Flooding hazards in northern Italy: two case studies

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Abstract

This paper examines the estimation of flooding hazards in the areas adjoining a watercourse. After describing methodologies which differ in the application effort required and in the accuracy expected, it compares the results obtained from their application in two case studies. The reliability of the methods is then discussed.

Keywords: flood, hazard, hydraulic models, computer simulations.

1 Introduction

Flooding hazard evaluation is a key problem in territorial planning. As is well known, hazard is the probability that an event may happen in a place and in a given time period.

Areas at risk of flooding can be identified by means of various methods, each of which involves very different operational difficulties.

Briefly, this risk assessment may (a) restrict itself to an overview of the historically flooded areas based on existing data; (b) localize the topographical areas below the level of the water depth in the river, estimating the latter through the peak discharge for a given return period; (c) use a combination of the parameters 'level' and 'distance from the flood origin' with approximate methods; (d) use a two-dimensional complete model based on the De Saint Venant equations. This paper refers to research using the well-known Flo-2D (O'Brien, [7]) program.

This last method, even if it is the most comprehensive and reliable, involves numerous difficulties because the results are extremely sensitive to the boundary conditions and to the description of the land topography. It therefore requires careful and critical analysis.

The above-mentioned methods were applied to two different case studies: the Seriate municipality, near the River Serio (Lombardia Region in the North of Italy) and the San Benedetto Po municipality, close to the River Po. These two towns have very different characteristics, and application of the different methods yields some general information about their reliability.

The various models were compared using two parameters: the flooded area and the flooded volume.

The paper also stresses that continuous interaction between the territorial planner and the hydraulic engineer is necessary.

2 Methods

As said, various methods can be used to identify potentially flooded areas. The simplest ones are based on simple morphologic parameters (land levels and slopes, distance from the river, etc.), whilst the more complex ones use mathematical models to describe the physical phenomena.

Three methods were used for the analysis reported in this paper: (i) a topographic method based only on the water depth in the river and the land levels; (ii) a curt method, which divides the landscape into squared cells and assumes that the water moves in concentric circles; (iii) the above-mentioned 2D model.

All three methods require knowledge of the flood hydrograph in every section of the river. Used as a consequence was the well-known 1D Hec-Ras program. The hydraulic behaviour of the River Serio was studied in steady flow conditions, considering the discharge to be constant and equal to the peak of the hydrograph. The River Po was studied in steady and unsteady conditions, obtaining very similar results.

2.1 Seriate case study

The municipality of Seriate is located in the Lombardia Region of northern Italy: the landscape is mainly flat, with average slopes of about 0.8 %. The River Serio crosses the town from north to south and is quite narrow in width.

As mentioned, water depths in the river were computed using the Hec-Ras program under the steady flow hypothesis.

The discharge was $Q_{Tr=200}=700\ m^3/s$, as evaluated in a previous hydrologic study, and it was characterized by a 200-year return period.

The present study reports analysis of 25 cross-sections of the river provided by the Seriate municipality.

The modelling took account of various structural elements along the river: the *via Italia* bridge; a weir for irrigation water diversion; a railway bridge; and the *corso Roma* bridge. Downstream from the town, two road bridges cross the river.

Application of the model showed two places where flooding could be expected to occur: the first (henceforth the *bridge zone*) was located in the town upstream from the via Italia bridge, and it was at risk because of the backwater effect caused by the bridge itself. The second (henceforth the *low zone*) was an area downstream from the town, where the river embankments are below the water depth corresponding to the discharge considered.

In the case of both zones, the topographic method, the curt method and the Flo-2D mathematical model were applied.

