STUDY OF FLOOD HAZARD IN THE CASTELFRANCO EMILIA AREA (MODENA PROVINCE, NORTHERN ITALY)

Jurjen BERTENS[*], **Doriano CASTALDINI**[**], **Cecilia GIUSTI**[**], **Mauro MARCHETTI**[**],
Massimo BARBIERI[**], **Jaime BONACHEA**[***]

[*]Department of Physical Geography, Utrecht University, Heidelberglaan 2, 3500 Utrecht, The Netherlands,
bertensj@ccaix3.unican.es

[**]Dipartimento di Scienze della Terra, Università degli Studi di Modena e Reggio Emilia, Largo S. Eufemia 19,
41100 Modena, Italy. castaldi@unimo.it, giustic@unimo.it, marchet@unimo.it, mb99@unimo.it

[***]DCITIMAC, Facultad de Ciencias, Universidad de Cantabria, Avda. de los Castros s/n 39005 Santander, Spain.
bonaechj@ccaix3.unican.es

Working Group TC VII-8

KEY WORDS: Flood hazard, flow-regulation system, hydrological modelling, Panaro River, Castelfranco Emilia.

ABSTRACT

The Castelfranco Emilia area is located in the Po Plain. The Panaro River have periodically caused flooding in the study area. The more recent floods took place between 1966 and 1973 (3 events).
In order to reduce flood hazards, several meander cuts were carried out along the river. As these interventions resulted to be ineffective, a flow-regulation system was constructed west of Castelfranco Emilia. It consists of a regulating dam built across the riverbed and a storage basin bordered by embankments. This structure is operating since 1985 but was finished in 1999: no flooding events have occurred since it is in operation.
The paper illustrates some aspects of flood hazard induced by the Panaro River, related to the construction of a high velocity railway in the study area, a tract of the connection between Milano and Bologna.
The relationship between precipitation data and the occurrence of a number of flooding events is studied, in order to establish whether or not a significant relationship between the two can be identified. Furthermore, a distributed dynamic hydrological model is constructed for simulation of the spatial and temporal proceedings of a flood event.
On the basis of merely precipitation no predictions can be made with respect to the occurrence of a flood event. The inclusion of alternative routes for the proposed railway allows for the evaluation and comparison of the spatial effects of a flood event. Critical points in the model are calibration and the calculation of soil saturation prior to the event.

1 INTRODUCTION

The study area, is a sector located to the east of Modena city in the southern central sector of the Po Plain with a population of about 25.000 people over 100 km^2 approx. (Fig.1). The Panaro River, which is one of the main rivers of the Modena Province, flows in the western part of the Castelfranco Emilia area and has periodically caused flooding in its territory.

In this paper, prepared in the framework of the European project GETS (Application of Geomorphology and Environmental Impact Assessment to Transportation Systems), the relationship between precipitation data and the occurrence of recent flooding events of the Panaro river was studied in order to establish whether or not a significant relationship between the two can be identified.

In the act of allocating a route for the high velocity railway (a tract of the high velocity railway connection between Milano and Bologna), the possible effects regarding flooding events will have to be considered. A preliminary attempt has been made to identify the crucial mechanisms, and the natural and anthropogenetic factors that can control the development of a flood event (this implicates the exclusion of all other factors as crucial in a flooding event); furthermore the time-scale on which these mechanism are relevant has been considered. This led to the definition of a number of processes which have been included in a dynamic model, with which the spatial proceedings of a flooding event can be simulated. Scenarios can be calculated, in order to make predictions regarding the way in which the spatial extent of a flood event could be affected by the presence of a hypothetical railway (one of three alternatives). This is achieved by using the hypothetical route as a friction factor (its presence will alter micro-relief) with respect to propagation, since the crest supporting the new structure will serve as an obstacle in case of a flood. It will protect the area located behind it and might increase problems for the area located between the river course and the railway.

