Spatial calculation of flood damage and risk ranking

Wouter Vanneuville, Kristien De Rouck, Koen Maeghe, Maarten Deschamps,
Philippe De Maeyer & Frank Mostaert
Ghent University - Department of Geography, Gent, Belgium
Wouter.Vanneuville@UGent.be
Ministry of Flanders – Flanders Hydraulic Research Department, Borgerhout, Belgium
Koen.Maeghe@lin.vlaanderen.be

SUMMARY

In comparison to the classical inundation maps, flood risk maps generate more information about the flooding event because they bring into account the effects of flooding. Risk maps are generated as a mathematical combination of damage maps with different return periods. These maps can be usefull to evaluate policy alternatives and they are an important input for social cost benefit analysis. In this paper, the advantages of the new methodology – an objective comparison between alternatives and between different hydrographical catchments - , the state of the art of the methodology and the opportunities for applications are described. The applications are diverse but, dealing with water management, a diagnose of the current situation and the knowledge of the effects of planned infrastructure and/or land use changes before the intervention is the most important. The basic model, with land use maps as a main input, is refined by introducing important line elements and discrete objects in landscape whose potential damage or damage function is significantly different from their environment.

KEYWORDS: *Risk, inundation, damage, GIS, Flanders*

INTRODUCTION

Until recently, most authorities as well as people assumed that floods could be prevented by building the dikes high and strong enough. Rainfall has to flow to the river and go downstream as soon as possible in this approach. In practice, dikes and other water management infrastructures were built a little bit higher than the highest known water level in the past. This results in a different safety level for different hydrographical catchments (and even a different level for sub catchments) because the return period of the highest water level will be different, due to mutual differences in length of observations and 'public memory'. In the past, flood inundation maps were used as a base to define safety levels and maps and a methodology based on the recurrence periods of flood maps was constructed. Water policy was based on inundation maps (with water levels and recurrence probabilities) and less on the effects to derive safety levels. As a result of this approach there is not always a clear distinction between probability of occurrence of floods in rural and urban areas.

Nowadays water management starts from the point that floods were, are and will be an unevitable reality. A total protection against flooding is not justifiable; socially nor economically, and technically not possible. Investments in water policy are still necessary, but water management is no longer limited to flood prevention at all costs everywhere. Water management aims to limit the damage. A risk methodology is developed which allows comparing objectively the needs in the different catchments. Risk maps produced from hydrologic and hydraulic simulations can generate a spatial representation with sufficient detail (spatial scale and attributes) to be a major input for social cost benefit analysis.

METHODOLOGICAL FRAMEWORK OF THE RISK ANALYSIS PROJECT

The steps involved

To define the risk related to flooding, some assumptions have to be made. The inundations taken into account in this research are inundations due to overflow and dike breaching, which is conceptually taken into account. For example, flooding from sewer systems is not taken into account. The calculation of risk can be divided into 3 steps (as illustrated by figure 1):

- defining the probability and extend of flooding;
- determining the occurring damage for every return period;
- combination of the damage maps to define an overall risk map.

