

INTEGRATED DATASETS, GIS AND 3-D SYSTEM ANALYSIS FOR ENVIRONMENTAL IMPACT ASSESSMENT IN A LARGE ALPINE VALLEY NORTH OF TRENTO (ITALY)

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ABSTRACT

The incorporation of geomorphologic considerations in an Environmental Impact Assessment (EIA) is usually hindered by the complexity of geomorphologic systems. This paper intends to make a contribution to integrate knowledge of geomorphologic processes into EIA procedures. More detailed elaboration of geomorphologic systems through modelling will enable to forecast change in indicators due to a development. As an example, the preliminary results of a case study near Trento (Italy) are presented. The objective of this case-study is to show how the construction of a new motorway will interact with the flood-propagation on the plain in case of a flooding. Such a study will be a contribution to reduce flood risk.

1 INTRODUCTION

An environmental impact can be described as the change in an environmental parameter, over a specific period and within a defined area, resulting from the development compared with the situation which would have occurred had the development not been initiated (Wathern, 1989). The assessment of environmental impact (EIA) of a development has become an important management tool in the decision-making process in many countries. It provides decision-makers with a systematic analysis of the environmental consequences of a development, so that they can include environmental considerations in the decision process (Beinat 1999).

Traditional EIA tends to focus on ecology and pollution. But many of the major effects are actually connected to the physical and geomorphologic conditions (Cavallin et al., 1994). Important ecotopes for instance are often characterised by their geomorphologic setting. This observation is not new, as can be demonstrated by numerous papers on the role of geomorphology in EIA (e.g. van Asch & van Dijck, 1994; Rivas et al. 1994). Still few EIA-examples of are available where geomorphology plays a central role. The inherent complexity and multi-disciplinary character of geomorphology makes it difficult to integrate it into an EIA. A stepwise approach is needed.

2 GEOMORPHOLOGIC ASSETS AND PROCESSES IN RELATION TO A DEVELOPMENT

Panizza (1994) suggests to divide geomorphology into two main components: 1) processes, that can cause hazardous situations; 2) assets, that comprise landforms and raw (extractable) materials. Geomorphologic hazards are natural conditions that can cause loss of life or damage to property. They can be described as the probability that a certain geomorphologic process will occur in a certain territory with a certain intensity in a given period of time. Geomorphologic assets are sites or landscapes of great scientific heritage value or – in the case of raw materials – of (potential) economic value. A development interacts differently with either of these two components according to Cavallin et al. (1994) who identified five different potential effects:

- **direct impact:** the development damages a geomorphologic asset;
- **indirect impact:** the development induces another hazard that can cause damage to a geomorphologic asset;
- **risk:** the possibility that the development is damaged due to a geomorphologic process (hazard);
- **direct risk:** the possibility that the development changes the characteristics of a geomorphologic process (induced hazard) which in turn may damage the development;
- **indirect risk:** the possibility of damage to the surrounding environment due to changes in the characteristics of a geomorphologic process, caused by the development (induced hazard).

Geomorphologic impact assessment

A lot of authors have proposed methodologies to evaluate geomorphologic assets and hazards. In general they are based on a detailed geomorphologic map which, in combination with additional information on e.g. lithology, hydrogeology, slope angle and of historic events, allows a quantitative assessment of the assets and the dynamics of the active processes in the area of interest. They permit to evaluate the direct impact of the development on the geomorphologic assets. These methodologies are not sufficient to assess the indirect impact and the risks posed by geomorphologic processes and more rigorous techniques need to be applied. Indirect impact, risk, direct risk and indirect risk are the result of geomorphologic processes or the result of changes in the geomorphologic processes due to the development. To be able to forecast the dynamics of the geo-morphologic processes and their interaction with the development, more fundamental knowledge about the mechanics of the geomorphologic system is required. It is here that system analysis can play major role.

3 GEOMORPHOLOGY AS A SYSTEM ANALYSIS

Geomorphologic processes are too complex to be studied as a whole. For a better understanding it is necessary to study separately the catchment basin system, the slope system, the fluvial system, etc., that can be understood by (a group of) experts. This will lead to an understanding of how that specific system functions. Then the task awaits to integrate all this knowledge into a integrated picture of the total. System analysis offers a framework to define causes, mechanisms and effects of the processes in terms of mass and energy. But the problem is to integrate some of these open systems into a synthesis that represents the complexity of the geomorphologic processes with their interactions.