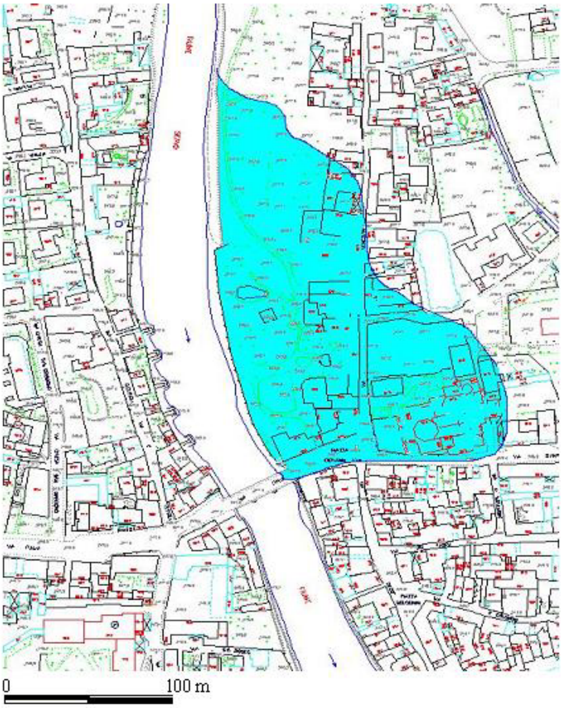

Figure 1: Potentially flooded area – evaluation by the topographic method.

2.1.1 Bridge zone

The area studied was divided into squared cells with 10 m sides.

Fig. 1 shows the potentially flooded area as evaluated by the topographic method. The area is characterised by a ground level below the river water depths.

The flooded area calculated at about 21000 m^2, with a corresponding volume of about 26000 m^3.

The curt method required previous estimation of one or more cells on the riverside where the flooding was expected. Obviously, the ground level was below the water depth in the corresponding river cross-section.

The behaviour of the flow through the inlet cell was described as the flow through a broad crested weir.

The flooded areas were then plotted on the hypothesis that water flows follow concentric circles, with their centre in the initial point of flooding, towards the cells where the ground level is lower. $Q_r=Q/n$ is the discharge of a generic cell at a distance r from the inlet; Q is the maximum flooded discharge linked with the considered node; n is the total number of cells with ground levels below the initial point of flooding within the $n = 2 \cdot \pi \cdot r / \Delta x$ (Δx is the side of the squared grid; as said, in this case Δx is equal to 10 *m*) cells on the circumference with radius *r*.

Thus, this method considers not only the ground level parameter but also the distance from the river: in fact, for flat landscapes, or more importantly for pensile rivers (the river course is higher than the plain), when the circles are of larger area, the number of cells satisfying the method's requirements increases. However, when Q_r reaches a minimum value (when the water velocity on the ground is negligible), the radius of the circle does not increase any further.

The sum of the discharges from each computing cell enables calculation of the required discharge distribution. This simplification, based on the hypothesis that flows within each cell are independent, does not respect the mass equation, but it enables a quite reliable flooding hazard scenario to be rapidly produced.

This method yielded the following values of the flood volume and area: $7400 m^3$ and $9300\ m^2$.

These results were compared with the ones obtained using the Flo-2D program. Using this program requires prior knowledge of the entire hydrograph, the topography, the roughness and the permeability of the landscape and the land use.

The first phase of analysis involves superimposition of a regular squared grid, with 10 *m* side, on an adequately defined map of the potentially flooded area with digitized ground levels.

Every cell is characterised by its ground level and by a Manning roughness coefficient *n*, depending on the land use (0.02 $m^{-1/3}s$ for streets and roofs, 0.05 $m^{-1/3}s$ for gardens and brushes, 0.08 $m^{-1/3}s$ for high vegetation).

The simulated site is about 500 *m* long and 250 *m* wide and urban areas are mostly included.

Preliminary search of the cell is not necessary where the flooding starts. Nor is it necessary to construct the outflow hydrograph, because the program itself allows study of the water volume exchanges between the river and the flooded area by computing the water depths.

The analysis performed with this program seems quite accurate from the hydraulic point of view. The results are shown in Fig. 2.

Fig. 2 also shows that the land on the right river side is also flooded, even if to a lesser extent. This was not shown by the topographic and the curt methods.

A comparison between flooded volumes and areas carried out using this latter approach and the others is shown in Table 1. This comparison highlights that the topographic method generally gives rise to an overestimation of flooded area: it does not take account, in fact, of either the flooding discharge or the presence of obstacles limiting the flooding wave propagation.

