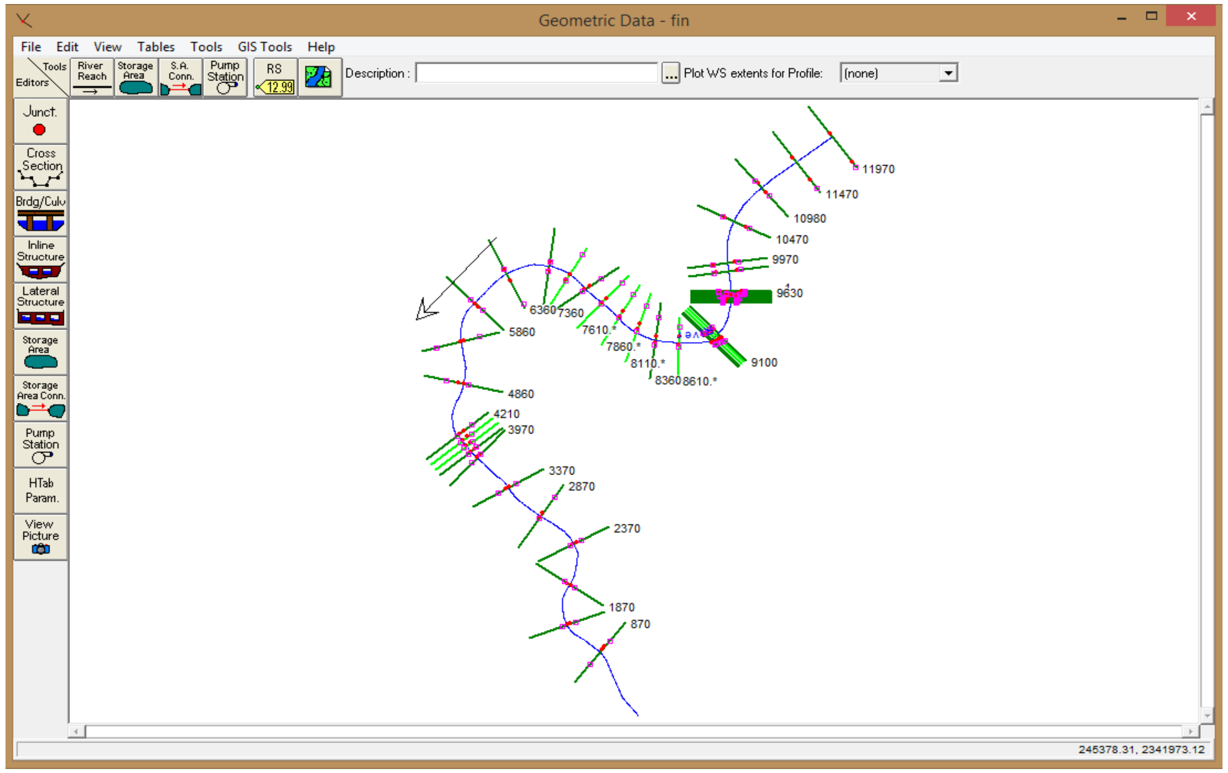




Reservoir Pournari I

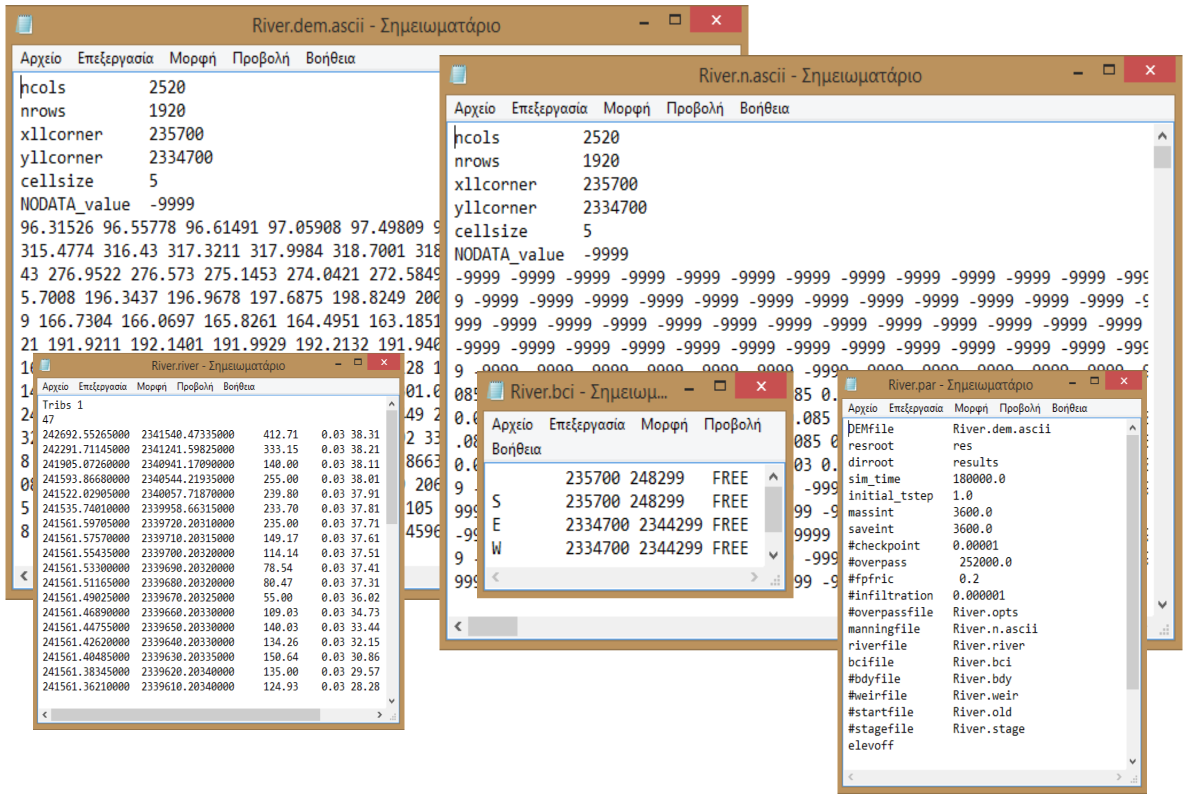
- **Flood control system**
  - 3 arched CG (12.5 x 13.5 m)
  - Maximum discharge: 5800 m^3/s
- **Hydropower plant (HPP)**
  - 3 Francis Turbines (3 x 100 MW)
  - Maximum Discharge: 500 m^3/s
  - Mean tailwater level: 68 m
  - Annually mean energy: 280 GWh