Given a breach location or a location where over-topping takes place along the embankments of the Panaro River and a value for the discharge from the breach, predictions can be made with respect to flood propagation. The model is essentially deterministic, however, due to lack of validation possibilities (calibration and validation will per definition be impossible for future conditions), it should be regarded as conceptual. The dynamic model was developed with the PC Raster Dynamic Modelling Package (Van Deursen & Wesseling, 1997).

2 STUDY AREA: GEOGRAPHIC, GEOMORPHOLOGIC AND GEOLOGIC OUTLINE

The Castelfranco Emilia area is located in the southern central sector of the Po Plain which is the most extensive plain in Italy (approximately 46,000 km^2, corresponding to 71% of all the plain areas and 15% of Italy).

The study area is situated in a temperate climatic zone (Type Cfa of Köppen's classification). From the pluviometric viewpoint the study area has an annual average rainfall of about 700 mm, with seasonal peaks concentrated in the fall and spring (about 250 mm), and minimum values in the summer (about 150 mm).

The Panaro River has a total length of 148 km and a catchment basin of 1,784 km^2, (Idroser, 1988). This river collects water from the central section of the Emilian Apennines (the mountain-basin extends over an area of 1035 km^2). At the point where it flows on to the plain formed a large alluvial fan (remains of older fans appear at the foot of the Apennines; Gasperi *et al.*, 1989) and, after a 85 km long course through the Po Plain it reach the Po River as the lowermost right-hand tributary.

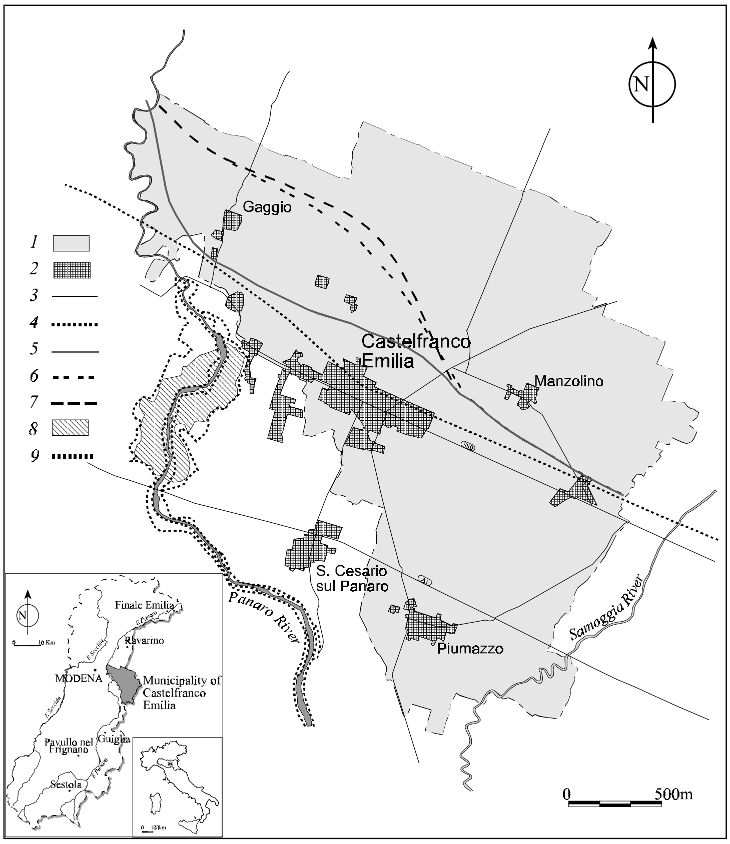

Figure 1. Location of the study area. 1) Municipality of Castelfranco Emilia, 2) built up area, 3) main road, 4) railway track, 5), 6), 7) alternatives tracks of the high speed railway project, 8) flow regulation system, 9) fluvial scarp.

