Risk flood areas, a study case: Basilicata Region

A. Sole, L. Giosa & V. Copertino
Department of Environmental Engineering and Physics,
University of Basilicata, Italy

Abstract

Recent hydrological events have increased both public interest and that of the Scientific Community in a more accurate study of flooding areas. The aim of this work is to define the inundation risk along the main rivers of the Basilicata Region in order to create flooded area maps for different flow rates corresponding to different return periods. Three different software programs have been used for hydrodynamic simulation: Hec Ras (River Analysis System) produced by United States Army Corps of Engineers River Analysis System and developed by the Hydrologic Engineering Center, Mike 11 produced by the Danish Hydraulic Institute, and Mike 21 bi-dimensional model produced by the Danish Hydraulic Institute to compare the different behaviour of the models and evaluate the most suitable. The simulations have been carried out on more than 1500 river cross sections to define the geometric characteristics of streams. Peak flows with 30 year, 200 year and 500 year return periods have been considered as upstream boundary conditions, and for the bi-dimensional simulations data was surveyed with laser scanning techniques. The integration of hydrodynamic models and very detailed data, such as laser scanning data, is very difficult and requires a great deal of pre-processing. Here we have put forward a method of integration. The water surface elevation and top width achieved in riverbeds for each simulation has been used with GIS software to draw the different flooded area maps.
Keywords: risk flood, hydrodynamic mono and bi-dimensional models, laser scanning techniques.

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1 Introduction

Current Italian land protection legislation dates from 1989 (L.183/89) and identifies the Basin Plan as the ideal territorial unit for research and action aimed at land protection and conservation of water resources. It is a complex environment where problems arise from the interaction of numerous factors including fluvial dynamics and slope stability as well as natural and anthropic phenomena. Additions to the law have been made to facilitate planning for such a complex environment and have also allowed for its utilization for sub basins and provisional order regarding priority sectors such as flood and landslide defence and water protection. Strict terms have been fixed for the location and delimitation of the area of hydrologic risk (from moderate R1 to very high R4) and for the adoption of safety measures for these areas.

The Hydro Geologic Safety Plan (PAI) thus provides for the location and delimitation of the hydraulic risk area through the definition of zones of fluvial corridor. These zones, considered as areas where respect is shown for water courses and their free evolution, play a strategic territorial role and are also subject to precise plans of action. In this way they are a kind of normative category aimed at protecting the territory from anthropic activity as well as protecting the river and its area of influence.

The Italian Basin authorities identify these areas in different ways, in relation to both flood risks as well as to possibilities of natural and environmental restoration. In general once the floodplain and the river's meander belt corridor are impacted by development and the river loses its ability to re-establish its natural functions, agricultural fields near the channel are critical for floodwater attenuation, ground water recharge, non-point source pollution buffering and providing habitats for wildlife. It therefore becomes necessary to protect these areas from any future human activity.

The plan for Hydraulic Safety drawn up by the Basilicata Inter-Regional Basin Authority defines the area of fluvial pertinence in relation to flood risk as well as in relation to the natural water course. In the former, three areas are defined: areas of probable flood risk with peak flow return periods of 30 years, up to 200 years and up to 500 years. "They contain and laminate the flood and together with the area made up of alluvial terraces and alluvial fans or cones, they serve as a shelter and protection of the environmental quality of the water course."

The dynamic nature of the riverbed is evident in its definition in fact the Basilicata Basin Plan cited above states "For rivers we mean the areas directly effected by the stream flow and digression of the water…", this concept of the area of natural digression becomes important during the peak flow, especially during extreme events when the concomitant phenomenon of solid transport becomes more serious and mixes with floating material, obstructing bridges and creating dams and thus exacerbating its destructive effects often in inhabited areas. This paper presents studies aimed at the determination of areas of fluvial pertinence within the framework laid out in the Basilicata PAI.

1.1 Area of study

The area under study covers about 8.830 km^2 and is made up of the total districts territory of the inter-regional watershed of the Bradano, Sinni and Noce rivers and the hydrographic basins of the regional Basento, Cavone and Agri rivers, figure 1. The first phase of the study was carried out on the Basento river, 157 km long and with a basin area of 1.535 km^2, Bradano river, 170 km long and with a basin area of 2.960 km^2; Noce river, 50 km long and with a basin area of 413 km^2; Sinni river, 94 km long and with a basin area of 1.427 km^2, the Agri and Cavone rivers are still under study.