4. The hydraulic models

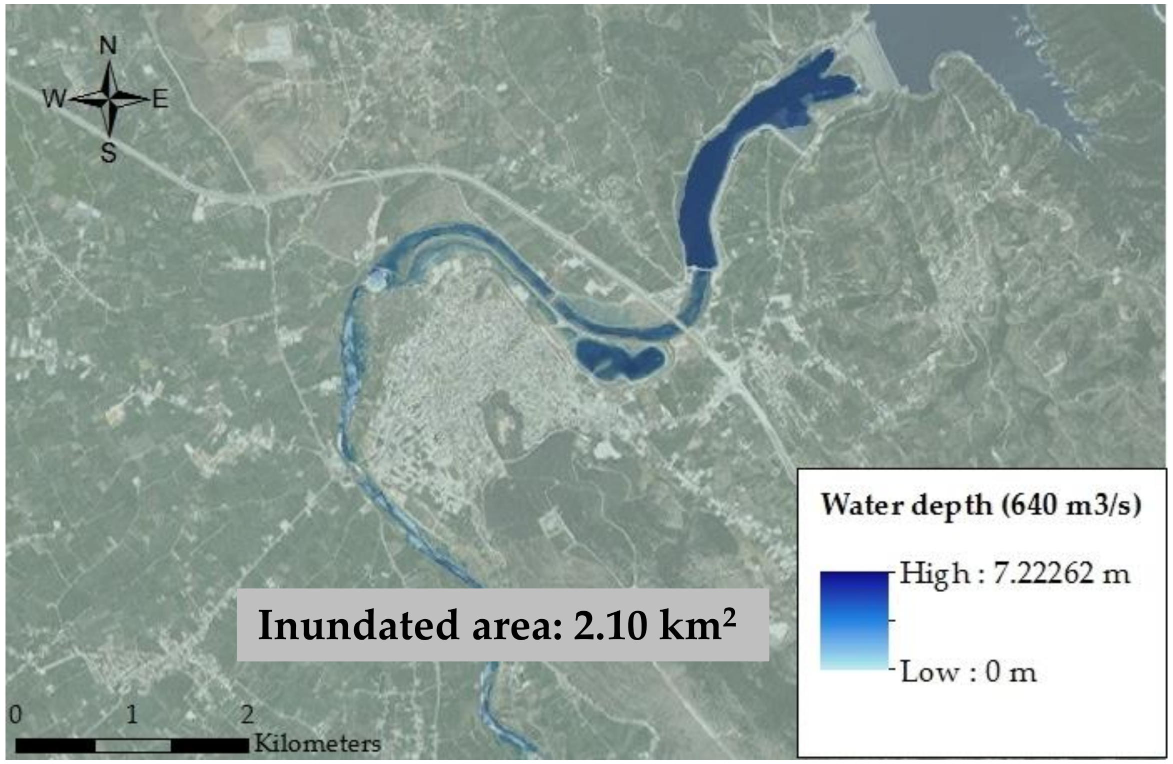


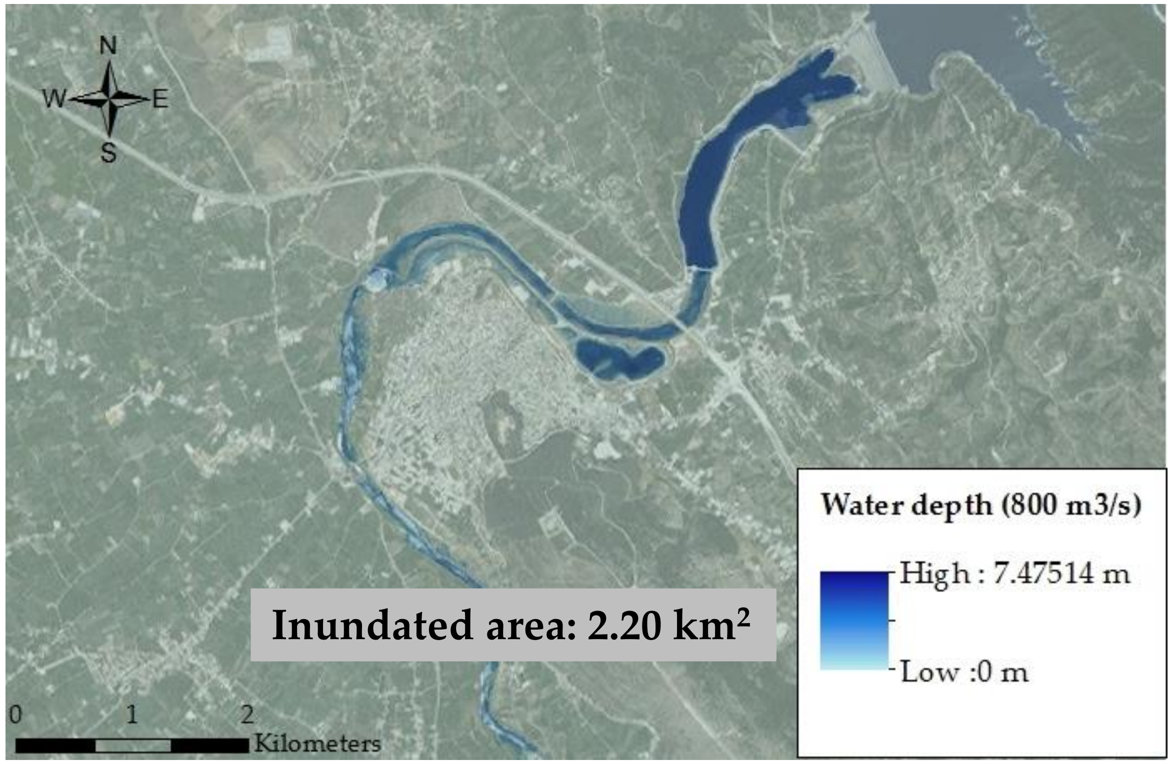
HEC-RAS is a freeware 1D hydraulic model for the simulation of flow characteristics, assuming either steady and/or non-steady flow conditions (Bruner, 2010). The model solves the dynamic wave equation in one dimension and in each cross section using an implicit finite difference method. The required initial data are the geometry of the cross section, the Manning coefficient along the cross section, the inflow discharge and hydraulic boundary conditions.