Without modelling the river, having imposed the breakage point and considering only the river left side, a further simulation was carried out using Flo-2D model. Results are reported in Table 1 as “Flo-2D (b)”. It will be seen that the hypotheses adopted play a major role and, as a consequence, they have to be carefully implemented.

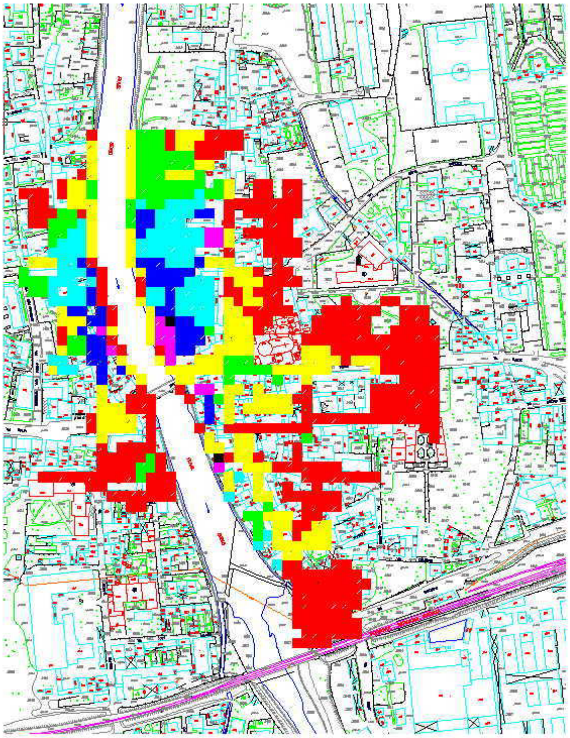

Figure 2: Simulation with Flo – 2D program: maximum flooded area.

Table 1: Obtained results for *Bridge Zone* in Seriate.

Method	Max. volume $[m^3]$	Max. area $[m^2]$
Topographic	26000	21000
Curt	7400	9300
Flo – 2D	50000	70000
Flo – 2D (b)	10000	13800

2.1.2 Low zone

The topographic and curt methods were also applied to the low zone, where the one dimensional model showed that the water depth in the river is higher than in the right bank when discharges are more than 600 m^3/s, corresponding to a 100-year return period.

This mainly flat landscape has few buildings and obstructions and is characterised by green areas.

A 30 *m* squared grid was superimposed on the topographic map of the area; the length of the side seemed to be a good compromise between precision and computational effort.

As Table 2 shows, the topographic method again produced marked overestimations of flooded areas when compared with the curt method.

Table 2: Obtained results for low zone in Seriate.

Method	Max. volume $[m^3]$	Max. area $[m^2]$
Topographic	138000	87300
Curt	36000	56000
Flo – 2D	35000	82800

Assuming that the results produced by the Flo-2D program are correct, to be noted is that although the topographic method is very easy to use, it yields overestimations of both the flooded volumes and areas.

The curt method, although different choices of the inlet cell are possible, yields a good evaluation of flooded volumes. Flooded areas, however, seem to be underestimated; this result seems to be a consequence of the choice of the inlet cell.

2.2 San Benedetto Po case study

The same methods applied to the Seriate case study were used for the San Benedetto Po municipality, near Mantova, where a stretch of the River Po river was studied. The river characteristics and the problems to be addressed were different from those of the River Serio. In this area, in fact, the River Po flows through a completely flat landscape (slopes of about 1‰). This is a hanging river and main embankments are present. In the stretch studied, the riverbed is about 500 *m* wide and the distance between main embankments is about 1 *km*.

Despite considerable re-embankment work on the main river and on its tributaries, the situation of San Benedetto Po landscape is still critical from a hydraulic point of view.

For these reasons, using the methods described requires different hypotheses to be adopted. First, the topographic method cannot be used owing to the landscape: in fact, for pensile rivers this method produces unacceptable overestimations of flooded areas.