Figure 1: Area of study.

2 Methodology applied

2.1 Data organization

Prior to undertaking a detailed hydraulic modelling which would allow for an appropriate utilization of hydrodynamic models of steady and unsteady mono- and bi-dimensional flow, a protocol for a survey of river cross sections and their granulometric characteristics was defined. Surveys of about 1.000 cross sections were carried out along the main river course. These included all the water works and all the river crossings (road and rail bridges, canal bridges, etc) and surveys were also carried out of the longitudinal profiles of the embankments. All the georeferenced and duly coded information was memorized in a geographic data base and superimposed on ortophotos with 1:5000 scale, realized at the same time of the surveys. In order to experiment new survey methods coupled with hydrodynamic simulation models, several surveys were carried out using laser scanner technology. In figures 2–7, an example of the information present in the database is reported. With the use of the data thus acquired together with historical bibliographical data a study of fluvial dynamics was carried out to classify the different river branch (incisions in rock formations or strongly cohered terrain, steep/pools, flood plain, braided or bar braided, anastomosed, meandering etc.) with the aim of defining its evolutionary tendencies and identifying branch for specific detailed modelling, [1–5], Figure 8 reports the position of the calculation sections and the relative classifications for the Sinni River.

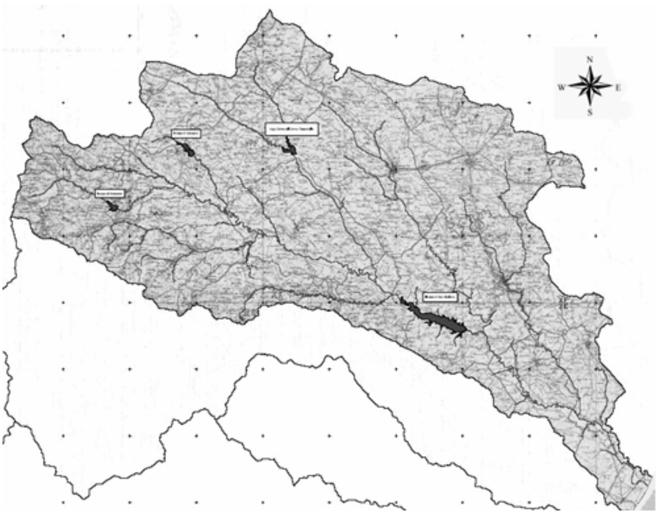


Figure 2: Bradano river: watershed and river network.

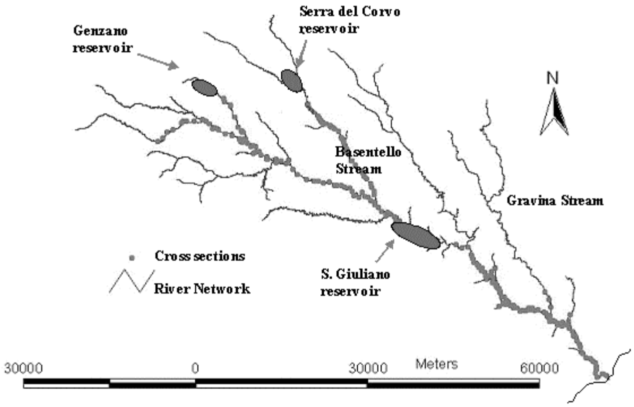


Figure 3: Bradano river: river ground surveyed cross sections used for hydrodynamic simulations.

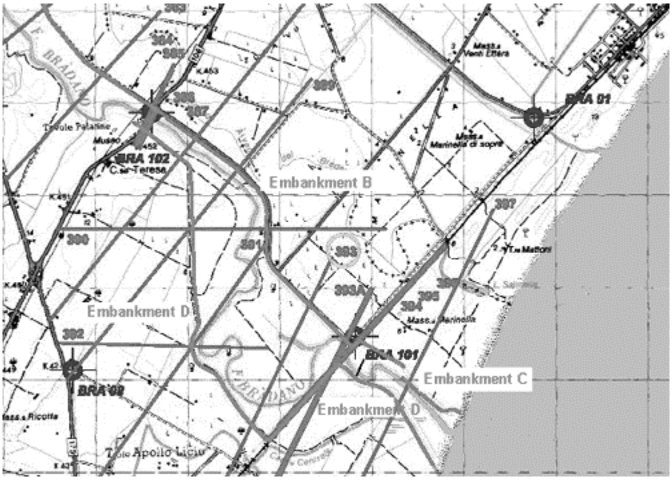


Figure 4: Bradano river: Example of waterworks position.