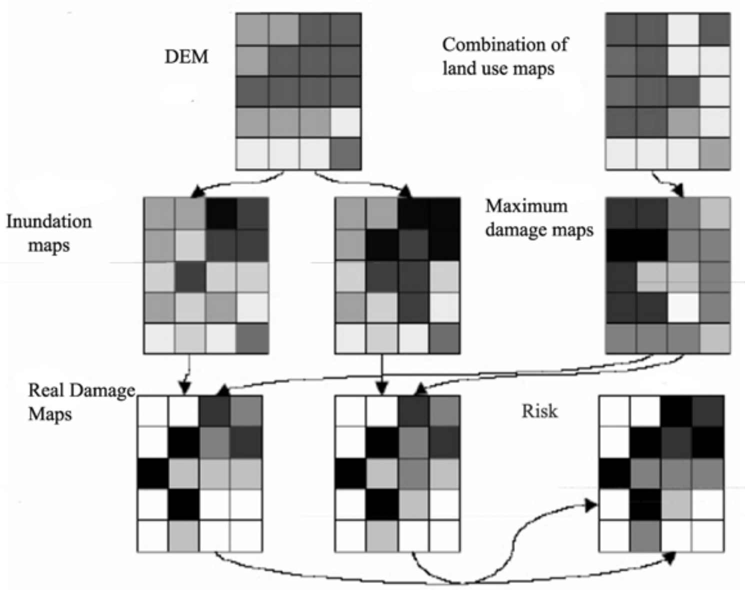

Figure 1 : General derivation scheme of risk maps

Damage maps are generated from inundation maps and a maximum or potential damage map. For each land use class water depth-damage relationships are defined, based on European experience (see e.g. Penning-Rowsell et al 2003), and adapted for the Flemish situation. Not only direct damage is taken into account, but the indirect damage can also be analyzed. Indirect damage is e.g. permanent loss of fertile soils, production losses, cleaning costs. The monetary value of the indirect damage is expressed as a fraction of the direct damage (Griggs et al 1976), also dependent of the water depth at a specific place.

The risk is calculated on the basis of the $probability \times vulnerability$ formula, summated over all recurrence periods. A more detailed background of the methodology and the mathematical basis is described in Vanneuville et al (2003) and examples can be found in De Maeyer et al (2003).

Most of the land use maps of the basic model are based on interpretations of satellite images: Corine Land Cover (based on Landsat), Small Scale Land Use Map of Flanders and Brussels (for one based on Spot), and an own classifications (based on IKONOS imagery). Their importance for water management based on risk methodology is described by Van de Sande (2001). The risk is refined by integrating line elements (e.g. roads and railways) and point elements (e.g. drinking water installations, historical buildings, telecommunications infrastructure, subway entries …) into the spatial information. These line and point elements are selected for their significant difference from the environment, concerning potential damage and damage functions.

The main interest of insurance companies is the potential damage to some specific objects in an area. Objects insured by other companies are not (or only globally) taken into account in the model of the insurance company. Reinsurance companies are interested in a more global view using an average damage and risk. Both insurance and reinsurance companies are mainly interested in private goods that can be insured. These companies have their own methodologies and they have built their own models, dealing as good as possible their questions.

A public authority, at the other hand, is interested in the damage to both public and private goods. It has not only to carry the cost for public goods but, e.g. through a disaster fund, they also have to budget money for exceptional situations where private goods are destroyed. The models of insurance companies do not answer the specific questions of public authority (nor does a model made for public authority answers the questions of the insurance companies). For that reason private (e.g. houses, industry, agricultural land …) and public (e.g. dikes, roads, drinking water areas …) goods are studied. The basic model is extended with line and point elements and a casualty model.

Geographic Information Systems and Science for risk calculation

Starting with land use maps and water depth maps, all steps to derive damage and risk are modelled in GIS based on grids. Initially some calculations were made in training areas to test the difference of the results when raster cells (100 m²) or polygons are used. The difference was in between 0,1% and 0,5% and can be considered as allowable in comparison to the uncertainty on the flood maps, the land use maps and the financial quotation of objects. Quite a big part of these differences occurs at the borders of the rivers where there are pixels with a high water depth (belonging to the river on the flood map) and a land use sensitive to damage in the land use map. The differences between the raster and vector risk calculations can be made smaller by using a neighbourhood operation to select the grid cells having a high water depth where their neighbours at the land side do not have this property and transform their land use to water. In theory the opposite is also possible and the water depth can be changed on these pixels but some tests show that the positional accuracy of the flood maps is higher then in the land use maps.

Based on the conclusions of the previous paragraph (small difference in results between raster and vector), the original nature of the most important data (interpretations of satellite images, grid results of hydraulic simulation models), the calculation time and the type of operations (mostly local operations) all modelling is done in a raster geometry. This leads to the need of large storage capacities but mostly powerful compression can strongly reduce the size of files.