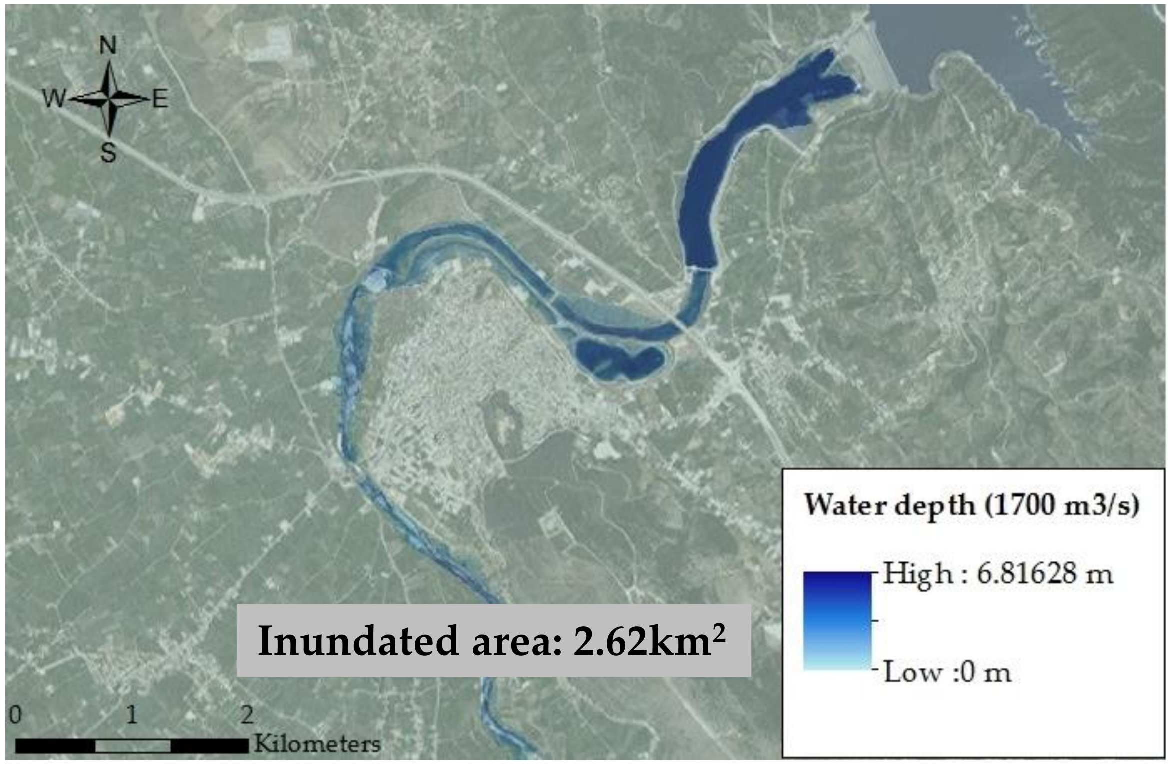
LISFLOOD-FP is a freeware quasi-2D hydraulic model, which estimates only the flow depth across the grid elements, under steady and non-steady flow conditions. It uses the Manning equation along the river and the 1D kinematic wave equation for lateral flow expansion. The required initial data are a DEM, the river location and its mean depth and width (the model assumes a rectangular cross section), the inflow discharge and some simple hydraulic boundary conditions (Bates et al., 2005).