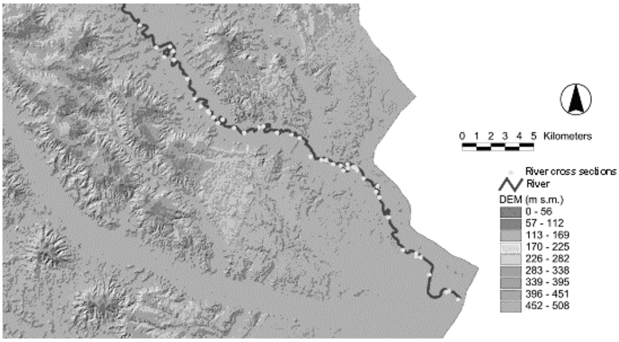


Figure 5: Bradano river: high resolution digital elevation model.

Figure 6: Bradano river: sketch of orthophotos with talweg, cross section position.

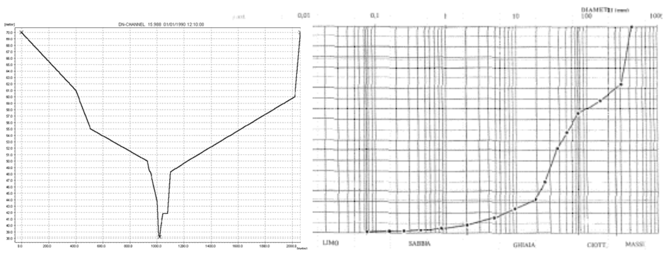


Figure 7: Bradano river: sketch of granulometric curve and river cross sections in hydrodynamic model.

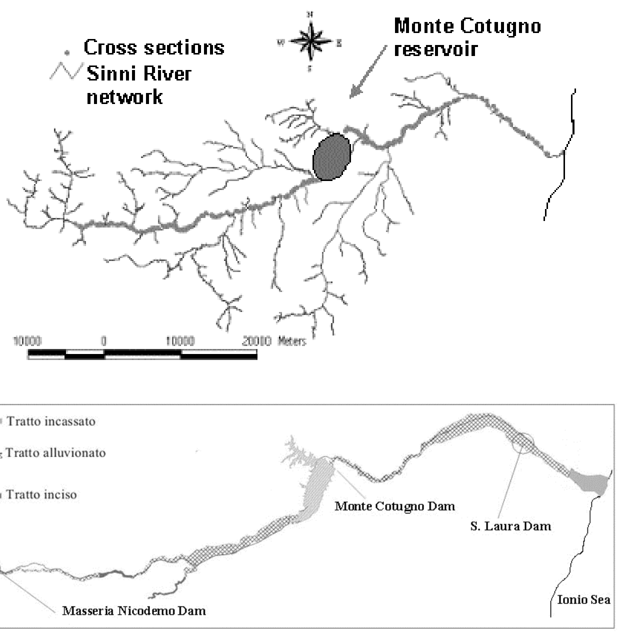


Figure 8: Sinni River: river network, cross sections position and morphological Classification.

2.2 Hydrologic study

The hydrologic study, utilized for the estimation of flood risk in any given section of the river network, is based on peaks methodology VAPI already carried out in the Basilicata region by Claps & Fiorentino [6]. This methodology makes reference to a probabilistic approach for the estimation of maximum annual peak flows. To reduce uncertainties related to the presence of very rare extreme events and to the spatial variability flood index, a methodology of regional analysis was adopted which also used conceptual models of the formation of stream flow caused by the heavy precipitations recorded in the basin. This approach allowed the use of all the hydrometric and pluviometric information of a given area. A two component extreme value (TCEV) [7], probabilistic model was adopted which interpreted maximum annual events as a result of a combination of two distinct populations of data: one producing ordinary more frequent but less intense maximum events, the other giving rise to less frequent but extraordinary and often catastrophic events. Reference is also made to a hierarchal regionalized procedure where the various parameters of the probabilistic model are calculated according to different regional scales as a function of the statistical order of the parameter. The above methodology is based on regional scale analyses which tend to overlook the presence of any local anomalies.