In the study area the Panaro River flows from south to north about 2 km to the west of Castelfranco Emilia and about 4 km to the east of Modena. In this area it shows two distinct sectors with quite different geomorphologic characteristics: at the north of Castelfranco Emilia it flows as hanging river within artificial levees whereas at the south it flows deepened in the alluvial deposits. The present morphological patterns of the Panaro river bed at the south of Castelfranco was defined in relatively recent times, starting from about 1950. Prior to 1950, it was a bed at the level of the surrounding plain and filled with gravelly material. Extraction of gravelly material for technological use (construction, roads, etc.) has triggered erosion and has resulted in a lowering of the bed levels by as much as 9 m in some spots (Pellegrini *et al.,* 1979; Castaldini & Piacente, 1999).

The hydrologic regime of the Panaro River is characterised by two very similar peaks in the spring (March-April) and in the fall (November), and a minimum in the summer (August). The watercourse has had variable flow-rates in time, although without showing particular trends. The mean flow-rate values in the 1951-1980 period have been calculated taking the river section west of Castelfranco Emilia as reference point: the value thus obtained is 21,2 m^3/s (Idroser, 1988).

The superficial alluvial deposits in the study area are Holocene in age; their particle-size distribution ranges from gravel to clay.

According to subsurface geologic data (Pieri & Groppi, 1981), the study tract of the Panaro River lies on the "Emilia-Romagna Folds" which are a continuation of the Apennine chain in the subsoil of the Po Plain.

3 STUDY OF FLOODS AND METEOROLOGICAL DATA

3.1 The flood events of the Panaro River in the Castelfranco Emilia area

The waters of the Panaro River have periodically caused flooding in the area between Modena and Castelfranco. The flood events of the last two centuries are indicated by Moratti (1988) and Provincia di Modena (1996); they occurred in November 1887, October 1889, October 1897, November 1928, May 1939. The more recent floods occurred in November 1966 (flooded area: 9,400 ha), September 1972 (f.a.: 2,540 ha) and September 1973 (f.a.: 5,700 ha) (Fig. 2).

In the 19th and 20th centuries, several other floods occurred in the lowermost tract of the Panaro River. In order to reduce flood hazard, several meander cuts were carried out along the river; these interventions resulted to be ineffective, of course, and they only transferred the problem to the tract of the river downstream of the cut. Because of these man's intervention, in the last two centuries the length of the Panaro River in the Po Plain tract was reduced by about 11 km (Castaldini & Piacente, 1999). The last meander cuts were carried out in the early 1970s: four meanders were cut west of Castelfranco Emilia and the shortening of the watercourse was about 3 km.