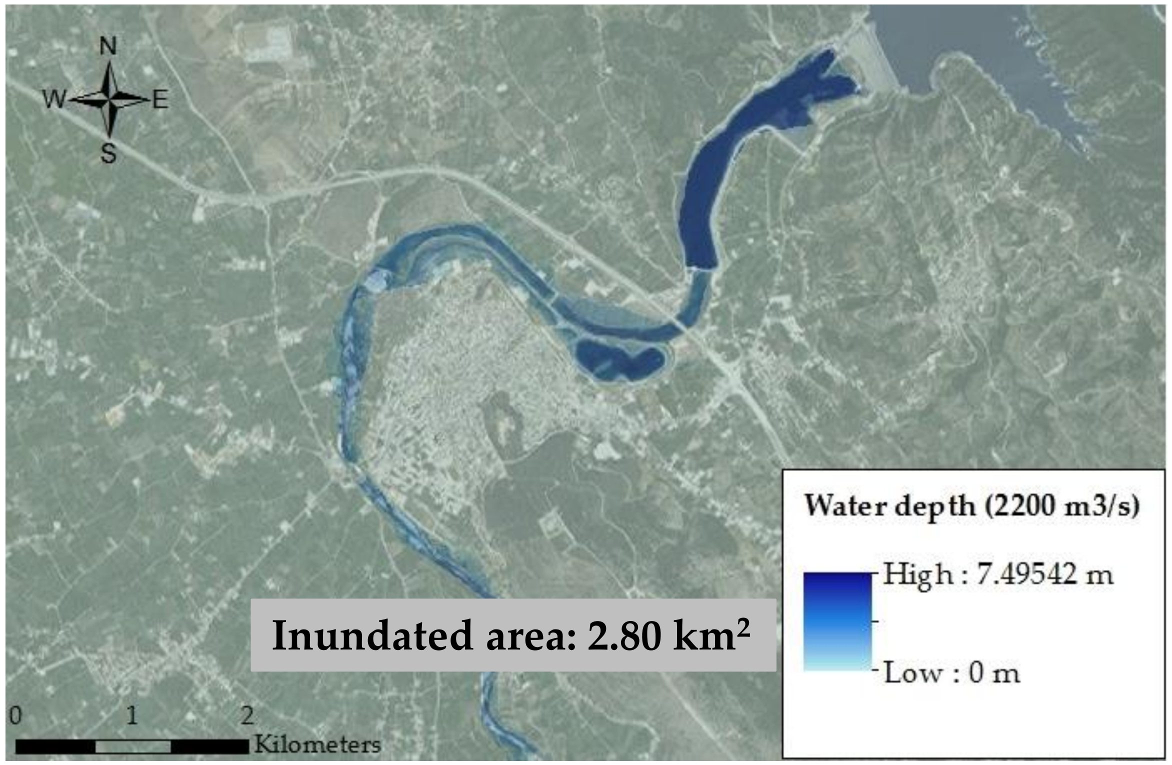


5. Simulation results – HEC-RAS model

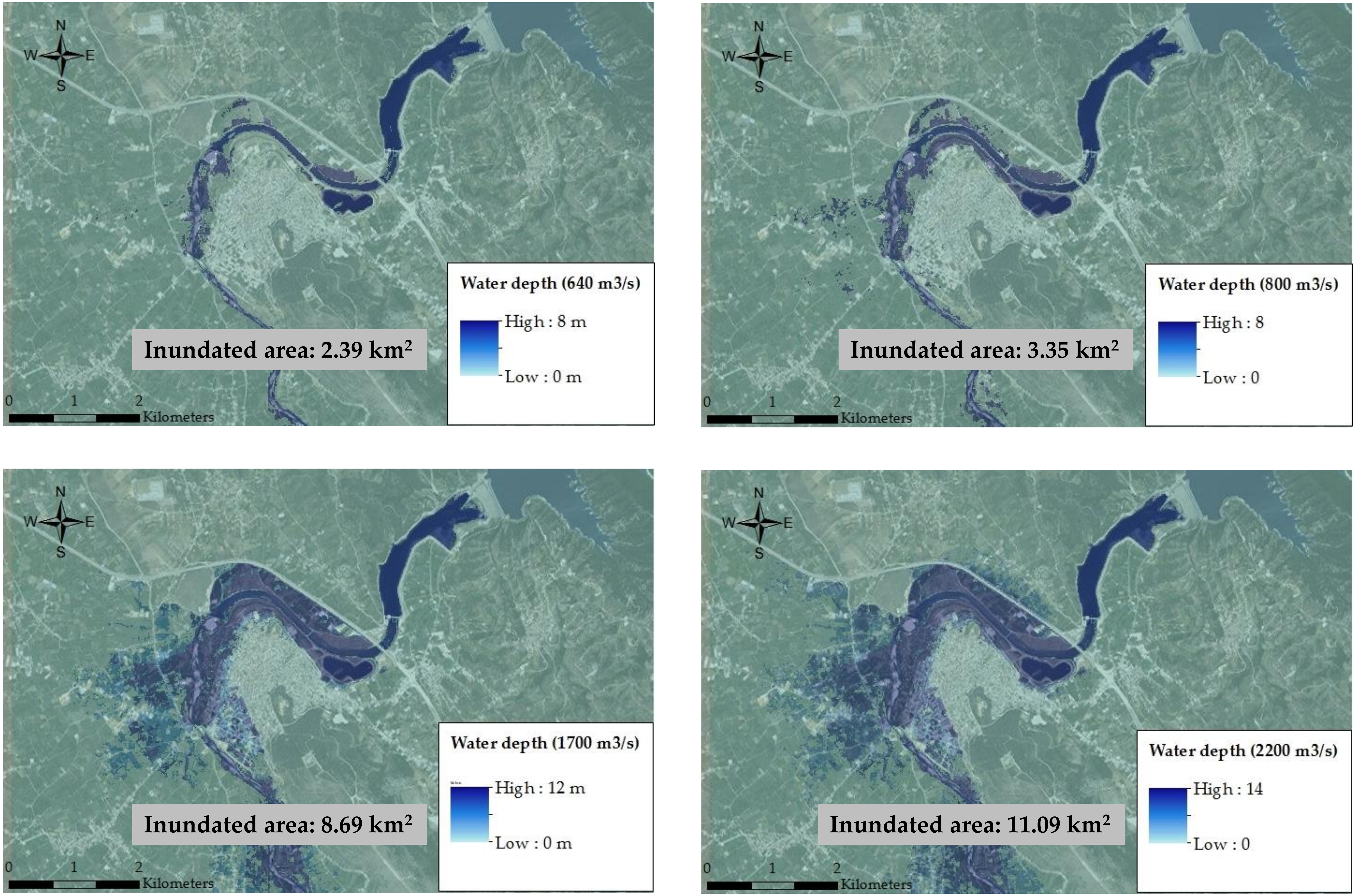








6. Simulation results – LISFLOOD model



7. A coupled simulation-optimization approach for optimal placement of embankments

- Considering embankments of constant length and width, and of infinite height, we seek their optimal placement along the river banks that minimizes the area of flood inundation (the embankment can be placed in different locations, thus resulting to numerous feasible solutions by means of all possible combinations of left and right locations, x_L and x_R, respectively).
- The coupled scheme comprises:
  - The LISFLOOD model for the estimation of the inundated area, for a given setting of the embankments (a time-consuming simulation);
  - The Surrogate-Enhanced Evolutionary Simplex-Annealing method (Tsoukalas et al., 2015) for the optimization of the placement of the embankments.
- The optimization problem is formulated as follows:
  - Two control variables, x_L and x_R.
  - The objective function to be minimized, is the total flood inundated areas.
  - Considering the constraint to prevent as much as possible the flood inundation to reach the city of Arta (by applying a penalty factor in the objective function).
