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Flood risk assessment for EIA; an example of a motorway near Trento, Italy

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Abstract
Flood risk assessment for EIA; an example of a motorway near Trento, Italy. There are various aspects of floods that can be described with indicator maps, like waterlevel, flow-velocity, etc. This paper gives an example how flood indicator maps can be transformed to a flood risk assessment. An example is given for economic damage (that can be quantified in monetary terms) and for social risk.

Keywords:
Floods, flood modelling, flood risk, environmental impact assessment

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1. INTRODUCTION

In recent years there have been a number of significant riverine floods in Europe and in the rest of the world, which resulted in tragic loss of life and in enormous material damage. In the past decades, thousands of lives have been lost, directly or indirectly, by flooding. In fact, of all natural risks, floods pose the most widely distributed natural risk to life today. It is also clear that no protection work can offer a hundred percent security against floods. There is always the possibility that a threshold is surpassed and that floodwater will enter into areas where it should not go, e.g. by overtopping or breaching of dikes. Another problem is that as the level of security is higher, people feel safer and are encouraged to life and work in potentially dangerous areas. The higher the dikes, the bigger the disaster if it goes wrong. Nowadays people have so much faith in the protection works that alluvial plains are among the most densely populated areas in the world with a large accumulation of valuable property. The Adige valley north of Trento is a good example of such an area. The area is characterised by high population density, intensive agriculture and is an important transit zone for international traffic. The near flood of October 2000 should serve as a reminder that floods are a serious risk to those living and working in the area.
New developments in areas that are potentially at risk of flooding can affect the consequences of a flood. The development of a new motorway in the Adige valley, Italy is used as an example to show how an embanked structure can alter the propagation characteristics of a

flood by changing the terrain topography and how this can affect the people and property in the inundated area. The objective of this study is to develop a methodology that allows including these potential broader impacts of the new construction into Environmental Impact Assessment (EIA) procedures that are usually mandatory for these kinds of projects.

2. FLOOD RISK ASSESSMENT

Assessment of the flood risk is a complex problem that can only be solved through interdisciplinary research. A two-step approach has been adopted. First it was needed to characterise the flood hazard using a selected set of indicator maps, like the spatial distribution of flow velocity, water height, speed of propagation, duration, etc.
The second step was to estimate how the flood hazard indicators interfere with human activities in the flooded area. Agricultural activities will suffer damage in different ways than for instance an industrial zone or an urban area. Also aspects of civil protection need to be considered, like when people need to be evacuated and which transportation lines are still available in the inundated area.

2.1 Flood hazard assessment

For the characterisation of potential floods a two-dimensional finite element propagation model Delft-FLS (STELLING *et alii*, 1998) was used. Delft FLS is specially designed to simulate riverine floods due to ruptures of the dikes and is very suitable for modelling of flow over initially dry land and complex topography. A systematic set of scenarios was modelled, varying the discharge of the main river and the location of the rupture. At regular time intervals the model generates maps for each scenario of the water height and flow velocity. These maps are then transformed into six indicator maps: maximum waterlevel, maximum flow velocity, maximum impulse (amount of moving water), maximum speed of rising of the waterlevel, duration and the arrival time of the first floodwaters. For each scenario, this set of indicator maps describes the various aspects of a flood event that could be useful for the risk assessment.

2.2 Flood risk assessment

The flood hazard indicators are independent of the land-use. To assess flood risk, additional information is needed on the tolerance to floods of the various land-use units in the inundated territory and their value. A preliminary flood risk model was made, using a GIS to integrate the flood hazard indicator maps, the tolerance to flood information and data on the value of property into two complementary impact assessments. One to estimate the risk that can be quantified in monetary terms (economic impact) such as damage to buildings and loss of agricultural production, and one to estimate the "social" risk, that relates to the human suffering that cannot be so easily expressed in monetary terms, like need to be evacuated. Due to the fact that little information is available on the tolerance to floods of the various land-use units, it is difficult to obtain absolute results. However, using expert knowledge from many different disciplines (agriculture, civil engineering, etc.) it is possible to compare the various scenarios and to obtain relative results, ranking the alternatives from best to worst.