It is a quite widespread misconception that raster GIS is out of date. Continued phenomena can be handled in vector GIS using isolines or contours for visualization but they are not efficient for numeric modelling and the study of spatial interactions. Most of the time variation is too complex to be described by a simple mathematical expression and it is necessary to divide geographic space into discrete units when continuous variables are used (Burrough and McDonnell 1998).

A *Visual Basic* routine allows to chose specific sets of files to run the (sub)models. For the different hydrographical catchments sets of basic data (land use maps, flood maps) are available with the same grid parameters. When new calculations are made, the result files can be added to the collection. Other choices contain the set of depth-damage relationships, the land use maps (for example CORINE Land Cover, a digital topographic map, the small scale land use maps of Flanders and Brussels), the evacuation rates for cars, the doorstep levels for housing and industry, etcetera. In basic mode, the results are a set of damage maps for different return periods. Their mathematical combination in a separated routine gives the risk for a scenario in a catchment (see further). When necessary the operator can interact on every step of the model to view additional results.

APPLICATIONS OF RISK METHODOLOGY

There are several possible applications for a damage and risk calculation model. Bringing into account only the actual situation, it is possible to give insight in the expected annual costs for all private and public goods, due to inundations. It becomes more interesting when several situations are compared. For study reasons, calculations back into time were made for 1995, 2000 and compared to the actual situation. In general, there was not really a significant rise of risk in Flanders, but the percentage of damage to housing in the total risk was increasing (Van Damme et al. 2004).

When working in an operational environment, it is not the past but future that is of main interest. Planned alternatives can be compared with the actual situation but in opposite to calculate a situation in the past, not all thematic data are available for the future. E.g. the land use in the past is known, but for the future there must be made extrapolations or assumptions. The scale of human interventions can differ a lot, from local adaptations to master plans for a whole river catchment. For both, risk methodology is a useable tool if the uncertainty out of basic data and the way they interact with other elements during calculation is described well.

New Sigma Plan

In the Netherlands, after the flood of 1953 in Zeeland, the Delta plan was developed. Although a serious flooding occurred in Flanders too that time, it was only after the flood in Ruisbroek in 1976 that a master plan was developed. On February 18th 1977, the Cabinet Meeting decided the realization of the Sigma plan. The objective was to protect all low areas in the Sea Scheldt catchment against storm surges. A safety standard for the probability of occurrence was decided to be one percent a century. The plan had to be completed using three types of measures:

- Raising and strengthening the dikes.
- Construction and compartimentation of controlled inundation areas.
- Construction of a storm surge barrier in Antwerp (Oosterweel).

At the moment, 80% of the dikes were built and 12 controlled inundation areas are in operation. The storm surge barrier was not yet built. Due to several reasons the Sigma Plan is actualized nowadays. The New Sigma Plan is worked out by several consortia of engineering agencies, under supervision of the Sea Scheldt Division and Flanders Hydraulic Research Division. For the Flemish part of the tidal Scheldt and all tidal tributaries, a social cost benefit analysis was made in which all measures and combinations of measures are evaluated. Calculation of damage and risk is a main input of this social cost benefit analysis (SCBA).

Another big challenge of the SCBA is to quantify all immaterial effects. How to compare the interest of shipping, agriculture, nature … Finally, all alternatives are brought together and compared to decide:

- Which combination measurements guarantee the best cost benefit ratio and which execution alternatives seems the best?
- What is the optimal safety level, bringing into account all tangible and intangible costs and benefits?

There are several reasons why this project is of great importance. From economic perspective, the Scheldt and its banks are the most important river for Flemish and Belgium economy. It is also new in Flanders that a risk methodology is used on such a big area. Not only the situation in 2000 is taken into account, but also assumptions for 2100 are made. An estimation of land use and population changes is discussed as an input for the SCBA and the flood maps (and return periods) are adapted to expected sea level rising. The results of the SCBA are expected by June 2005.