  - The computational budget is set equal to 100 model evaluations.

8. The Surrogate-Enhanced EAS method

- Surrogate-Enhanced Evolutionary Simplex-Annealing approach (SEEAS) is a novel global optimization algorithm for **time-expensive** functions.
- The algorithm incorporates Surrogate Modelling (SM) techniques to build, maintain and exploit approximations of real response surfaces, aiming to **support transitions** and **accelerate search** towards favorable areas of the response surface.
- The role of SM in searching procedure is twofold:
  - Providing new promising points that are directly embedded in the current population (similarly to SBO);
  - Assisting specific transitions of the **simplex-based** evolutionary operator of EAS.
- Balance between **exploration** (i.e., detailed sampling) and **exploitation** (i.e., blind use of predictions) is achieved through a **dynamically adjusted weighted prediction-distance metric**, termed **acquisition function** (AF).

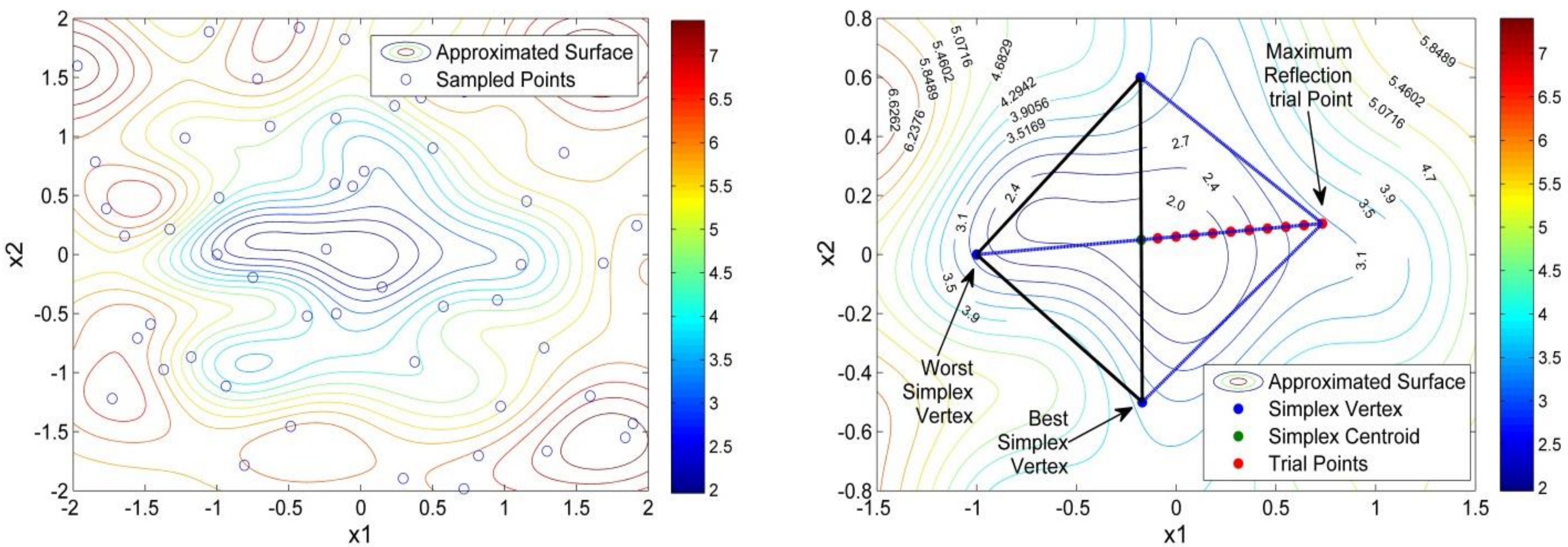


***Figure* 1**: Demonstration of a randomly selected simplex and the modified surrogate-enhanced reflection movement using candidate points on the line formed from the simplex centroid and the maximum reflection point; the simplex is reflected at the candidate point with the minimum function value.