3. FLOOD MODELLING

3.1 The flood model

The flood inundation model Delft-FLS is developed at Delft-Hydraulics and was considered to be very suitable this research. The numerical schemes can tackle flow over initially dry land and flow phenomena occurring shortly after dam-break. Both the progressive wave phase and the basin filling are described accurately. It computes on a rectangular grid and geometrical input data can be specified in a number of ways, so that land layout features as dikes, roads, railroads, waterways, viaducts etc. can easily be included in the analysis. The user can force dam-breaks so that "what if" scenarios can be investigated. For more information on Delft FLS, see HESSELINK *et alii,* 2001).

3.2 Required data

The model requires the following input data:

- An accurate and detailed DTM that contains all relevant terrain features, including the river bed (figure 2a)
- The relation between discharge and waterlevel (Qh-relation) at one location in the river.
- A discharge time series (figure 3a).
- A surface roughness map (resistance to flow by friction).

The digital terrain model was obtained from the Servizio Urbanistica of the Autonomous Province of Trento. A filtering operation was applied to smooth the valley floor. Riverbed morphology and dikes heights were added manually, based on cross-section data that was provided by the Autorità di Bacino dell'Adige. The same was done with important anthropic terrain features like the Brenner motorway and the railroad line. The required hydrological data was obtained from the Ufficio Acqua of the Province and the surface roughness map was derived from the landcover map, made by GENELETTI (2002). Table 1 shows the values for Manning's n that were attributed to the various landcover units.

3.3 Scenario construction

A scenario is defined as the unique combination of the following three elements:

- Rupture location (8 locations – see figure 2b)
- Discharge Adige (2 return intervals – see figures 3b and 3c)
- Motorway alternative (3 alternatives, including present situation – see figure 2c)

This resulted in a total of 48 flood scenarios.

3.4 Flood indicator maps

For each scenario the model output was transformed to a set of six indicator maps. Figure 4 shows the six indicators, aggregated over rupture location for the 50 years flood. This is the "worst case" situation.

LAND-USE	Manning	LAND-USE	Manning	LAND-USE	Manning
Bare	0.005	Larch wood	0.12	Orchards	0.10
Pasture	0.04	Oak wood	0.12	Vineyards	0.07
Grassland	0.03	P. Nigra pinewood	0.16	Road	0.005
Shrub lands	0.05	Scots pinewood	0.16	Urban	0.20
Orno-Ostryetum	0.06	Fir wood	0.16	Water	0.04
Beech wood	0.10	River vegetation	0.12	Canal	0.01