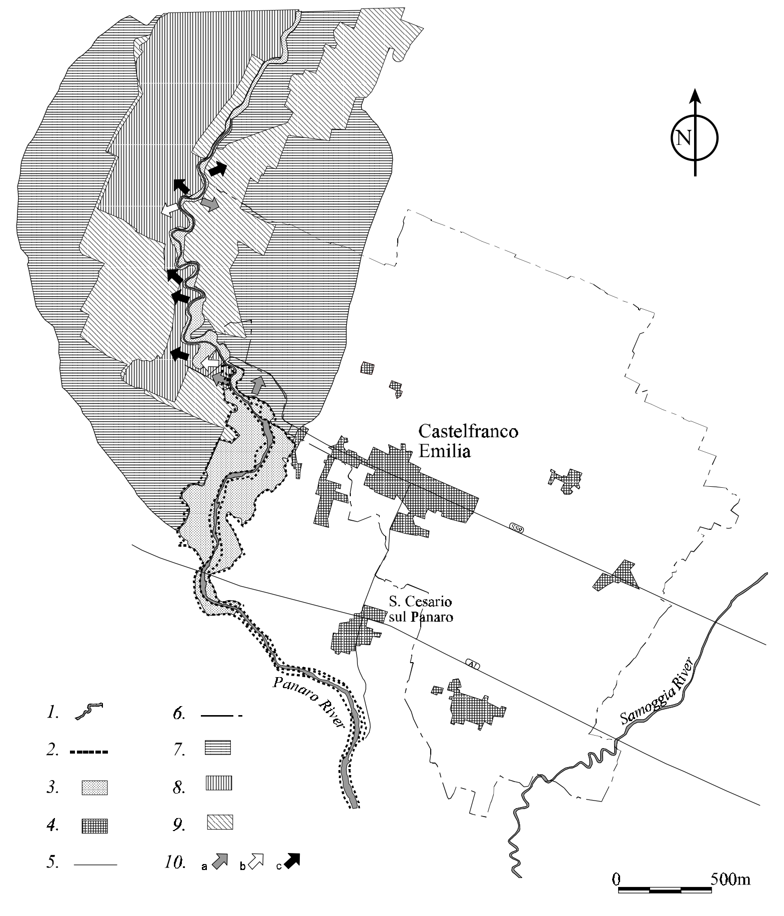

Figure 2. Areas flooded by Panaro River in more recent flood events. 1) River, 2) fluvial scarp, 3) high water bed, 4) built up area, 5) main road, 6) boundary of Castelfranco Emilia Municipality, 7), 8), 9) flooded area which occurred on 1966, 1972, 1973 respectively, 10) crevasse or overflow: a) 1966; b) 1972; c) 1973.

Since these cuts did not reduce flood hazard adequately a "flow regulation system" was planned and constructed along the river. The Panaro river "flow regulation system", operating since 1985 but finished in November 1999, is situated slightly to the west of Castelfranco Emilia, in a quarrying area within a fluvial depression that is 1.5 km wide and bordered by artificial embankments. In fact, it is located in a geomorphological situation that is optimal for storing large volumes of water without necessitating huge works for such purposes (Castaldini & Pellegrini, 1989).

The flow regulation system principally consist of the following structures:

a) a regulating dam: a transversal structure which permits discharge through 9 conduits. During periods of low water, the water is discharged through apertures located at the level of the river bed. In the event of floods, no more than a limited amount can be discharged through these same apertures. Excess water is stored up-stream from the regulating dam, producing an increase in the water levels and regulating the flow downstream.

b) a main storage basin: the basin is represented by an area of 280 ha providing temporary storage of the water contained by the regulating structure up to a capacity of about 19 million m^3.

c) an auxiliary storage basin: an area of 70 ha providing temporary storage to a capacity of about 5 million m^3 for extra flow in the event of an emergency.

The main and auxiliary storage basin is completely bordered by embankments about 6 km long and 4-5 m high that were constructed to increase the capacity of the storage area.

d) a downstream barrier: a transverse structure constructed downstream from the regulating dam and which serves the purpose of maintaining the river bed level, thus ensuring protection against bed erosion.

e) a selective barrier: a structure constructed upstream from the regulating dam which consists of a transverse net which serves to prevent large plants and trees from blocking or interrupting the discharge from the apertures in the regulating structure.

The flow regulation system has not yet been tested as to its efficiency under the flood conditions for which it was built, anyhow since this hydraulic structures have been in operation no floods have occurred.

3.2 Meteorological data

On the basis of the database it was not possible to forecast floods on the basis of merely precipitation. The three recorded floods are concentrated around the months September and November (Nov. 1966, Sept. 1972 and Sept. 1973) (Fig. 3). The question is if it is possible to identify a trigger mechanism (e.g. exceedence of a threshold quantity of precipitation or critical stage) to which the 3 more recent floods comply. This does not seem the case: the September events stand apart from the one that took place in November. A good illustration is the fact that e.g. in 1966 a flood occurred under meteorological circumstances which were far from exceptional. It appears however that soil moisture conditions play a role in the process. The two floods that occurred at the beginning of the wet season came after extreme amounts of precipitation, in some cases the highest amounts ever observed. The other flood (November 1966) occurred after much less intense precipitation, but were preceded by wet periods. Therefore (partial) saturation of soil storage capacity throughout the study area, would favour runoff. Antecedent soil moisture conditions could, in combination with precipitation, play an important role in the triggering of an event. Further study of soil moisture could aid confirmation of this surmise.