In local basin scale studies and analyses, the elaboration of such anomalies may be fundamental in terms of the correct estimation of the distribution of probability of annual maximum flood peaks: in all such cases ad hoc hydrologic studies could be necessary. With reference to these it should be emphasized that the decisive factors in the definition of probability distribution of peak flows concern average climatic features of the basin as well as geopedological and soil use factors. The former are important in the definition of average number of heavy annual rainfall and the "yield" in terms of the average annual number of peak flows. The latter influence only the "yield" of the heavy rainfall in terms of average values and numbers of peak flows.

A number of river section, largely corresponding to the principal affluent on the water courses under study, have been identified and their catchments areas calculated.

Table 1: Example of Flood Discharge (T=30, 200, 500) for the different cross section along Basento river.

Sections	Basin Area	Q30	Q200	Q500
	km^2	m^3/s		
La Tora monte	77	124	191	223
Gallitello valle	144	200	308	361
Rifreddo m.te	166	260	419	496
Rifreddo valle	193	291	469	555
Tiera monte	210	310	500	592
Tiera valle	295	403	649	768
Camastra monte	424	532	858	1015
Camastra valle	781	850	1369	1621
Chiaromonte	868	921	1485	1758
Scalo Grassano	985	1015	1636	1936
Staz. Salandra	1048	1064	1715	2029
Vella monte	1166	1155	1861	2203
Vella valle	1247	1216	1960	2319
Canale monte	1309	1262	2034	2407
Canale valle	1372	1308	2109	2496
Outlet	1535	1425	2298	2719

In these river sections the mentioned method VAPI, has been applied and flood peaks have been computed for three different return periods: 30, 200 and 500 years. An example of discharge values with VAPI methodology, sub catchments areas are reported in Table 1 for Basento River. It should be emphasized that the three return periods were estimated in order to:

- Define the maximum flow levels and safety margins in relation to river bank protection;
- Evaluate the impact of the planned water works on the natural expansion of the peak flow;
- Simulate several scenarios obtained varying location and typology of water works and estimate their efficacy and their downstream and upstream effects;
- Verify the extent of the flooding area.

2.3 Hydraulic study

2.3.1 Mono dimensional models

The hydrodynamic data were calculated using two well known and consolidated hydrodynamic models: HEC-RAS (River Analysis System) developed by the Hydrologic Engineering Centre, of the United States Army Corps of Engineers, [8], and Mike 11 of the Danish Hydraulic Institute Water & Environment, DHI [9], Sole & Zuccaro [10].

HEC-RAS software, based on different forms of numeric integration and interpolation of the calculation sections, permits the evaluation of hydraulic profiles of gradually varying motion and unsteady motion in natural and artificial channel networks. It can also be used to simulate conditions of sub critical motion, iper critical and mixed motion as well as evaluate the effects of lateral inflow, dikes, weir, floodgate, culvert, bridge, flow obstructions and constructions built in the flood plain.

The Mike 11 model is the most complex and allows for the activation of three different descriptions of motion through three different mathematical formulations: 1) “cinematic wave” approach; the motion conditions are calculated by imposing a balance between gravitational and friction force. This simplification does not permit the simulation of the effects of back water. 2) “diffuse wave” approach; here the hydrostatic gradient is taken into consideration as well as gravity and friction so as to be able to also evaluate the upstream effects of downstream boundary conditions i.e. simulate the phenomena of back water. 3) “dynamic wave “approach; through the use of the complete motion equations including the forces of acceleration, it is possible to simulate rapid transitory, tide, etc. It is possible to choose the description of the most appropriate motion in relation to the type of problem which needs to be resolved.

The hydraulic resistance was evaluated using the Manning coefficient *f*, varying along river branch and in some cases within the same section (main channel, flood plain areas etc). For several water courses with stations measuring water levels and the relative stage discharge curve, model calibration operations were carried out to identify the correct value for the above mentioned coefficient.

In the other instances reference was made to literature values and different simulations were carried out with diverse values of *f* to test model sensitivity in given hydraulic conditions of that parameter [11]. For each section with water works or crossings, two more sections without works have been added – one upstream and one downstream – to facilitate a correct interpolation between sections.