Dender Catchment: Denderbellebroek

The Denderbellebroek (DBB) is situated downstream on the Dender catchment, just before the Dender flows into the Scheldt. The Denderbellebroek marsh is used as a storage area for the Dender river when his water level is to high and there are no possibilities to drain the water into the Scheldt because of its tidal regime. When the water level in the Scheldt is low enough (and the Dender can drain into Scheldt) the water is pumped out of DBB into the Dender.

In case of extreme high water levels for several days on the Dender, the pumps are not able to empty DBB anymore and there is a possibility of flooding from several brooks flowing into the DBB area. Finally, when the water in the Dender can not flow into the Scheldt during high tide and not in the full DBB, the whole surrounding area is threatened. At first, installation of pumps with a higher discharge capacity was considered. Simulations of the hydraulic Dender model proved that discharge sluices are much more efficient and are expected to be less costly. Several hydraulic calculations showed that discharge sluices of 12 meter wide (twice 6 meter) are sufficient to make empty the DBB in time during low tides on the Scheldt. A risk calculation was executed. The actual situation is compared with the planned alternative with 2 discharge sluices of 6 meters (figures 2 and 3).

Comparison of the inundation maps of the actual situation and the planned alternative shows a decrease of water depth and smaller extend of flooding. Intuitively, people can say that the situation improves but it is impossible to quantify the improvement. Making the risk calculations demonstrates there is 30% risk decrease in the study area. The risk (not shown in the maps) in the upstream part remains stable. Although the values on the risk map (and the risk difference map) can not be interpreted as exact values, they provide a good estimate of the risk decrease.

Once the decrease in risk is quantified, it can be compared with the building and exploitation costs for the discharge sluices. At the north of the controlled inundation zone, there is still flooding but the water levels decreased significantly. Statistically, the floods in this area are lowered. Reducing the water level (implying a lower risk) on a small area has already a big influence on the total risk because of the land use (in this case a residential area but the same effect occurs e.g. when the land use is industry or infrastructure).

As told before, not only economic evaluation has to be made by the water management. When the cost of intervention can be justified in comparison to benefits (this not necessarily means the benefits are higher) the social aspects that have to be taken into account are the (number of) people and nature affected. Affected means having less damage due to flooding but can it can also be affected due to nuisance during construction or maybe even permanent discomfort. Also the effect on (mortal) victims has to be taken into account.

In this project, the social and economic benefits are big enough in relation to construction and operation cost so normally, the construction of the sluices will take place. Some extra simulations are now considered to study the effects and probabilities of dysfunction of one of the sluices during high water periods. First results show an increase of inundation area and water level and so an increase of risk. However the situation seems to be better then the actual one and the other studied alternatives where more pumping installations are installed.