Figure 3. Breach in the embankments of the Panaro river in occasion of the flood occurred on 25-09-1973 (Moratti & Pellegrini, 1977).

There is however a fairly linear relationship between the amount of precipitation that falls immediately prior to the event and the magnitude of peak discharge.

Flood forecasting on the basis of (daily) rain intensities along with information on the saturation of soils (e.g. the freatic water-level) will probably give more satisfying results, since the events that occurred directly after the dry season (Sept. 72 and 73) were accompanied by much larger quantities of precipitation than other event, which was preceded by relatively wet months.

4 MODELLING OF FLOOD PROPAGATION

In general flood control strategies range from correlation of flood potential by means of simple descriptive indices to more sophisticated analyses of flow and sediment transport (Dunne, 1988). These two extremes coincide with the two main types of flood forecasting: 1) on the basis of frequency relationships; and 2) on the basis of dynamic models. In the first statements are made on the basis of statistical relationships (e.g. Meigh *et al.*, 1997 (recurrence intervals); Jiang, 1998 (probability of flood release due to overtopping)). In the second usually conceptually physically-based runoff models (also conceptual rainfall-runoff models, also CRRMs; Franchini & Galeati, 1997) are used that transform precipitation input into a quantitative description of stream response (E.g. Bentura & Michel, 1997; Göppert *et al.*, 1998; Romaniwicz & Beven, 1998; Peschke, 1998; Chang & Hwang, 1999; Estrela Monreal, 1999). These forecast models aim at providing forecasts for a discharge hydrograph. Samuels (1998) notes the importance of hydrological modelling for real-time forecasting and warning as well as the development of scenarios for climatic change impact assessment.

Despite the effort invested in flood control works world wide, neither flood occurrences nor damages are decreasing (Kundzewicz & Takeuchi, 1999). In fact, recent floods have not only exceeded previous damage record (due to increasing urban population and confidence in flood protection measures), but also absolute record stages.

Problems exist with respect to the understanding of the process itself and calibration. Causes are frequently associated with extreme precipitation, steep slopes and poorly infiltrating shallow soils (e.g. Peschke, 1998). Samuels (1998) names precipitation, structure failure and marine conditions as caused. Gilvaer & Black (1999) name overtopping as the most common mechanism that results in flood embankment failure. However, the knowledge of the origins of floods and its possible magnitude in a given region remains unclear (Bérod *et al*., 1999).

These models must be calibrated and validated on observed data, but extreme events, land-use change and possibly climatic fluctuations will typically be outside recorded experience (Peschke, 1998). The floods that took place recently in the Panaro River basin occurred under different circumstances than floods recorded in earlier centuries. The course of the Panaro river has been modified in the last centuries (Pellegrini *et al.,* 1979; Castaldini & Piacente, 1999) and large records referring to equal conditions are not likely to exist. This problem increases when predictions are made with respect to future conditions or when for current conditions no large data records exist.

The establishment of a more disaster conscious society with improved preparedness (safe-fail) rather than unrealistic fail-safe (safe from failure) design of flood defences seems more sustainable (Kundzewicz & Takeuchi, 1999). Safe-fail means that when a system fails, it fails in a safe way. Flood defence does not guarantee complete protection. Communication of risks in a tangible way will increase consciousness among the public more when using living with floods as a guiding principle rather than prevention. Samuels (1998) notes that with respect to flood management return periods are not a helpful way of communicating risk to the public. Therefore, the goal of the model presented here is not predicting when a flood will occur, but rather prediction of the consequences of a flood event of a given magnitude.

4.1 Model structure

The model assumes relevant processes to take place at different locations and model variables are a therefor function of space. The processes and their parameters also vary in time, and these variations can be incorporated, by computing updated values for variables (e.g. quantities of water) after an arbitrarily chosen amount of time has elapsed. The model can thus be called a distributed dynamic model.