Conceptual model

An integrated system synthesis can be represented by a conceptual model. The conceptual model is the assemblage of all possible elements that may be of importance for a geomorphologic system and through links one can indicate that in some way the various elements are related or interact (fig. 1). Some links may indicate cause-effect relations, according to mass and energy. A correct conceptual model helps to define the system, and functions as discussion tool for those scientists that are involved in the analysis. In the study of a geomorphologic system it is necessary to link it with the anthropic system. For each element one can ask the question “why is this element important for my task?”. This will ultimately lead to the recognition that we need data about each element because they affect human concerns – things that we care about, like human life and health, but also economic and environmental considerations. The construction of a conceptual model is very important. Those elements should be included in the model that are sensitive to the development and that have a link with human concerns: if the development changes the characteristics of an element then eventually it will affect things we care about.

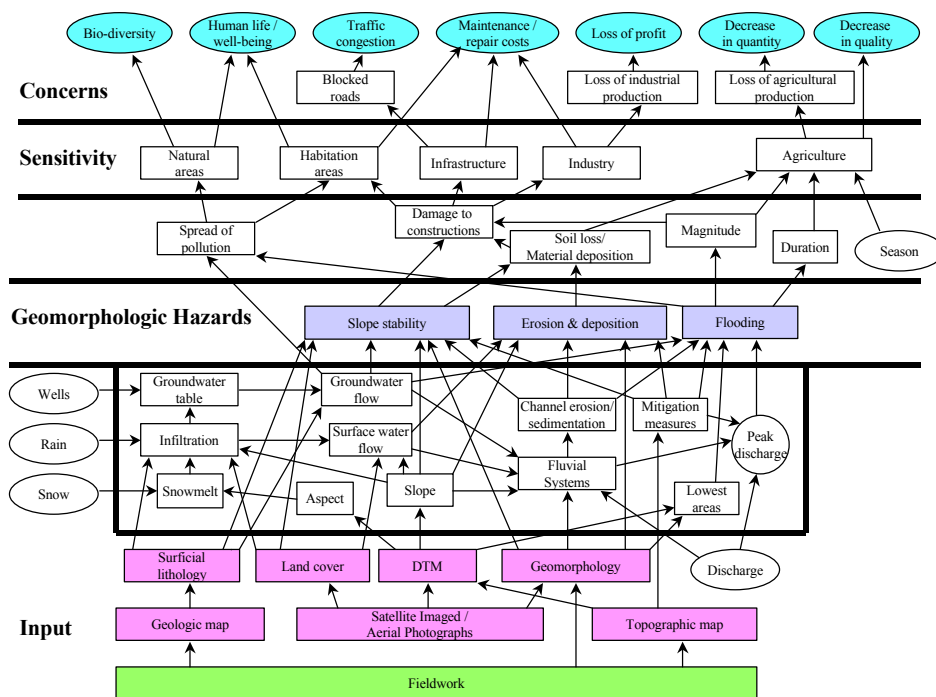


Fig. 1: An example of a conceptual model.

Indicators

A correct conceptual model can summarise a geomorphologic system. Once the link between the anthropic system and geomorphology is established, key-parameters can be identified that have a dual function: 1) they summarise the output of a specific part of the geomorphologic process; 2) they describe the interaction of a specific part of a geomorphologic process and human concerns. Key parameters that have such a dual function are called indicators. Lorenz, (1999): "Indicators describe the system or process such that they have significance beyond their face value; they aim to communicate information of the system or process; the dominant criterion behind an indicator's specification is scientific knowledge and judgement". Whenever geomorphologic processes with a certain intensity interact with human concerns, they are called hazards. Indicators are thus important parameters that on one hand give information on the hazard (like magnitude, frequency, spatial distribution, etc.) and on the other have additional importance because we can translate them into impact or risk if we know the sensitivity (or vulnerability) and value of the various elements of the anthropic system to these parameters.

Identification of critical elements

A development will interact with a geomorphologic system and this may lead to a change in the parameters of the indicators compared to the initial situation. Consequently, changes in indicators will result in change of impact and risk. The critical part is to identify a priori which elements within the geomorphologic system will be affected by a development. Cendrero (1991): geomorphologic risk and impact assessment must be based on the following four steps:

- identification and definition of the existing geomorphologic systems and land-units;
- determination of their descriptive parameters;
- evaluation of those morphologic features which are relevant for the individuation of hazards;
- identification of those morphologic features that represent assets.

