FLOOD RISK SCENARIO CALCULATIONS AS A DECISION SUPPORT AND EVALUATION TOOL IN WATER MANAGEMENT PLANS

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Abstract

Whatever the measures taken there will always be a probability for flooding along rivers and in the coastal zone. In a densely populated area like Flanders most of the floods cause damage. But there are large differences in the amount of damage depending on land use. A flood risk methodology is developed for Flanders and implemented in the raster GIS software shell *LATIS*. The probability and consequences of floods can be evaluated under current conditions and for several types of alternatives. Socio-economic, climate and/or hydraulic changes can be simulated.

In a risk methodology the effects of measures must be evaluated for extreme hydrologic and hydraulic conditions but also for more regular events. All of the resulting damages are weighted with their probability of occurrence. These combinations lead to a more accurate appraisal of the expected annual damage: the risk.

Damage, victims and risk calculations need interpretation of the system's operator. The robustness and sensitivity of planned actions cannot be expressed by one or some statistical values. *LATIS* produces risk maps. In addition to the overall gain of measures and evaluation of the spatial variations of risk can be made. Because measures can have different effect on damage and victims both are evaluated separately. The LATIS tool is not deciding but supporting the decision. In the decision process, the pronouncement of the risk model has to be refined by adding non tangible effects (ecological and historical values, well-being of inhabitants …). Also the existing and/or expected regulations on different policy levels that act as constraints have to be taken into account. This can be done is a social cost benefit analysis.

Until now the Flemish risk methodology is used to make a flood risk map for Flanders, to evaluate several smaller measures and for four regional water management plans. The most important ones are the Sigma plan for the river Scheldt and the Integrated Safety Plan for the Coastal zone.

Keywords: flood risk mapping, decision support tool, raster GIS

1. Introduction

In the past decades, Flanders – the northern part of Belgium – has suffered from several river floods, causing substantial damage to buildings, roads, crop fields, etc. As Flanders is one of the most densely populated and industry-developed regions in the world, a decent water management policy is needed. Drain off the water downstream as fast as possible is not a sustainable solution. And to the man-influenced character of the waterways and the adjacent areas a policy based on hold up, storage and discharge of the water is not always able to avoid flooding. Moreover, water defence infrastructure can always fall subject to geotechnical failures, such as breaching, creating even more damage compared to the case with no infrastructure. This brought the Flemish water authorities and managers to an approach which focuses on minimizing the consequences of inundation instead of avoiding high water levels (Vanneuville et al. 2003).

By means of geographic information systems, a risk-based methodology has been set up to assess a quantitative risk for flood damage, based on a variety of land use information and socio-economic data. This methodology not only considers the probability of a certain disastrous event, but also its consequences.

2. A risk-based methodology

2.1 Calculation of Damage and risk

The calculation of damage and risk consists of three steps, namely (i) defining probability and extent of flooding, (ii) determining expected damage, and (iii) defining risk. The different steps are schematically presented in figure 1.

The first step is in fact preliminary to damage and risk calculations. It comprehends the estimation of an area's flooding probability through statistical analysis of water levels and flow rates in the past. Researchers calculate the average period of time in which a particular maximum water level may reoccur. Higher water levels and discharge volumes correspond to larger return periods of occurrence. Furthermore, flood maps are created using hydrologic and hydraulic models, together with digital elevation data. These maps not only show maximum water level in each grid cell, but indirectly indicate the extent of a certain inundation. Additional information such as flow velocity and rise rate of water (especially important for casualty assessment) can also be obtained.

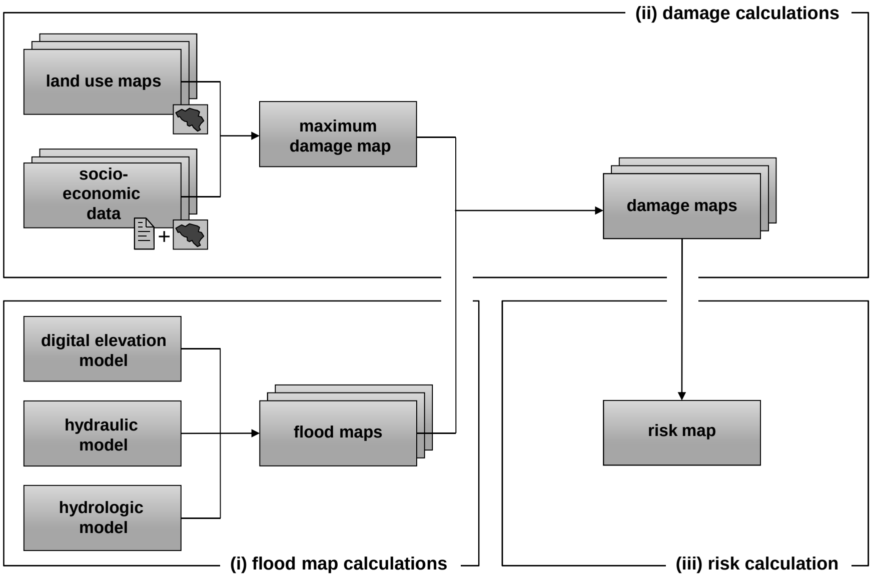

Figure 1: Derivation scheme of risk mapping

Secondly, land use information and socio-economic data is used to produce maximum damage maps. When combining the latter with the flood maps, expected damage for a given inundation can be calculated. Besides this, land use information can be derived out of a variety of land use maps, based on topographic maps, satellite imagery, orthophotographs, CORINE Land Cover, etc. In addition, socio-economic data is gathered. E.g. the number of persons and vehicles per surface area, values for a great number of goods, land use categories, buildings, etc. Thus, to determine the expected damage for a given flood, the replacement value of goods is used, not the original value of purchase. Based on this information, a maximum damage is computed by unit of surface for each land use category (buildings, industry, pastures, etc.).
These categories all have different relations between maximum damage and water depth, called damage functions or α-factors. The expected damage inside an inundation area is then calculated by multiplying the maximum damage of each land use category with the corresponding α-factors and by subsequently summarizing these with all different land use categories of a certain area.