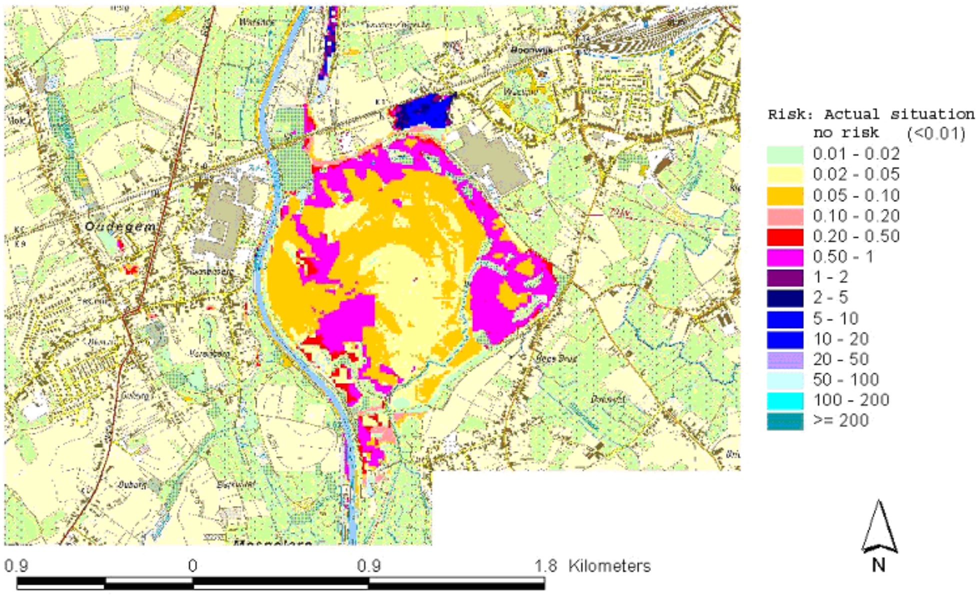

Figure 2 : Risk map of the actual situation
(background: raster topographic map 1: 10.000 © National Geographical Institute Belgium)

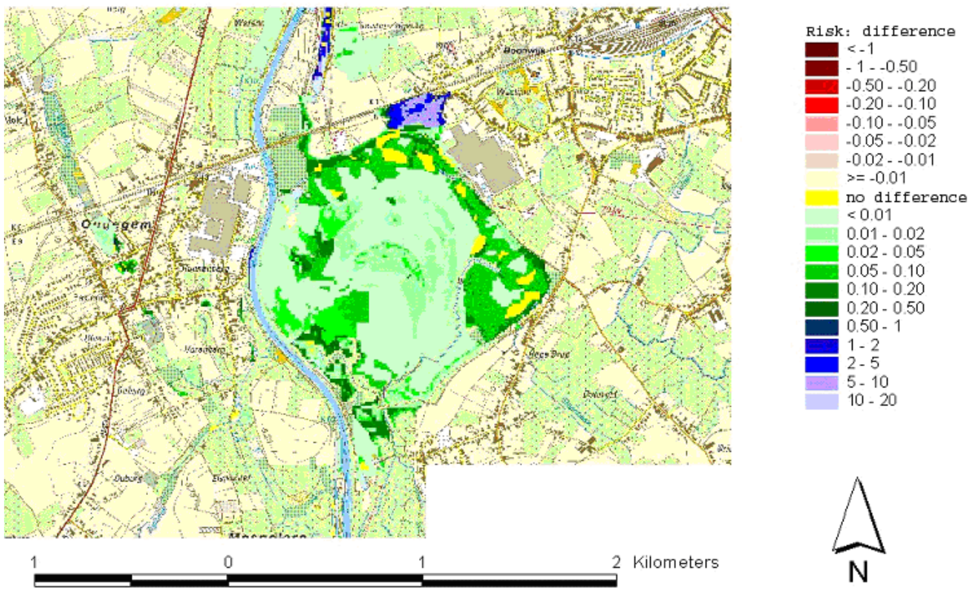

Figure 3 : Difference in risk between the actual situation and the planned alternative (green till blue values: decrease of risk after construction of discharge sluices)
(background: raster topographic map 1: 10.000 © National Geographical Institute Belgium)

CONCLUSIONS

Assuming risk must be calculated along all navigable waterways in Flanders, some generalization was necessary resulting in a output less usable for insurance companies. For public authorities, the results of the model give a very good impression of the order of magnitude of public and private risk. This scientific base for the calculations allows spending financial resources in a more efficient and objective way (Vanneuville et al 2003).