Model selection

The critical elements of a geomorphologic system and their descriptive key-parameters (indicators) are identified that can be used to assess impact and risk. The next step is to quantify the interaction between a development and a geomorphologic element. Tools are required that allow to forecast the change in indicators due to the development. Fortunately in the last decades a lot of researches have been dedicated to get a better understanding of the characteristics of geomorphologic systems. Deterministic models would seem the more obvious choice as tools because of the physical explanation they give to the underlying deterministic cause-effects relations. Still some problems might not be suitable for such an approach, either because the interaction between different systems are not yet understood or are too complex, or because the studies require different spatial and temporal scales, or because the required data are not available or are insufficient. In some of these cases predictions can be made using statistical techniques like prediction models. (e.g. Chung and Fabbri 1996).

Input data

Once the objectives are defined and the tools are selected, a clear overview will arise of what input data are needed.

In most cases the budget and timeframe put serious constraints on collecting new data so only old data can be used. These have to be put together into an integrated database. The fact that the data are retrieved from various sources will inevitably result in problems of scaling and unknown data quality. Another problem is that most data have been collected for a different purpose and have been elaborated for other goals.

It is therefore important to get data that are as good as possible to make sure that overall data quality is maximised.

The ideal conceptual model already indicates which data may be required. There are different types of data that could be integrated into a database to allow easy querying and data retrieval:

- fieldwork and field data;
- thematic maps: topographic maps, geologic maps, geomorphologic maps, land-use maps,;
- remotely sensed images: Aerophotos (black/white, colour, infra-red, multi-spectral) and Satellite images;
- temporal data: precipitation, river discharge, groundwater fluctuations,
- historic events data: Occurrence of past events, magnitude, duration, spatial extend;
- geophysical and geo-technical data,

Spatial data and temporal data

Most spatial data have an inherent temporal component. Remote sensing images are snapshots of the area at a specific time and some thematic maps are valid only during a limited period due to the development and dynamics of the processes in the area. This put constraints on the elaboration because one should not use data retrieved from different time-periods in one analysis. When one can assume that one or more data-layers are not an accurate representation for

that time-period this will pollute seriously the final results. It also offers opportunities, because it allows analysis at various periods in the development of the area and makes comparison between the results possible – if for these periods all required data are available. For geomorphologic risk assessment, such an exercise is very interesting as will be demonstrated in this work. It could show if the development of some large structures has increased or decreased risk and impact in certain areas.

4 3-D SYSTEMS

Maps are graphic representation of data and their spatial relationships on a two-dimensional projection. However, geomorphologic processes are rarely limited to this two dimensional framework. To enable geo-morphologic modelling, one usually needs information on the distribution of a parameter in the third spatial dimension. Many geomorphologic processes are related to geo-hydrological cycle for which good knowledge of the subsurface distribution of the controlling parameters is critical. An integrated methodology implies that surface and subsurface processes are considered to interact (see fig. 1).

Another, important, fact is that 3-D analysis also offers great opportunities for visualisation of the results to managers, decision makers and other stake-holders. 3D images are usually attractive and much more clarifying than 2-D images could ever be. When geomorphologic aspects have to be balanced against other considerations, such a communication tool may be of greater importance than graphs and maps.

5 THE TRENTO CASE STUDY

The study area is located in the large alpine valley of the river Adige in northern Italy (see fig. 2). It includes the northern part of the city of Trento, a historic town with about 100.000 inhabitants. The study area extends about 20 kilometres northward.

A new motorway

Plans exist to construct a new motorway connection in the area (see fig. 3). The aim is to forecast how such a new structure may interact with the geomorphologic system and if this interaction could cause additional risks for the people living and working on the plain.

Anthropic system

On the alluvial plain the scarce space is claimed for urban areas, industrial sites, infrastructure and agricultural activities (vineyards and orchards). Urban areas does not only include the historic town of Trento, but also various townships. Several large industrial areas can be found northward of Trento, at the confluence of the tributary river Avisio with the Adige river and south of Mezzocorona. Along the Adige a railroad and a major highway have been constructed to connect Italy with central Europe through the Brenner pass. Around the town of Trento a large bypass has been built to avoid traffic congestion. Furthermore the area is well known for its wine-production and its apple orchards. Human activities have thus strongly influenced the landscape of the area. (see fig.4).