The two numeric models used for the hydrodynamic simulations have given comparable results. The differences are a result of the different ways of resolving the motion equations and the generation of the interpolated sections. In each case the differences in the hydraulic height, arising from the morphological conformations of the river beds, have led to variations in the top width, which are insignificant in terms of the scale used for the map of the flood areas (planimetric scale 1:5000 and altimetric with contours level equidistant every 5 meters). However, the results to safety advantage have been considered. Figure 9 shows a comparison between adimensional differences between the two water levels obtained from the two models for Q_{30} in relation to the Basento River.

As stipulated in the PAI, areas of fluvial pertinence subject to flood risk are identified through a consideration of conditions of steady flow with maximum discharge estimated for given return periods. These conditions lead to constant flow values along the river for the entire hydrodynamic simulation period equal to the maximum values defined in the different sections of the river. Therefore on the basis of the flows calculated in correspondence to the various sections, the boundary conditions along the river were defined through the flow value in the various river branch for Tr=30, Tr=200 and Tr=500 years, respectively. For the boundary downstream condition, a constant water level at the sea outlet was applied (an average sea level of 0.5 m). The calculation was carried out by considering the bed as fixed and thus not taking into consideration excavations occurring during the peak flows. This is a typical phenomenon of alluvial river beds and for these areas morphological analyses linked to the evolutionary dynamics of the branch were carried out. Utilizing the results of the hydrodynamic simulation: the hydraulic height and the top width in each section, using the ortophotos 1:5000 scale as cartographic base, in ArcView environment, the areas of fluvial corridor were drawn.

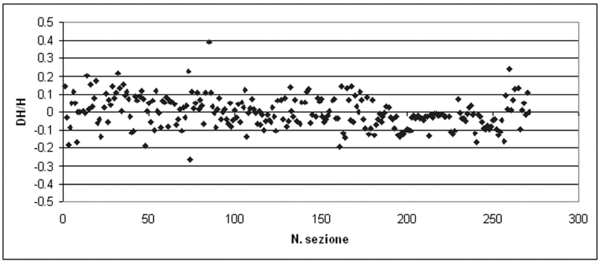


Figure 9: Basento River: comparison betwen Mike 11 and Hec Ras hydrodinamic adimensionalized results for Q30.

Figures 10–11 show, for the Basento river, the river network with the calculation cross sections and the main channel of indicating the areas of fluvial pertinence subject to flood risk for the three given return periods. Figure 12, for the same river, shows a detail of flood risk areas for a meandered river branch.

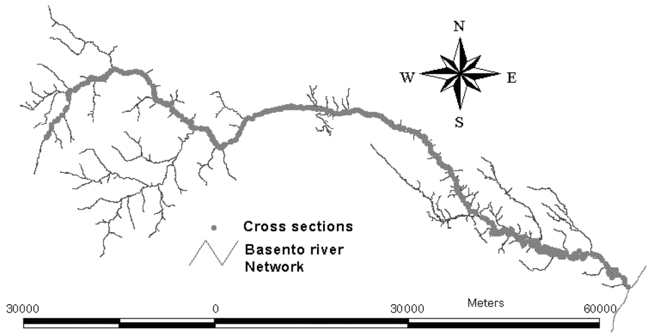


Figure 10: Basento River: river network and cross sections position.

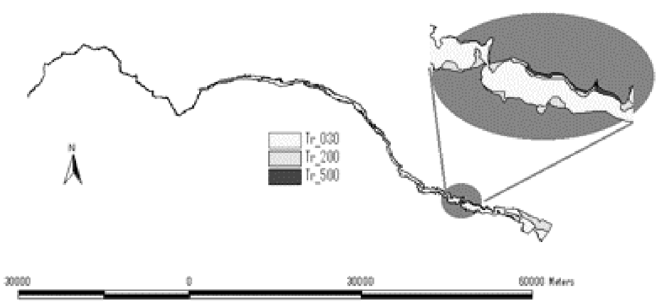


Figure 11: Basento River: flooded areas for the three period of return.

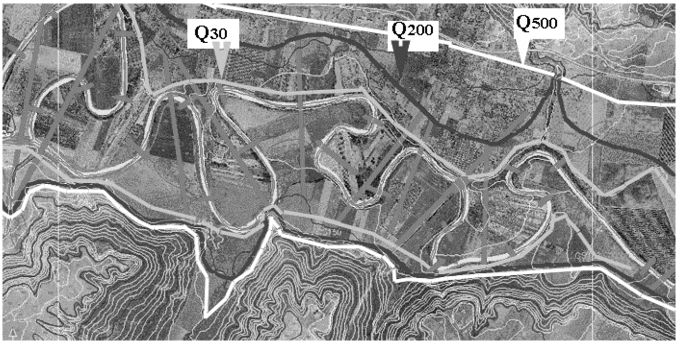


Figure 12: Basento River: a detail of flooded areas for a meandered branch.