Table 1: Listing of Manning's coefficients

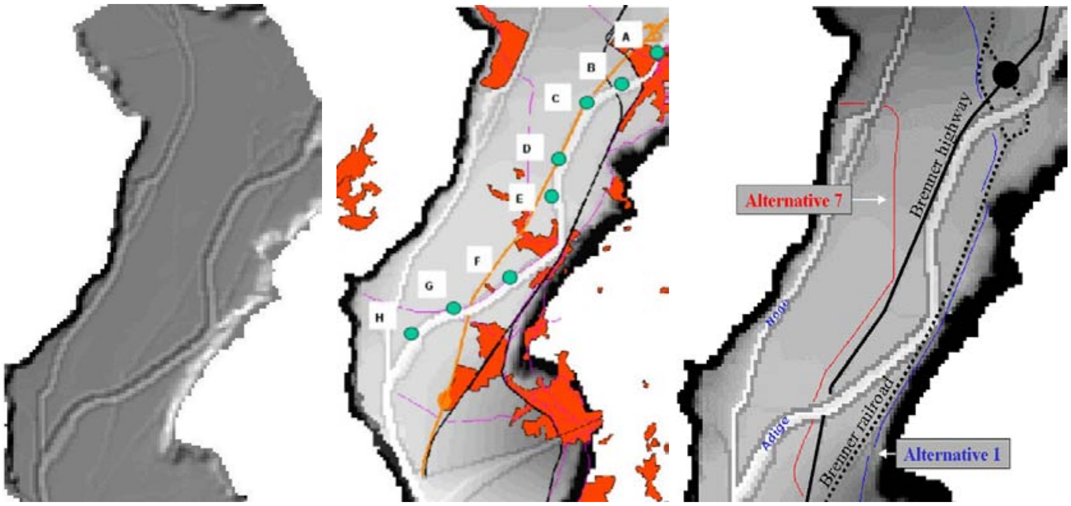


Figure 2: a) The smoothed DTM with inserted the Adige riverbed and main infrastructure; b) the location of the breaches in the scenarios; and c) the 3 road alternatives: no new road, road alternative 1 and road alternative 7 (numbering coincides with GENELETTI AND ALKEMA, 2002)

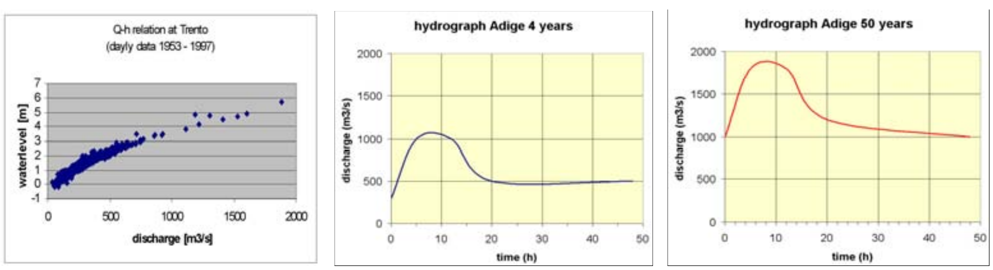


Figure 3: Hydraulic data; a) q-h relation of the Adige at Trento; b) flood hydrograph of the 4 year flood; and c) the flood hydrograph of the 50 year flood

4. RISK ASSESSMENT

The five indicator maps describe the distribution of flood hazard for each scenario, but they don't take into consideration what the effects would be on the area that is inundated. In other words, the flood hazard maps are independent from the land-use. Clearly if one wants to carry out an impact assessment, the occupation of the flooded territory needs to be included in the procedure. The indicator maps need to be combined with vulnerability information and data about the value of the various anthropological elements in the flooded area.

4.1 Damage versus social risk

A distinction is made between economic and social impact. With economic impact is indicated all damage that can be quantified in monetary terms, like damage to houses or reduction in agricultural production. With social impact are indicated those impacts that relate to human suffering but are not so easily expressed in monetary units, like the warning time people have to prepare themselves to be evacuated.