Fig. 2: Location of the study area.



Fig. 4: The industrial area north of Trento (view is towards the south) enclosed by the Trento bypass. Also visible are the river Adige and the Brenner highway.



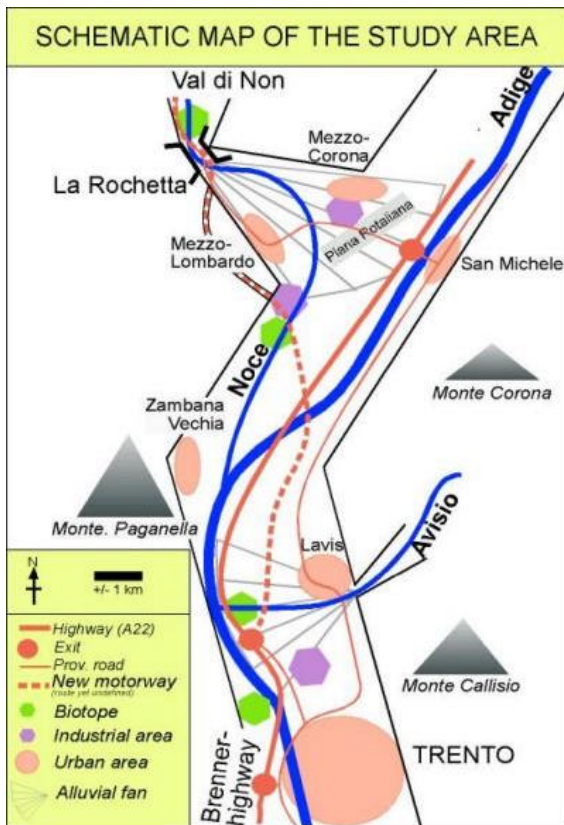


Fig. 3: Schematic map of the area Geomorphologic system

(<http://wwwdb.gndci.pg.cnr.it/>)

As stated before, one of the most important steps in the geomorphologic assessment is the identification of the critical subsystems. For the Trento case-study, floods were identified as the most critical geomorphologic process.

6 ANALYSIS

The objective of this case-study is to show how the construction a large human-made linear structure will interact with the flood-propagation on the plain in case of a dyke-failure and if such an interaction will increase the risk.

Flood modelling

To assess the dynamics of the interaction between the new motorway and flooding, the required tool is a flood propagation model. For this study the propagation model Delft-FLS was used (Stelling, 1999.).

This model needs the following input data (required):

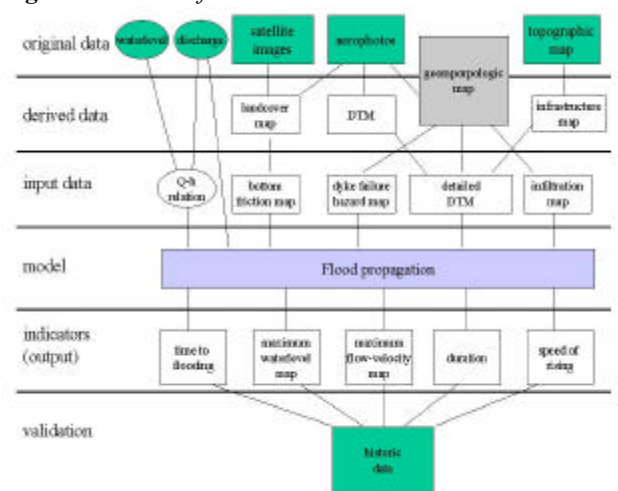
- a detailed digital terrain model (DTM);
 - the Q-h relation;
 - a time-series of discharge and water level;
 - location of dyke failure;
- (optional):
- bottom friction map;
 - infiltration map.

Figure 5 illustrates how this data was obtained from the integrated dataset.