9. Application of the scheme in a toy-model

- The proposed schema was initially tested in a toy model: a 200 x 13 grid (each cell having dimensions 50 m X 50 m), with a 2% longitudinal slope and a lateral slope ranging from 0 to 90°.
- From the northern point of the river we apply a steady discharge of 1000 m^3/s.
- We are seeking the optimum placement of two rectangular embankments (one for each river bank) with a fixed length of 1 km, so that the resulting flood inundation is minimized.
- For simplicity reasons, the embankments are considered to have infinite height.
- In total, there are 180 X 180 possible scenarios (180 positions for each embankment) .

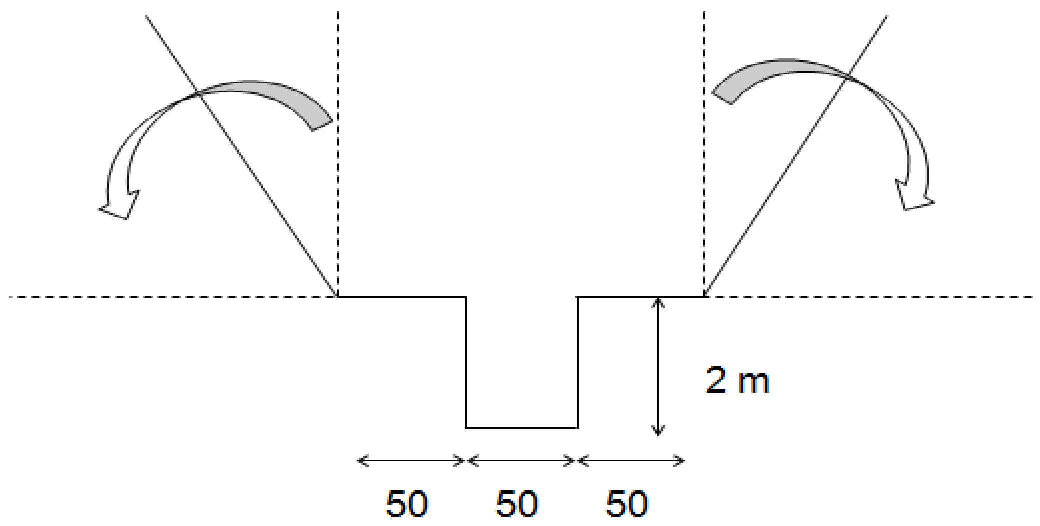