2.3.2 Bi-dimensional hydrodynamic model

For the bi-dimensional data, used only in several particular morphologic branches (meandered or very flat areas) the MIKE flood by DHI Water & Environment was utilized allowing the dynamic coupling of the bi-dimensional code MIKE 21 and the one-dimensional MIKE 11, under unsteady flow conditions.

The area under study covers a fluvial strip which extends for about 3.5 km on both the hydraulic left and right. The topographical data was obtained by means of Laser Scanning [12]. The functioning principle of laser scanning lies in the scansion of the territory from the aircraft platform using a telemetric laser, which measures the distance from the area in terms of the time taken by the laser beam travelling at the speed of light, to complete a return journey (figure 13). Knowledge of the position and the condition of the aircraft at every moment which is usually assured by the integrated system GPS-INS, facilitates the identification of the points in space which reflected the laser beam.

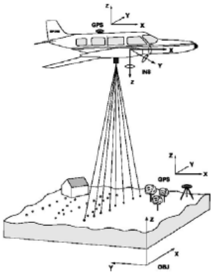


Figure 13: Sketch of Laser scanning.

The first product of the scansion laser is a cloud of points which constitute the DSM (Digital Surface Model) of the area flown over figure 14. They have a density which varies from several units per square metre to several tens of units and can be utilized directly or elaborated to calculate the value of a regular grid using interpolation filter techniques. Starting from a DSM it is possible to generate a Model Keypoints (MKP) containing data considered to be key points of the digital surface (figure 15). In the case under examination the utilization of MKP permitted the generation of bathymetry.

The interpolation of a bathymetry, figure 16, is done in 3 steps: 1) Finding the grid cells that have a centre inside the land polygons identifies all the land points. This is known as *Land Generation*. 2) The grid cells that aren't land points needs to be assigned a depth. The grid is used for sorting the data (loose points, contour points and polygon vertices). All points used for the interpolation are distributed into optional lookup-tables for each grid cell. This enables a much more efficient search instead of something which is proportional to number of horizontal grid cells times number of vertical grid cells times number of raw data points. 3) Only grid cells defining land have been assigned an elevation (z-value). Each of the remaining points need to be assigned. The raw data points are used for this interpolation. This is the *Gap Filling* process.

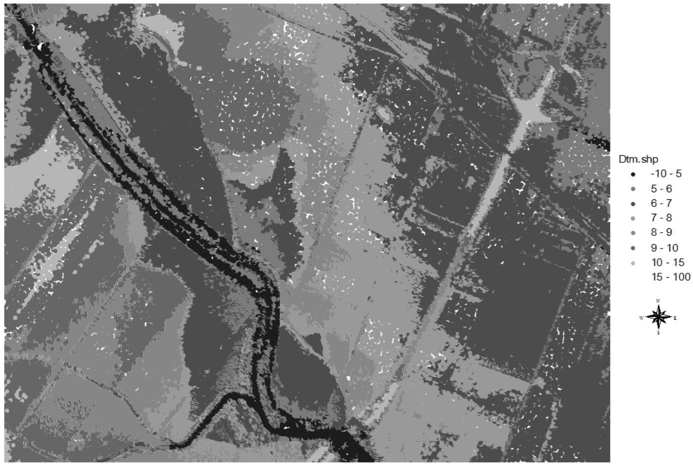


Figure 14: Digital Surface Model of the area.