The Adige valley is an old North-South oriented glacial valley with steep slopes on both sides. The valley plain consists of alluvial sediments that were deposited after the glacier's retreat. On the western slopes of high and nearly vertical dolomite cliffs, the presently active geomorphologic processes are mostly hydro-gravitational related: rock-fall and debris-flows. On the less steep eastern slope the processes are mostly related to fluvial activity (down-cutting, erosion) and to slope activity (landslides, soil-slips). On the alluvial plain, the major geomorphologic actors are the river Adige and the Avisio river. The Adige is a highly dynamic river with an average discharge of about 200 cubic meter per second (at Trento), but during floods this number can rise to over 1000 m³/s. The river can respond very quickly to meteorological events. To protect the plain from regular flooding the river has been constrained in its activities by numerous mitigation measures, of which dykes on both sides are the most visible ones. Floods pose the major risk on the people living and working on the floodplain.

The database of the Italian National Research Council (CNR-IRPI) gives a overview of historic events of slope-instability and floods in Trento

Fig. 5. Overview of how the data was obtained.



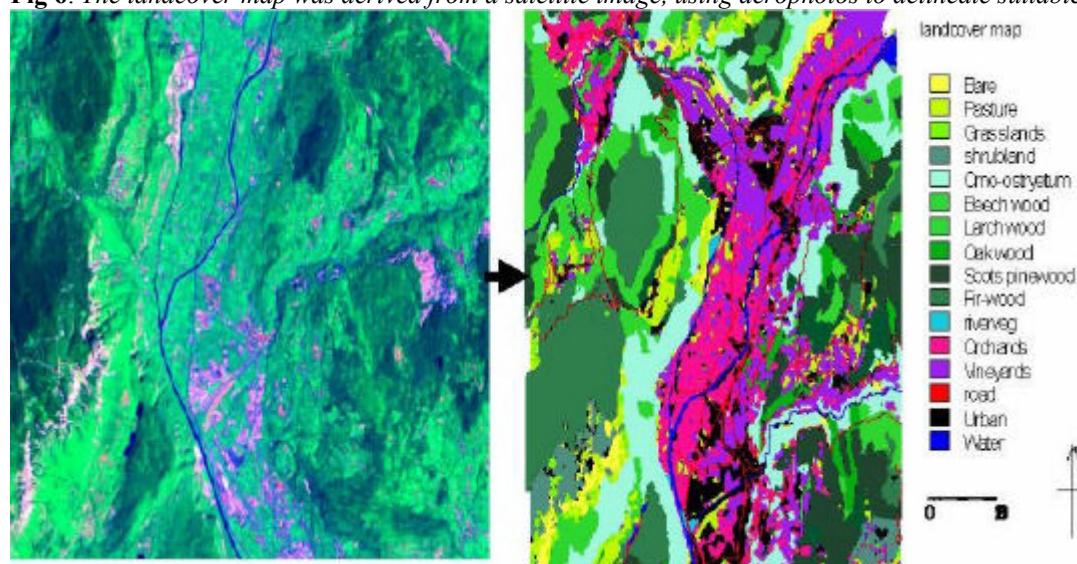
Data preparation

A geomorphologic map was made both by using fieldwork data (raw data) and stereo-photo interpretation. A landcover map was derived from the satellite images and the aerophotos (Genelletti 2000) (fig. 6). The topographic map was used to obtain an infrastructure map together with additional information from the Urban Planning Office of the Autonomous Province of Trento (P.A.T.). Digital stereo-photo processing techniques were used to reconstruct a DTM. The geomorphologic map was used in several ways to obtain the required input data for the model. Firstly it was used to derive the dyke failure hazard map, based on the considerations that the dyke failure (of a dyke of uniform quality) is most likely to happen for the following reasons:

- just after a curve where water with the maximum velocity hits the outer bank (where erosion is usually severest);
- where the dykes cross paleo-riverbeds; these are infamous sites for piping (a subsurface process that may cause dyke-instability);
- at the confluence of two rivers.

Secondly it was used to derive an indicative infiltration map. It is indicative because it is based on the assumption that geomorphologic units, that have a common genesis, will have similar hydrologic properties. Furthermore, the infiltration rates are estimated values. It allows to estimate the interaction between surficial floodwater and groundwater. Thirdly it was used to create a detailed DTM, together with data from the coarser DTM derived from the aerophotos. The Digital Terrain Model was further modified to reach a satisfactory level of detail by adding information of the infrastructure, to include the available cross-section of the river Adige and to add the height and sizes of all build-up structures (houses and industry) (see fig. 7).

Fig 6. The landcover map was derived from a satellite image, using aerophotos to delineate suitable segments



The landcover map was used to derive the bottom friction map. This map shows the spatial distribution of Manning's friction parameter (Selby 1989). It is a measure of the resistance that the various land-cover elements pose on the floodwater propagation.