***Figure* 2:** Typical cross section geometry of toy model's river with river's depth 2 m and width 50 m.

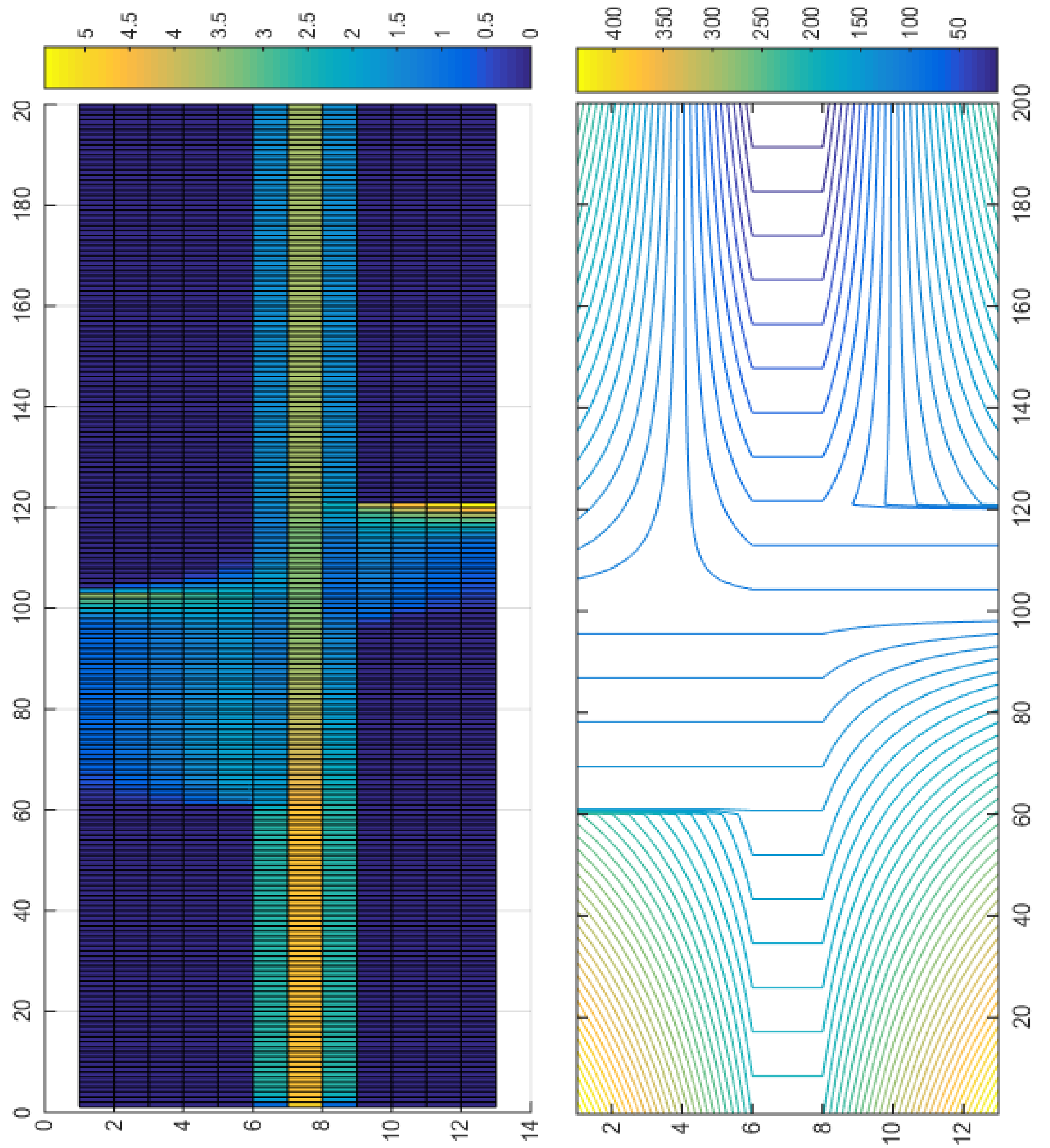


Figure* 3:** (right***) Toy model DEM (color-map is for elevations in m); (***left***) toy model initial flooded area with no embankments (color-map is for water depths in m).

10. Toy-model results

- The best solution to place the left embankment is at the 60th cell (3 km from the river's initial cell) and for the right one at the 90th one (4.5 km from the river's initial cell). According to this scenario, the flooded area drops to 78% of the initial one (with no embankments).

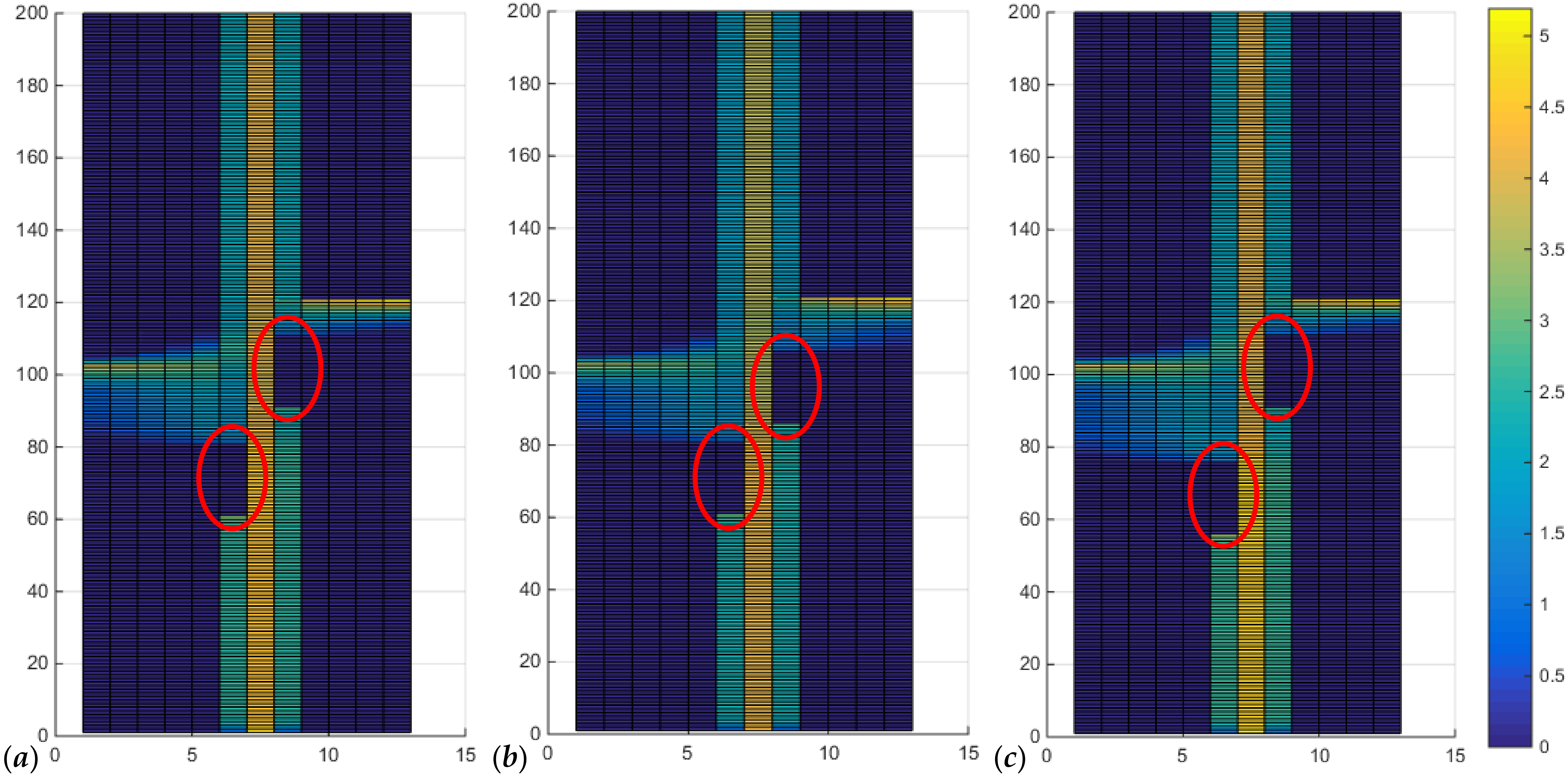
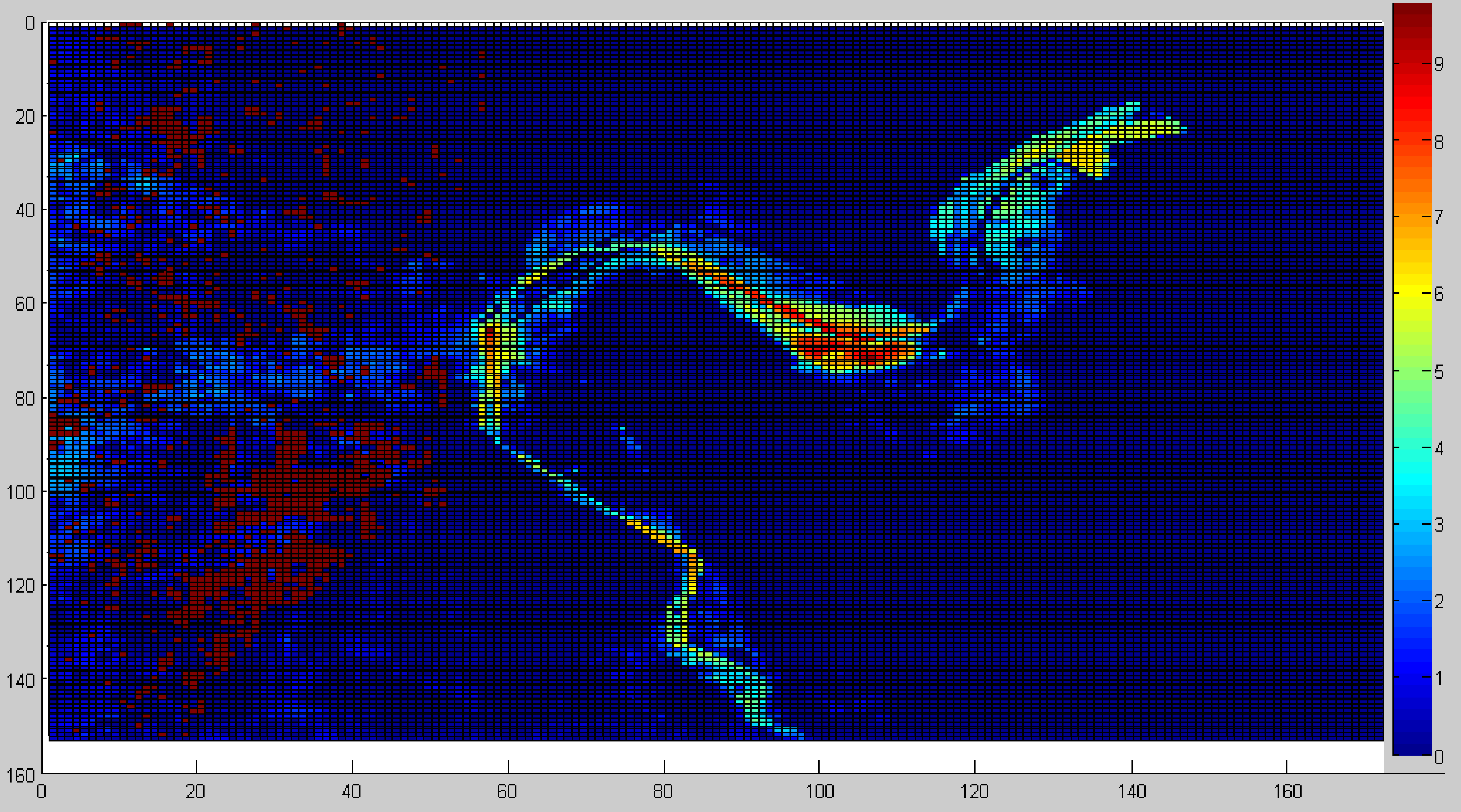