On the other hand, when embankments are present it is necessary to conduct the study with different scenarios, assuming breakage of the bank in different positions and in different situations.

In this case, the area investigated was about 90 km^2 large. The choice of the area was based on historical events and on the characteristics of the landscape, which has low ground levels and is bounded by the Po and Secchia embankments.

A regular 100 *m* square grid was superimposed on a topographic map of the potentially flooded area. The grid selected was a compromise between the desired detail level and the computational effort (due to the extension of the area). Moreover, this choice was justified because the landscape was very flat, with ground levels varying between 15 and 18 *m a.s.l.*, so that greater detail would not have produced more significant results.

As said, the curt method requires the previous selection of the cells for the flooding wave input; in this case a single cell was used, positioned where the embankment breakage was assumed to occur.

The embankment breakage was simulated as a breach of 100 *m* width and 4.5 *m* height (these values were estimated by analysing photographs taken after a breakage occurred in the area during the flooding of 2000) occurring when the water level in the river reached 21 *m a.s.l.* The output from the river bed was simulated as the flow through a broad crested weir.

In order to evaluate the output hydrograph from the breach, the wave in an upstream cross section of the river was computed. This hydrograph formed the basis for computation of water depths in the section concerned using Chezy's formula (steady flow hypothesis). It was found that lamination phenomena between the two sections (the distance was 20 *km*) were negligible, because the volume that could be stored in the flood plain areas was very small compared to the total wave volume (assuming a water depth of 5*m* in 600 *ha* of flood plain area (where the ground level is on average 19 *m a.s.l.*), the stored volume is equal to $3\cdot10^7 m^3$, which is 0.75% of the total wave volume).

The total volume of the wave with a 200-year return period was about $4.6\cdot10^9$ m^3. The maximum discharge flowing from the breach was 979 m^3/s, while the ground level of the matching cell (equal to the bottom of the breach) was 19 *m a.s.l.*

While in Seriate the flooding circle radius was drawn until cells with higher ground level were met, this was not possible in San Benedetto Po because excessively high overestimations of flooded areas would be computed. In order to take due account also of the distance from the river, the distance where the discharge Q_r (previously defined as the discharge assigned to a cell with distance r from the inlet of the flooding wave ($Q_r=Q/n$) was equal to 1% of the maximum inlet discharge was computed. The 1% of the maximum discharge (equal to 9.79 m^3/s) was calculated to be a distance r equal to 3.1 *km* from the embankment breakage. The flooding radius did not extend any further because, for discharge values lower than 10 m^3/s traversing a cell with an area of 10000 m^2, velocities were negligible.

Flooded volumes and areas computed with this method were respectively $6.3\cdot10^7$ m^3 and $1.6\cdot10^7$ m^2.

The two dimensional Flo–2D model was then used to simulate the progress of the wave in the landscape. The simulation results are reported in Figures 3 and 4.

The figures show that the potentially flooded area lies between the embankments of the River Po (to the north-west) and the River Secchia (to the east). The north-east zone in this area is the lowest, and as a consequence has the deepest water depths. A further restriction on the wave flow is the railway, which crosses the municipality landscape from the north-west to the south-east, following the southern boundary of the area in which the greatest water depths are found. Other structures like roads and pensile canals seem not to influence the wave propagation significantly, owing to their low heights.

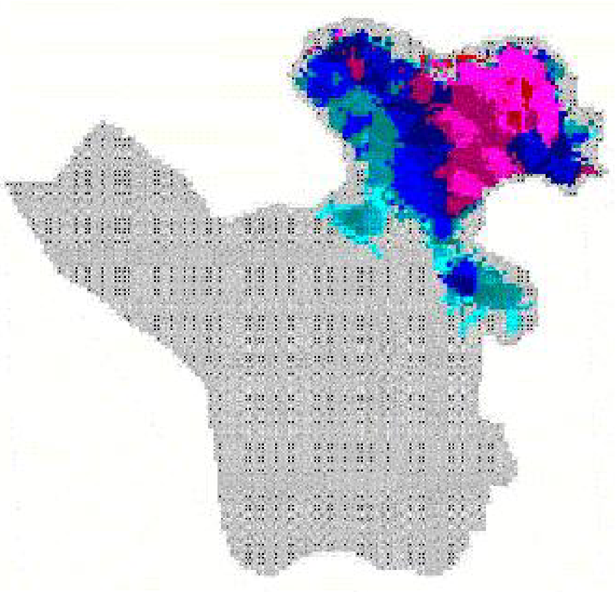

Figure 3: Flooded area 24 hours after breakage.