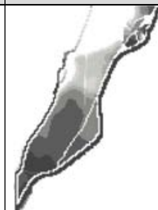
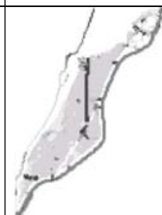
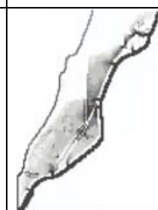
Indicator	**Key**	**Present situation (0 alternative)**	**Road Alternative 1**	**Road Alternative 7**
Water-level (Maximum inundation depth)	0 0.0 - 0.2 m 0.2 - 0.5 m 0.5 - 1.0 m 1.0 - 1.5 m 1.5 - 2.5 m 2.5 - 3.5 m > 3.5 m			
Flow velocity (Maximum flow velocity)	0 0.0 - 0.1 m/s 0.1 - 0.5 m/s 0.5 - 1.0 m/s 1.0 - 2.0 m/s > 2.0 m/s			
Impulse (Waterlevel x flow-velocity = Quantity of moving water)	0 0.00 - 0.10 m * m/s 0.10 - 0.20 m * m/s 0.20 - 0.30 m * m/s 0.30 - 0.40 m * m/s 0.40 - 0.80 m * m/s > 0.80 m * m/s			
Rising (Maximum speed of rising of the water-level)	0 0.00 - 0.10 m/h 0.10 - 0.30 m/h 0.30 - 0.50 m/h 0.50 - 0.75 m/h 0.75 - 1.00 m/h > 1.00 m/h			
Duration (Estimated duration of the inundation)	0 < 2 days 2 - 4 days 4 - 7 days 7 - 10 days 10 - 14 days > 14 days			
Warning time (Time between dike failure and the arrival of the floodwaters)	0 < 1 hour 1 - 3 hours 3 - 5 hours 5 - 8 hours 8 - 12 hours > 12 hours not within14 hours			

Figure 4: Aggregated indicator maps of the 50-year flood for the three road alternatives; The results of the eight rupture locations were combined to obtain these "worst-case" results.

4.2 Damage

The economic damage estimate was based on four components: There are agricultural activities and buildings that can both be affected by non-structural damage and by structural damage. With non-structural damage for agriculture is intended that the harvest is not destroyed but that the yields have become less either in quality or quantity. Non-structural damage to buildings can be interpreted as damage due to the wetting of carpets, wallpaper, furniture, machines, appliances, etc. Structural damage to crops means that the harvest is destroyed. For crops that produce more than one year (e.g. vineyards and orchards this means, not only income for the year of the flood is affected but also the income of the following years because new plants have to be planted and need to grow before they start to produce again. Structural damage to buildings means that (part of) part of the structure needs to re-build.

4.2.1 Non structural damage

Non-structural damage is considered to be a function of inundation depth (maximum waterlevel) and the duration of the inundation. For each land cover unit, a matrix was constructed that contained an estimate of the degree of damage for every possible combination of waterlevel and duration, ranging from 0 (no damage) to 1 (complete loss). Figure 5 shows an example of such a matrix for vineyards. The damage is calculated as the product of degree of damage and the total value of the landcover unit.

	0	0.0 – 0.2	0.2 – 0.5	0.5 – 1.0	1.0 – 1.5	1.5 – 2.5	2.5 – 3.5	> 3.5 m
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
< 2 days	0.00	0.00	0.00	0.10	0.30	0.60	0.80	0.80
2 – 4 days	0.00	0.00	0.00	0.20	0.50	0.80	1.00	1.00
4 – 7 days	0.00	0.00	0.10	0.30	0.70	0.90	1.00	1.00
7 – 10 days	0.00	0.10	0.20	0.40	0.90	1.00	1.00	1.00
10 – 14 days	0.00	0.10	0.20	0.60	1.00	1.00	1.00	1.00
> 14 days	0.00	0.10	0.30	0.80	1.00	1.00	1.00	1.00

Figure 5: Example of the non-structural damage matrix of vineyards, based on duration of the inundation and maximum waterlevel.

4.2.2 Structural damage

Structural damage is related to the amount of moving water, i.e. to the impulse. A lot of water moving fast will cause more damage than little water that doesn't have a high flow velocity. Structural damage can happen to buildings (damage to walls, etc.) or to multi-annual crops like vineyards and orchards. If the vineyards are destroyed, not only the harvest of one year is lost, but also the harvest of the next years.

Two thresholds were defined that need to be surpassed before structural damage can occur: First a minimum waterlevel is required where damage starts to occur. Once a critical impulse (product of waterlevel and flow-velocity) is reached the object can be considered as a total loss. These thresholds are defined for each landcover unit separately. The degree of damage between these two limits is estimated, using a parabolic function, as illustrated in figure 6 for agricultural landcover units.