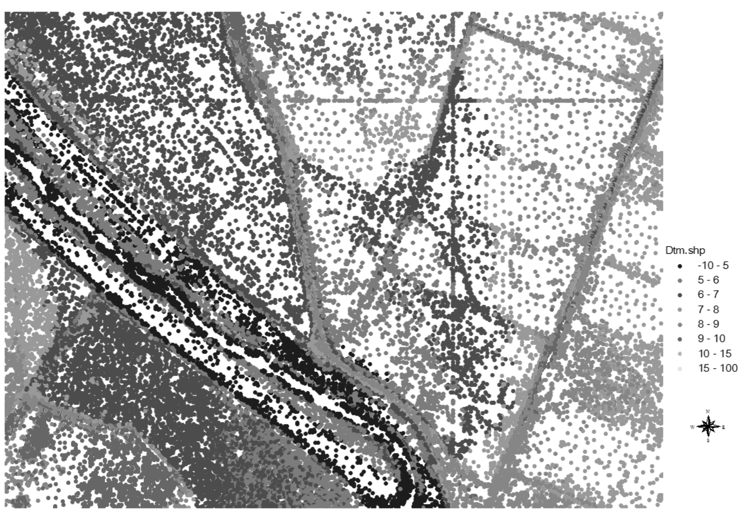


Figure 15: Model Keypoints.

The representation of the water works or infrastructures (bridges, longitudinal protection works,..) was carried out using topographical data obtained in 2003 along the Basento River as well as DTM laser. In order to check for flood wave overflow of the crossings particular attention was given to the reconstruction of the form of the bridges.

In all the hydraulic simulations carried out as initial conditions, a hydraulic height in river bed equal to 0.50 m. was considered. For downstream boundary condition a constant value equal to 0 m above sea level was used.

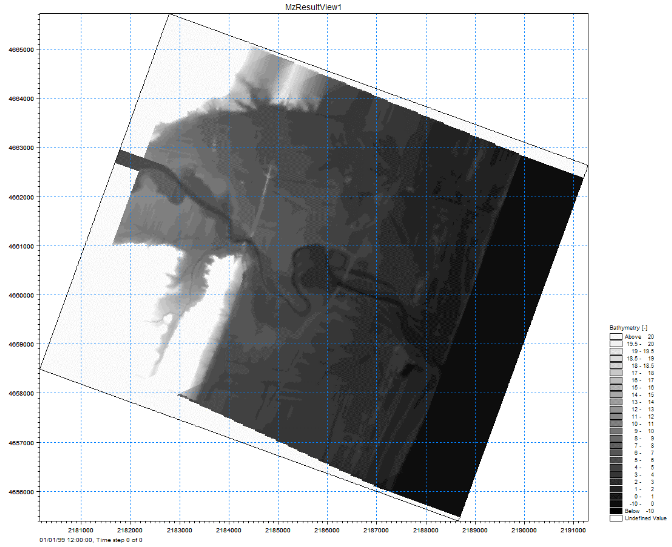


Figure 16: Bathymetry.

The application of the bi-dimensional model was carried out in conditions of unsteady flow, considering a triangular flood hydrogram with a maximum flow value calculated with the below cited methodVAPI, a time span of 48 hours and the peak at 16 hours. In particular the maximum flows considered result as: Q_{30} = 1425 m^3/s, Q_{200} =2298 m^3/s and Q_{500}=2719 m^3/s. Further elaborations were carried out through the utilization of the curve of the reduction of flood overflows which for the Basento River takes the following form:

$$Q(t)=Q_T\, e^{-2|t|/Kv} \quad [13] \tag{1}$$

In (1) the estimation of the maximum flow rate, "Q_T", with given return time of, T, is given as the product of the index flood "E(Q)" for the factor of growth "K_T" [6]:

$$Q_T = K_T\, E(Q) \tag{2}$$

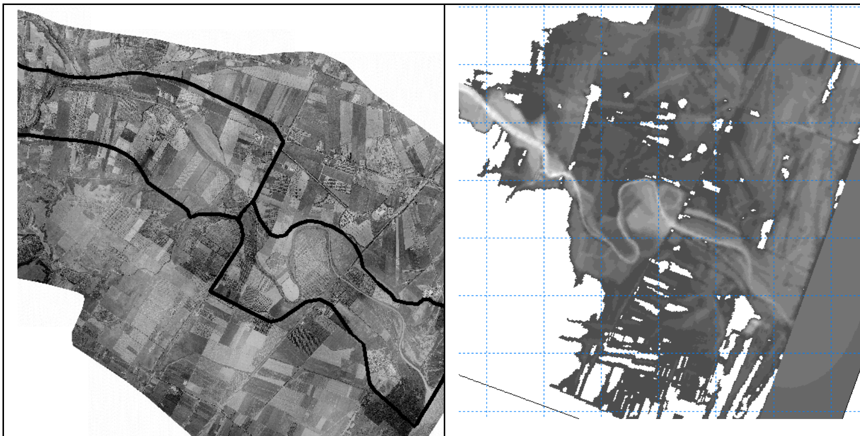
E(Q) named just so flood index, whose variability is strongly influenced by the basin area, can be estimated using a law such as:

$$E(Q) = \alpha\, A^{\beta} \tag{3}$$

For the watercourse considered the coefficient α= 2.13 and the coefficient β= 0.766, basin area is A= 1535 km^2, kv (h) = 9 is given, the factor of growth $k_T(T)$, is equal respectively to 2.427 for T = 30years; 3.912 for T=200 years and 4.629 for T=500 years.