The infiltration map is considered as a water-loss map. Per time step a certain amount of water is taken from the vertical waterbalance of each pixel. Temporal variation of the infiltration loss (because the soil eventually will become saturated) is not taken into account due to limitations of the software.

Infiltration allows to link the flood process with the water table. Floods may cause the uncontrolled distribution of hazardous materials, and thus, through infiltration, important aquifers may be polluted.

The discharge and waterlevel data were used to retrieve the Q-h relation (waterlevel as function of the discharge) using data of the Hydraulics Service of the P.A.T. (fig. 8).

1966 vs. 1997

Data with the specific lay-out of the new motorway are not yet available.

Therefore the present infrastructure is used as a training set. For the simulations the hydrologic conditions of November 5th 1966 were used, when large parts of the studied area were flooded.

Fig. 7 The detailed Digital Terrain Model that was used in the flooding simulations. Indicated are some important surficial features.

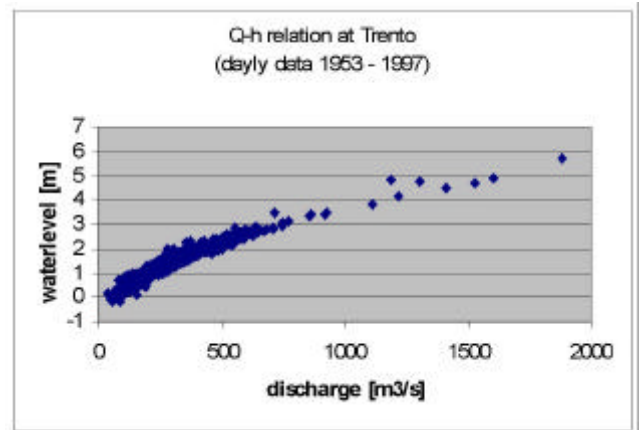
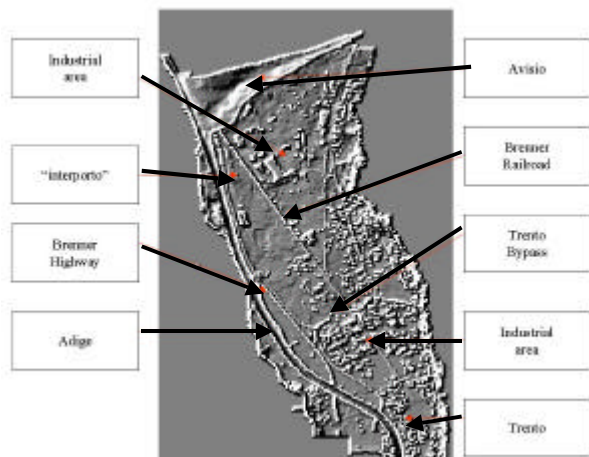


Fig. 8: The waterlevel as function of the discharge.

The discharge at Trento was over $1600 \text{ m}^3/\text{s}$ and the water level was about 5 meter above the reference level. At that time the Brenner highway, the Trento bypass and the Trento “interporto” were not yet constructed. For each simulation two detailed DTM were used: One representing the situation of 1966 (see fig. 9a and 10a) and another that represents the present topography (see fig. 9b and 10b). The reconstruction of the 1966 event is useful because it allows to validate the model results with the historic data as model validation. The simulation with the present topography shows how the discharge like the of 1966-flood would propagate if it happened in the present landscape. This allows to assess the effect of change in the flooded area due to these constructions.

7 PRELIMINARY RESULTS

The output of the model are water level maps and flow-velocity maps for every hour after the dyke-failure. These maps are used to obtain the following indicator maps:

- time to flooding;
- maximum water level map;
- maximum flow velocity map.

These indicator maps can be used to plan evacuation of inhabitants (the time to flooding indicates the time the floodwaters will reach a certain area). The water height map and the maximum flow velocity were multiplied to obtain a “mass-energy-map”

If the vulnerability and the value of the area are known the impact can be calculated for each scenario. The difference of impact can be attributed to the large structures (assuming other factors didn’t change).

From the results as shown in figure 9 it seems as if the constructions that are included in the map on the right-hand side (9b) have a positive effect on the time to flooding. The floodwaters seem to be delayed which can be considered a positive impact.