The basis of the model is formed by the basic water budget, where the change in storage volume (here regarded as the floodwater on the surface) is determined by inflow and outflow of water from a unit area. Inflow will be consist mainly of precipitation, surface runoff from the upstream area and spilled water from the channel. Processes such as subsurface drainage and base-flow respond much slower, particularly in areas with small gradients. Outflow will consist mainly of surface runoff (back into channel or to another unit area) an infiltration.

Spatial input data for the model is stored in maps representing topography (for derivation of drainage network and slope), hydraulic conductivity, storage capacity and a map depicting the presence of infrastructure (plus alternative railway routes) (Fig. 4). The storage capacity map is prepared on the basis of precipitation records of the period preceding the

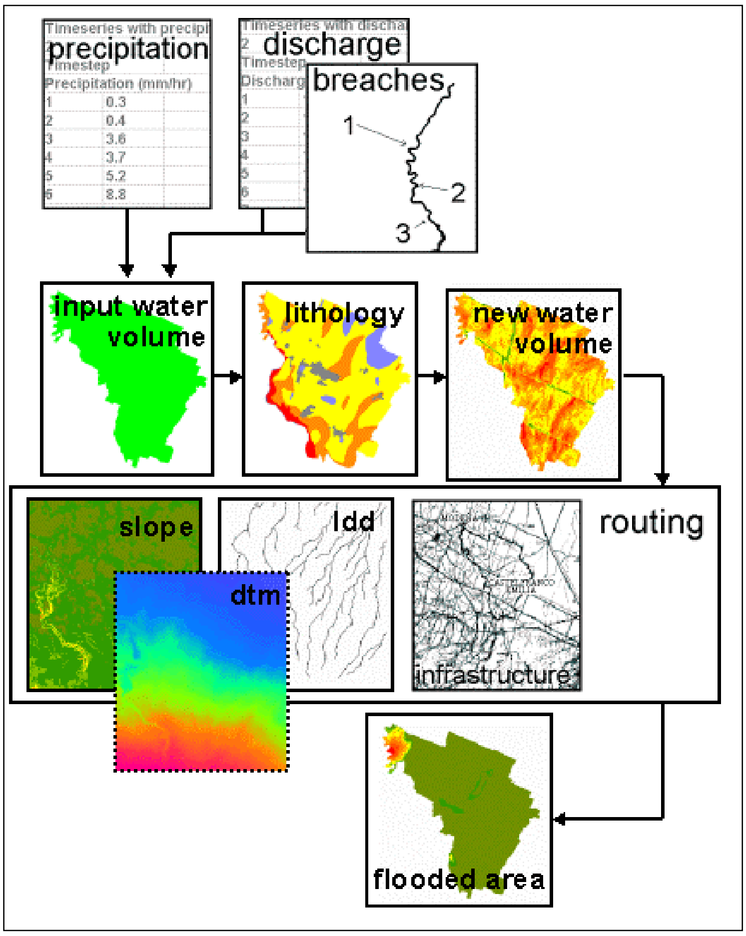

Figure 4. Input and structure of the model

event. Furthermore, a breach location or spillage zone has to be specified, for which records on previous flooding events is used. Temporal input for the model consists of precipitation and discharge records (5 minute or hourly intervals). Spillage from the channel is calculated as a function of channel discharge.

Flood routing (the process of tracing water movement through determination of time and magnitude of flow in the watershed; Chow et al., 1988) is performed treating flow of water as kinematic wave motion, where motion of water is described principally by the equation of continuity. Water moves according to the steepest gradient from one element to another. For each time interval (5min or 1hr) the quantity of water in each grid-cell (25 or 50 m^2) is updated as a function of input and output. Three problems arise from the use of a drainage network for routing purposes: 1) Flow restrictions: water can only move as far as the (diagonal) length of 1 grid element. To resolve this problems the pixel-size and used time interval can be reduced (increasing computational expense); 2) Micro-relief: the presence of infrastructures does not become apparent in the digital elevation model (due to its vertical resolution). To resolve this problem additional relief is added where infrastructure is present; 3) Local drain direction is fixed: Water can only discharge to 1 specific downstream pixel during the entire simulation. Therefore the digital elevation model is recalculated after an arbitrary time interval on the basis of the actual elevation and the quantity of water present in a grid cell.