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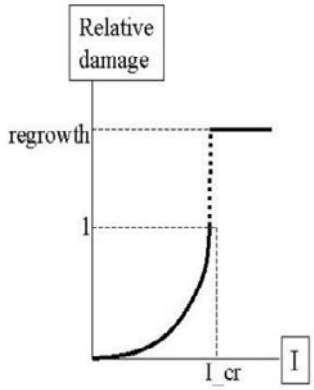

Figure 6: Damage as function of the impulse.

At low impulses there is little damage, but as impulse nears the critical value, the damage percentage rises fast to 1. When the maximum impulse is higher than the critical impulse, the curve becomes discontinuous and jumps to the level defined by the "regrowth" value. This implies that the crop (or building) is considered as a total loss and that the damage is not only limited to the loss of one year's production, but that also the loss of future harvests should be included, until the newly planted crops start to produce again. For buildings "regrowth" can be interpreted as clean-up costs and costs for evacuation shelter etc.
The total structural damage is the product of the degree of damage and the estimated value of the landcover unit.

4.2.3 Total damage map
For each map-pixel two damage estimates are available: the structural damage and the non-structural damage. The total damage map represents the maximum value of these two.

4.3 Social risk
The social risk is defined on two criteria: 1) Is the area flooded within four hours and 2) does the waterlevel rise higher than 2 meters? Note that this doesn't mean that the waterlevel rises above two meters within four hours. In fact a fifth class is defined for those areas where the waterlevel rises to a level of higher than two meters within six hours after the rupture of the dike. This is illustrated in figure 7.

Social Risk		Time to flooding < 4 hours	
		No	Yes
Maximum Waterlevel > 2m	No	1	2
	Yes	3	4
Waterlevel > 2m in < 6 hours			5

Figure 7: Criteria for social risk zonation

4.4 Flood risk comparison

The procedure described above results in a total damage map and a social risk map for each of the 48 scenarios. These were divided in six groups:

- road alt. 0; 4 years flood;
- road alt. 1; 4 years flood;
- road alt. 7; 4 years flood;
- road alt. 0; 50 years flood;
- road alt. 1; 50 years flood;
- road alt. 7; 50 years flood;

For each group, a single maximum damage map and maximum social risk were calculated by taking the maximum values for each of the breaching locations: The worst-case scenario. For the 4 years flood and the 50 years flood, the two road alternatives were then compared with the zero alternative using two different methods: 1). Summing up all pixel-values to a total risk value and 2). The risk map of the zero alternative was subtracted from the risk maps of alternative 1 and 7.

The first method means that the spatial component is lost, but it does allow the ranking of the three alternatives from highest to lowest risk (see table 2). The second method shows where the risk will increase and decrease because of the new development, thus keeping spatiality (see figure 8), but it does not allow ranking of the alternatives. The second method also shows that, even though the overall situation may have improved, not everybody benefits equally from to the protective function of the new motorway.

ECONOMIC DAMAGE	**Present topography**	**Road Alternative 1**	**Road Alternative 7**
Return Interval 4 years	1.0	1.0	0.69
Return Interval 50 years	9.6	9.7	9.8
SOCIAL RISK			
Return Interval 4 years	1.0	1.0	0.77
Return Interval 50 years	6.7	6.8	6.5

Table 2: Comparison of the total economic damage and social risk. The present topography / return interval 4 years is used as reference (=1). The higher the value, the higher the damage or risk.

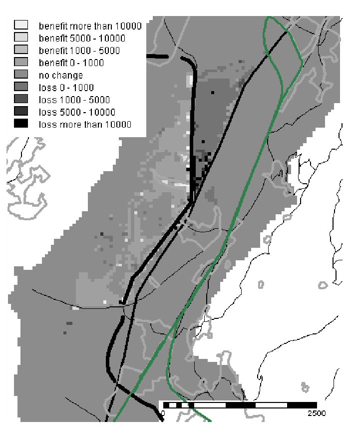

Figure 8: Spatial distribution of difference in economic damage due to road alternative 7.