When one looks at the “mass-energy” maps, (fig 10) the values are higher for the 1997 situation. The structures funnel the water such that they have higher flow-velocities and reach higher levels. So the extend of the flooded area may be less, the potential for causing damage in those area that are flooded is higher.

These two examples show the complex nature of flood impact. Vulnerability studies and multi-criteria analyses will be needed to aggregate all possible impacts into a comprehensible impact assessment that can be included in an EIA.

Fig. 9: Indicator map: Time to flooding. 9a: DTM of 1966; 9b: DTM of 1997

The rupture in the dyke is indicated with the arrow. On the left are shown the results of the simulation, using the DTM of 1966. On the right are presented the results of the simulation that used the DTM of 1997

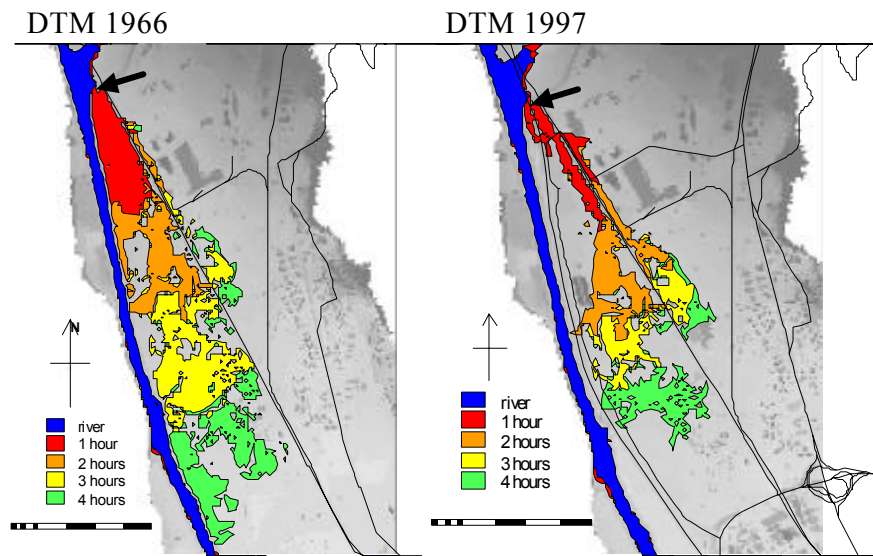
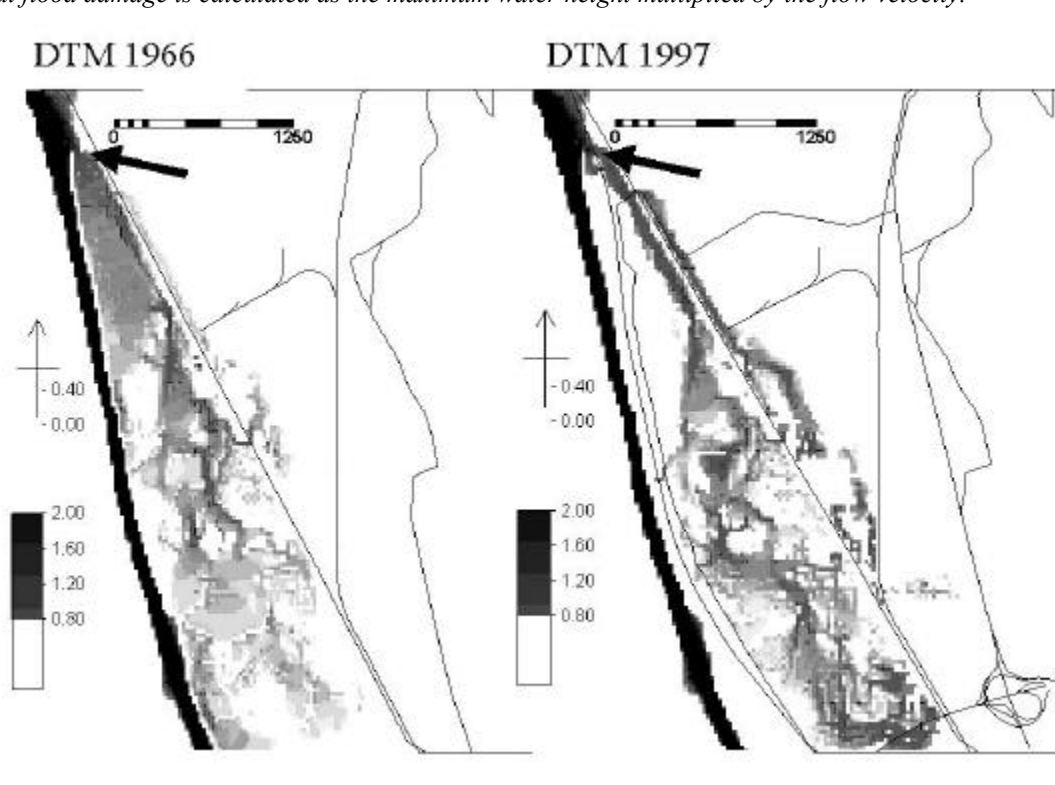