4.2 Model output

For every interval a map is created depicting the quantity of water in a grid-cell. In these maps areas with urbanisation can be identified. Water-level in time can be reported as a hydrograph at any location in the area.

In figure 5 two simulations are displayed, the first with one of three alternative routes for the railway and a second for the present situation.

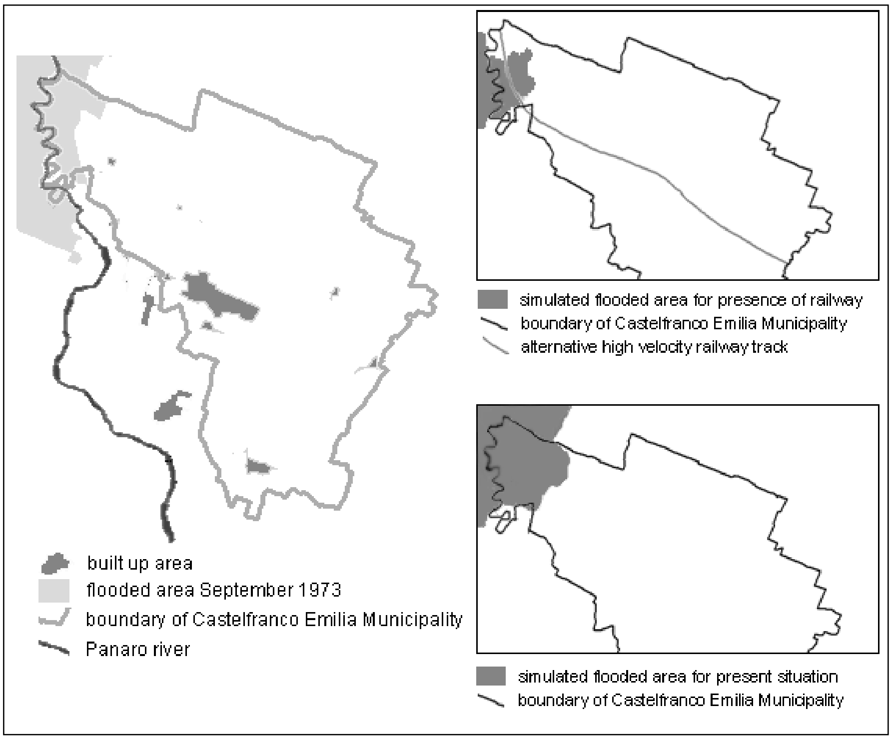

Figure 5. Presence of water on surface for the 1973 flood (left), and a simulation for one of the proposed railway routes (upper right) and the same simulation for the current situation (lower right).

5 CONCLUSIONS

From the study of meteorological data it became clear that on the basis of merely precipitation no predictions can be made with respect to the occurrence of a flood event. Given the difficulties in understanding and thus modelling the mechanisms that provoke an event, it is thought to be more fruitful to make predictions with respect to consequences of what-if scenarios, rather than predictions with respect to occurrence. Or, as Kundzewicz (1999) puts it: “it is necessary to be aware of the possibility of floods... living with floods seems more sustainable than a hopeless striving to combat floods”. In this light, a distributed dynamic model is constructed which allows for the calculation of flood scenarios, which can be fed by historical or hypothetical precipitation and discharge records.

The inclusion of alternative routes for the proposed railway allows for the evaluation and comparison of the spatial effects of a flood event. Critical points in the model are calibration and the calculation of soil saturation prior to the event.

ACKNOWLEDGMENTS

The financial support for the study was provided by the European project: “A European Research Network for the Application of Geomorphology and Environmental Impact Assessment to Transportation Systems (GETS)”, (contract ERBFMRXCT970162), Local Co-ordinator of the Modena and Reggio Emilia University, Prof. M. Panizza.

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