5. DISCUSSION

Road alternative 1 does not seem to have a great effect on the flood risk and damage. This is for a large part due to its location on the side of the valley. It crosses the valley at a point where the Adige alluvial plain is at its narrowest, thanks to the alluvial fan of the Noce (Piana Rotaliana). This narrow stretch forms a bottleneck for floodwaters to pass from north to south. The addition of an embanked road does not seem to increase this hinder. Road alternative 7, however does have a significant effect on the flood risk and flood damage estimate for smaller floods (4 year return interval). For the 50 years interval the effect on the total risk and damage is less clear. However, figure 7 shows that locally the effect of the road can be significant. For some inhabitants, the situation has clearly improved, while for others floods have become an even greater risk. These local effects should be considered seriously in an Environmental Impact Assessment.

6. CONCLUSION

This example demonstrates that it is possible to foresee how new developments on an alluvial plain may interfere with the flood characteristics in case of a flood event. Such studies could help to prevent undesirable side effects of the development and to implement mitigation measures. This could help avoiding that a dramatic event like a flood turns into a disaster because of unwise planning. These kinds of studies should be integrated into environmental impact assessments that are usually mandatory for large projects like a new motorway. This allows to balance considerations about flood risk against other environmental impacts due to the project. Furthermore, the visualisation power of flood simulations will help to bridge the gap between the scientific community and the responsible authorities. For non-experts the extend of a potential flood is usually hard to imagine. Simulations are a valuable communication tool to visualise the flood hazard in terms of magnitude, area affected and return intervals.

The integration of flood hazard and the vulnerability and value of the various land-use units into a flood impact assessment is a crucial next step that requires the cooperation of a team of interdisciplinary experts and the responsible authorities. This example demonstrates that a relative assessment is possible so that a ranking of the various project alternatives can be carried out. It is hard to assess an absolute risk estimate because of limited information about the exact damaging effects of floodwaters related to the various land-use units. The transformation of the flood hazard indicator maps into a flood impact assessment requires additional research.

7. ACKNOWLEDGEMENT

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Summary

New developments on an alluvial plain can seriously affect the characteristics of a future flood. With flood propagation models, future flood scenarios can be simulated, to quantify these changes with indicator maps. However, to assess if the flood risk has increased or not, the results need to be combined with information on the vulnerability and value of the exposed elements. This paper gives an example how flood indicator maps can be transformed to a flood risk assessment. An example is given for economic damage (that can be quantified in monetary terms) and for social risk. To allow comparison between various scenarios, the results need to be aggregated to single values. This results in a loss of spatial information that can hide the fact that even though the situation for the total area may have improved, not everybody benefits equally. In fact, in some local areas the risk may have increased significantly.

Riassunto

Nuove insediamenti antropici in una piana alluvionale possono seriamente influenzare le caratteristiche dei fenomeni alluvionali. L'utilizzo di modelli bidimensionali di flusso permettono di poter simulare e quantificare questi cambiamenti mediante l'utilizzo di carte di indicatori. Tuttavia, la valutazione del rischio richiede anche che il risultati sia integrato con la vulnerabilità ed il valore degli elementi esposti.

Questo lavoro fornisce un esempio di come queste carte degli indicatori possano essere utilizzate per la valutazione del rischio. Nell'esempio il danno viene valutato a livello economico (che può essere quantificato in termini monetari) e come rischio sociale. Al fine di permettere la comparazione tra i vari scenari, i risultati che si presentano in forma spaziale, devono essere aggregati in singoli valori. Ciò comporta una perdita di informazione spaziale che può celare il fatto che a livello generale si ottenga che si possa avere un certo beneficio ma che questo non sia costante su tutta l'area.

Infatti in alcune aree locali il rischio subisce degli incrementi rilevanti.