Figure 4: (*a*) Minimum flooded area (~78% of the flooded area with no embankments) resulting from the optimum placement of the two embankments at the left and right bank of the river (at the 60th and 90th cell, respectively); (*b*) second best scenario (with ~81% of the initial flooded area), placing the embankments at the 60th and 85th cell; and (*c*) third best scenario (with ~82% of the initial flooded area), placing the embankments at the 55th and 91st cell.

11. Application of the scheme in the case study area



This is the initial flood inundation for the 1700 m^3/s discharge. The cells in red colour indicate the positions where no flood occurred after the optimum placements of the embankments at the left (from 6 to 8.5 km) and right (from 8.5 to 11 km) river banks, decreasing the total flooded inundation by ~20%.

12. Conclusions

- Based on the results from both hydraulic models, the city of Arta is considered to be at high flood risk.
- However, the large differences between the inundated areas produced by the two models (varying from 0.29 to 8.29 km^2) highlight the uncertainty in hydraulic flood modelling.
- Based on the citizen's observations, we infer that the flood inundations produced by LISFLOOD are more realistic in comparison to the 1D HEC-RAS ones. This is attributed to the quasi-2D nature of the model.
- The preliminary application of the coupled simulation-optimization approach for optimal placement of embankments along the river banks, highlights the potential of the proposed methodology aiming towards the improvement of the flood resilience of the urban areas.

References

- Bates, P., Horritt, M., Wilson, M., Hunter, N., LISFLOOD-FP, User manual and technical note, School of Geographical Sciences, University of Bristol, 2005.
- Bruner, G., HEC-RAS, river analysis system user's manual, US army corps of engineers, Hydrologic engineering center, 2010.
- Tsoukalas, I., P. Kossieris, A. Efstratiadis, and C. Makropoulos, Surrogate-enhanced evolutionary annealing simplex algorithm for effective and efficient optimization of water resources problems on a budget, *Environmental Modelling & Software*, 2015 (submitted).