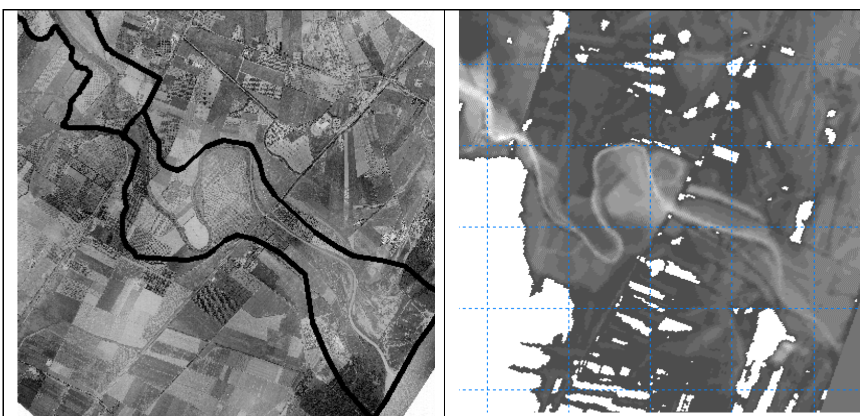
In particular the maximum reduced flows result as Q_{30} = 1394 m^3/s, Q_{200} =2248 m^3/s and Q_{500}=2659 m^3/s, with the peak centred at 24 hours.

Figures 17 and 18 show the results of the application of the model and a comparison with the mono dimensional model.



a) b)

Figure 17: Q $_{T200}$ a) monodimensional – b) bidimensional.



a) b)

Figure 18: Q $_{T30}$ a) monodimensional – b) bidimensional.

In Table 2 are reported the values of the hydraulic heights (m a.s.l.) in some sections for different discharge and models, as described above. It can be noted that for $Q_{T=30}$ the mono and the bi-dimensional model have the same behaviour because the discharge is fully contained in the main channel. For $Q_{T=200}$ and $Q_{T=500}$ the bi-dimensional model return values that correctly take into account the terrain morphology.

Table 2: Comparison between mono and bidimensional results.

	monodimensional			bidimensional		
N section	Y_{w30}	Y_{w200}	Y_{w500}	Y_{w30}	Y_{w200}	Y_{w500}
543	9.7	10.95	11.51	9.63	9.78	9.97
3	8.58	10.82	11.4	9.27	9.28	9.40
547 m	8.04	10.4	11.02	9.10	9.11	9.23
549bis	5.32	6.8	6.95	7.37	7.37	7.42
558	3.3	4.23	4.32	3.2	3.21	3.24
561	2.76	3.65	3.57	2.87	2.96	3.03

3 Conclusions

This paper illustrates the studies carried out to identify areas of fluvial pertinence in relation to flood risk for flows with given return periods, as required by the Italian regulations regarding hydraulic safety.

Obviously a more complex approach, taking into consideration hydraulic, hydrologic and fluvial instability problems together, would be needed to comprehensively address the problem of definition of flood risk zones.

Fluvial instability, is the principal risk factor in water courses characterized by perennial but highly variable flows, where the fluvial morphology are in frequent and rapid mutation and there is strong interaction between stream flow, bed and existing water works, a situation typical of southern Italian rivers. This study, while responding to Italian norms, requires much more work related to both the performance of the hydrodynamic models and evaluation of the water course's evolutionary process. A research group is working on both these fronts, one in a scientific research programme of national interest in the area of fluvial instability and the other in the control of mono and bi-dimensional hydrodynamic models in relation to their capacity to correctly simulate the reservoir phenomena during a flood event. Coupled with these studies it is important to describe with accuracy the terrain morphology with the proposed laser scanning technology, to integrate this technology into hydrodynamic bi-dimensional models in order to represent correctly the flooded areas.

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