Fig. 10: Indicator map: Mass-Energy. 10a: DTM of 1966; 10b: DTM of 1997 The rupture is indicated by the arrow. The potential flood damage is calculated as the maximum water height multiplied by the flow velocity.



CONCLUDING REMARKS

In this paper are presented the first results of a research and will illustrate the approach chosen and considered useful to integrate knowledge of geomorphologic processes into EIA procedures. It will be a contribution to reduce the flood risk. 3-D system analysis offers opportunities to divide geomorphologic systems into manageable elements. By linking geomorphology to the anthropic system, one will be able to identify the critical elements and to define those indicators

that permit to evaluate geomorphologic risk in a comprehensible manner. Floods are a serious hazard for people living on alluvial plains because human actions can increase or decrease these risks.

ACKNOWLEDGEMENTS

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REFERENCES

- Beinat, E., Bressan, M., Jones, M., Fabbri, K. (1999). Geographical information systems and environmental impact assessment. *UNIGIS introduction module*, Faculty of Economics, Vrije Universiteit Amsterdam, the Netherlands
- Cavallin, A., Marchetti, M., Panizza, M. and Soldati, M. (1994). The role of geomorphology in environmental impact assessment. *Geomorphology 9*. Elsevier, the Netherlands
- Cendrero, A. (1991). Environmental impact assessment for master plans; a methodological proposal. *Internal. Report of the meeting geomorphology and EIA*, Valencia, oct. 1990. Council of Europe, Strasbourg.
- Fabbri, A.G. and Chung, C.F., 1996. Predictive spatial data in geosciences. In: *Spatial analytical perspectives on GIS in the environmental and socio-economic sciences*. (Eds: Fisher. M., Scholten, H.J. and Unwin, D.). Taylor and Francis, London, United Kingdom.
- Geneletti (2000). Using classification and spatial indices on remote sensed data for environmental impact assessment. In Press. ITC, the Netherlands.
- Lorenz, C.M.(1999). *Indicators for sustainable river management*, PhD thesis, Vrije Universiteit Amsterdam, the Netherlands.
- Panizza (1994). Introduction to a research methodology for geomorphology and environmental impact assessment. In: *Geomorphology and Environmental Impact Assessment* (Eds: Marchetti, M. Panizza, M, Soldati, M. Barani, D.) Quaderni di Geodunamica Alpina e Quaternario. CNR. Milano, Italy.
- Rivas V., Rix, K., Frances, E., Cendrero, A and Brunnsden, D. (1994). The use of indicators for the assessment of environmental impacts on geomorphologic features. In: *Geomorphology and Environmental Impact Assessment* (Eds: Marchetti, M. Panizza, M, Soldati, M. Barani, D.) Quaderni di Geodunamica Alpina e Quaternario. CNR. Milano, Italy.
- Selby, M.J. (1989). *Earth's changing surface*. Clarendon Press. Oxford, United Kingdom.
- Stelling G. (1999) Delft-FLS is developed by the WL-Delft-Hydraulics. Delft, the Netherlands
- Van Asch T.W.J. and Van Dijck, S.J.E. (1994). The role of geomorphology in Environmental Impact Assessment in the Netherlands. In: *Geomorphology and Environmental Impact Assessment* (Eds: Marchetti, M. Panizza, M, Soldati, M. Barani, D.) Quaderni di Geodunamica Alpina e Quaternario. CNR. Milano, Italy.
- Wathern, P. (1989). *Environmental Impact Assessment: theory and practice*. Unwin Hyman. London, UK