The difference in risk between two situations (e.g. the actual state and a planned alternative) is the benefit site of the economic cost benefit analysis. The benefits, as the reduced annual damage, have to be compared with all costs to realize the alternative situation. Not only construction and maintenance costs but also the cost of execution in a pre-defined time lap (e.g. 50 or 100 years) for which the intervention is planned to be effective. The economic optimum (see figure 4) will be reached when the sum of all costs (remaining damage and cost of policy actions) is minimal (Vanneuville et al 2003). Due to the natural phenomenon of flooding and its impact on people and their property, the economic optimum is not always the policy optimum. So the number of people affected should define the social optimum, instead of monetary valuable damages (e.g. natural, historical, cultural values).

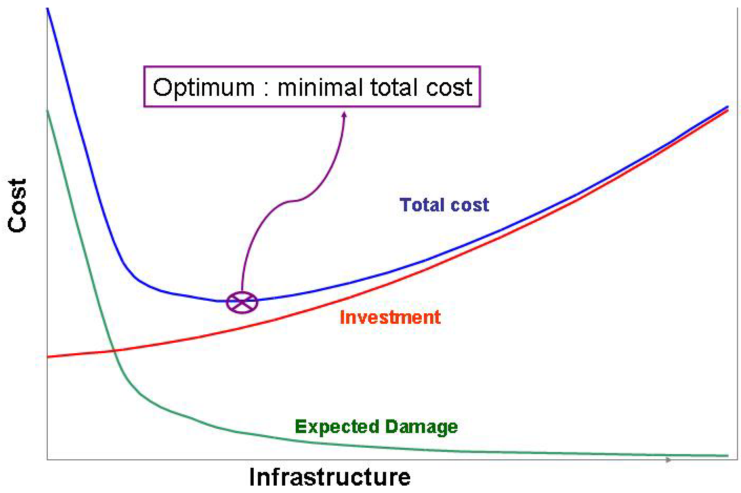

Figure 4 : Economic optimum in the cost benefit analysis.

Ultimately, a risk analysis will be carried out for all calculated hydraulic scenarios on navigable waterways as an input for social cost benefit analyses. To take the right conclusions out of the damage and risk calculations, precise and accurate basic data are indispensable. The hydraulic model results are converted to real GIS layers because the cartographic representation of the numerical risk model output is seen as the most desirable way to make the right interpretations by policy makers to evaluate the overall effect of planned actions.

BIBLIOGRAPHY

Burrough P.A. & McDonnell R.A. (1998). *Principles of Geographical Information Systems,* Oxford University Press, Oxford, pp. 333.

De Maeyer Ph., Vanneuville W., Maeghe K. & Mostaert F., 2003 Modélisation des effets de crue dans la basin de la Dendre, basée sur une méthodologie de risque. GEO Evenement 2003, 4-6 mars 2003, Paris (in French).

Grigg N.S., Botham L.H., Rice L., Shoemaker W.J. & Tucker L.S., Urban Drainage and flood control projects – economic, legal and financial aspects. In Hydrology Papers, Colorado State University, Fort Collins, Colorado, nr. 85, February 1976.

Penning-Rowsell E., Johnson C., Tunstall S., Tapsell S., Morris J., Chatterton J., Coker A. & Green C., 2003 The benefits of flood and coastal defence: techniques and data for 2003. Flood Hazard Research Centre, Middlesex University, pp 321 (+ CD-Rom).

Van Damme M., Uitdewilligen D., Leemans I., Vanneuville W., Van Eerdenbrugh K., De Rouck K. & Degans H., 2004 Chapter 2.14 Verstoring van de waterhuishouding (Disturbance of the water system). In MIRA – Nature and Environment Report, Flemish Land Agency, Lannoo nv, Leuven, pp. 315-325 (in Dutch).

Van De Sande C., 2001 River Flood Damage Assistant using IKONOS Imagery. European Commission: Joint Research Centre, Space Applications Institute EGEO Unit, Ispra, Italy, pp 77.

Vanneuville W., De Maeyer Ph., Maeghe K. & Mostaert F., 2003 Model the effects of a flood in the Dender catchment, based on a risk methodology, Society of Cartography Bulletin, Vol 37 (2), pp. 59-64.