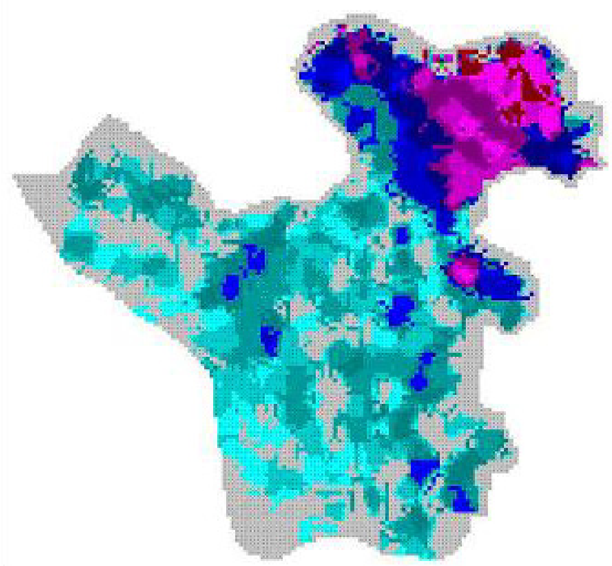

Figure 4: Flooded area 72 hours after breakage.

The results show that the wave reaches the town 24 hours after the embankment breakage; this evaluation is extremely important for emergency action planning.

Flooded volumes and areas are respectively $8.06 \cdot 10^8$ m^3 and $6.6 \cdot 10^7$ m^2.

It will be observed that after the wave has overcome structures of minor importance, it is also able to overcome the railway, which is positioned 6 *km* from the breakage and at a ground level of 19 *m a.s.l.*

The values obtained with Flo-2D are significantly higher than the ones carried out with the curt method (Table 3). This result highlights that the working hypothesis strongly affects the results, especially when the area studied is very flat, so that small variations in the hydraulic levels produce important variations in the flooded areas.

Table 3: Results for San Benedetto Po.

Method	Max. volume $[10^6\ m^3]$	Max. area $[10^6\ m^2]$
Curt	63	16
Flo-2D	806	66

3 Conclusions

The need for more detailed and complete investigations is obvious from the results set out in the paper; for instance, greater detail in topographic maps is generally required.

The topographic method performs best for embedded rivers (the river course is lower than the plain), where the ground levels increase further away from the river itself.

The Seriate case study lies in an intermediate situation. Serio is an excavated river where the thalweg is lower than the riverside ground levels; however, the adjacent areas are quite flat. For these reasons, the curt method application should be always preceded by detailed study of the landscape.

Nevertheless, the results seem to furnish a good representation of flooding hazards in the areas studied.

It is also obvious that only the convolution of this hazard with exposed elements vulnerability on the land can yield definition of the related flooding risk. Analysis thus requires the drawing of maps that visualize the various risk levels on the land and enable verification of consistency between planning choices and flooding risk prevention and mitigation actions.

A multi-disciplinary approach is always necessary in this kind of study; a good example of this necessity is the choice of the position of the embankment breakage for simulations of the flooding of a pensile river. If the breach dimensions are assumed in relation to the embankment conditions, and if account is taken of past accidents, its position should be selected bearing in mind both its probability of occurrence (and in this case a hydraulic engineer is required) and the risk connected with the breakage. In the latter case, because both the flooding hazard and the land vulnerability are involved, the decision should be taken jointly with the planner.

Similarly, planning is tied to soil use hypotheses on which the results closely depend.

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