Based on the formula *probability * vulnerability*, the damage maps are combined into one risk map, which indicates the expected average annual damage for a given area. The map indicates flood risk as a cost per surface a year (€ / m².year).

Until recently, damage and risk calculations were limited to flood events caused by overflow, restricting the main damage factor to water depth. In case of geotechnical failures, such as dike/dune breaching, damage to buildings and/or constructions may be much larger compared to overflow. In the vicinity of the breach, high flow velocities can even cause total collapse of buildings. In general, it is assumed that flow velocity generates an additional damage on top of the present damage calculations. Based on findings of Vrisou van Eck (et al., 1999), new damage functions were developed for levels of water depth in combination with flow velocity. These velocity-based damage functions are tested for the Integrated Safety Plan for the Belgian

Coastal Zone. The additional damage based on flow velocity causes a surplus of up to 25% compared to the basic damage calculation. The basic calculations only based on water levels cause a significant underestimation, which can already influence the type of solutions to be taken and the balance in the cost benefit analysis.

Besides material damage, the number of casualties will also be higher in case of high flow velocities, because of instability of people and building collapse (Jonkman, 2007).

2.2. A raster GIS model

The development of a risk-based methodology alone is not enough to perform risk management. In addition, the method needs to be translated into a useful model which carry outs all necessary steps in a pre-programmed chain of actions. Because of the data properties and the analyzing techniques, a raster-based GIS was chosen above a vector-based. Indeed, most of the computations are point-operations, which can be optimally performed in a raster-based GIS (Eastman, 2007).

However, this early GIS model structure poses some disadvantages. First, adaptations and extensions to the model are difficult to process and can result in a disable system. Moreover, the GIS model demands an intensive start-up procedure for each risk computation, as input data is listed in a rather unfriendly user-interface (figure 2). Finally, the model doesn't have a data management system. On the one hand this leads to an overload of data, because all temporary files are saved. On the other hand it lacks the possibility of using (important) temporary files to skip general calculations, causing long processing time.

All this has lead to the development of *LATIS*, a GIS application tool that guides the user through each step of the different damage and risk calculations in a user-friendly interface. *LATIS* is described in more detail in the next section.

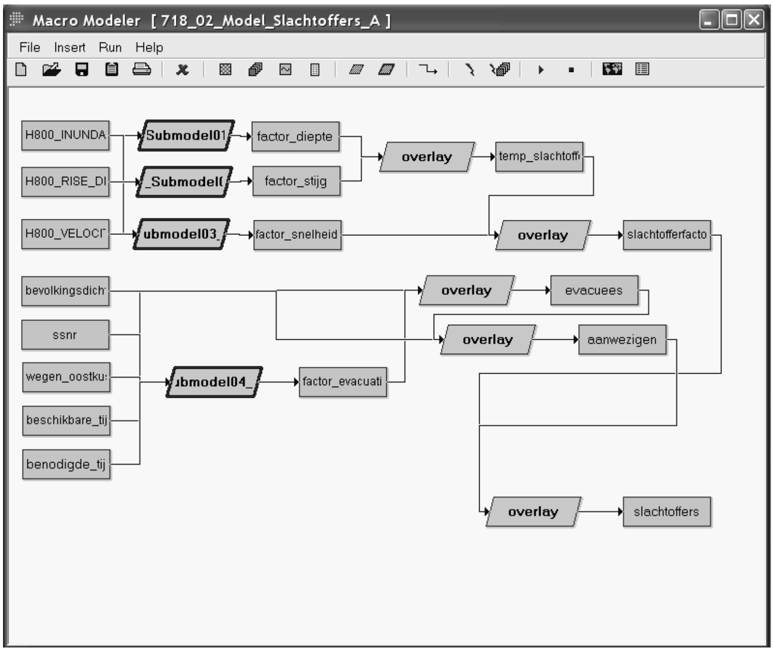

Figure 2: Screen dump of the previous raster GIS model for flood risk calculations (scheme for victim calculation)

2.3 LATIS

In 2007, Flanders Hydraulics Research and Ghent University have developed a GIS tool as a substitute for the previous GIS model structure. This tailor-made tool is called *LATIS*, referring to the Celtic god of water.

LATIS is built on Microsoft.NET technology in combination with the raster GIS package Idrisi (Clark Labs). The user interface (figure 3) of the application and algorithm of the model were implemented in the programming language C#.NET. For all the geospatial operations, *LATIS* uses the optimal computing capacity and built-in standard modules (stand-alone executable files) of Idrisi. The tool performs all necessary actions with the corresponding parameters so the user only has to take care of the input data. *LATIS* was developed in English and will be available with an extended help-document. Furthermore, the tool has a data management system which easily allows the administrators to manage the basic land use maps and socio-economic data. These maps and data are gathered in a uniform way for the whole extent of Flanders and are centrally managed on a data server. This leads to a more efficient data storage and easy pre-processing. The application namely selects and cuts the necessary data for the extent of a certain scenario from the data server. Because of this, damage and risk maps are calculated in an easy (the user only has to take care of input flood maps), uniform (same method and data for the whole extent of Flanders) and reproducible way (data management system records the set of input data).

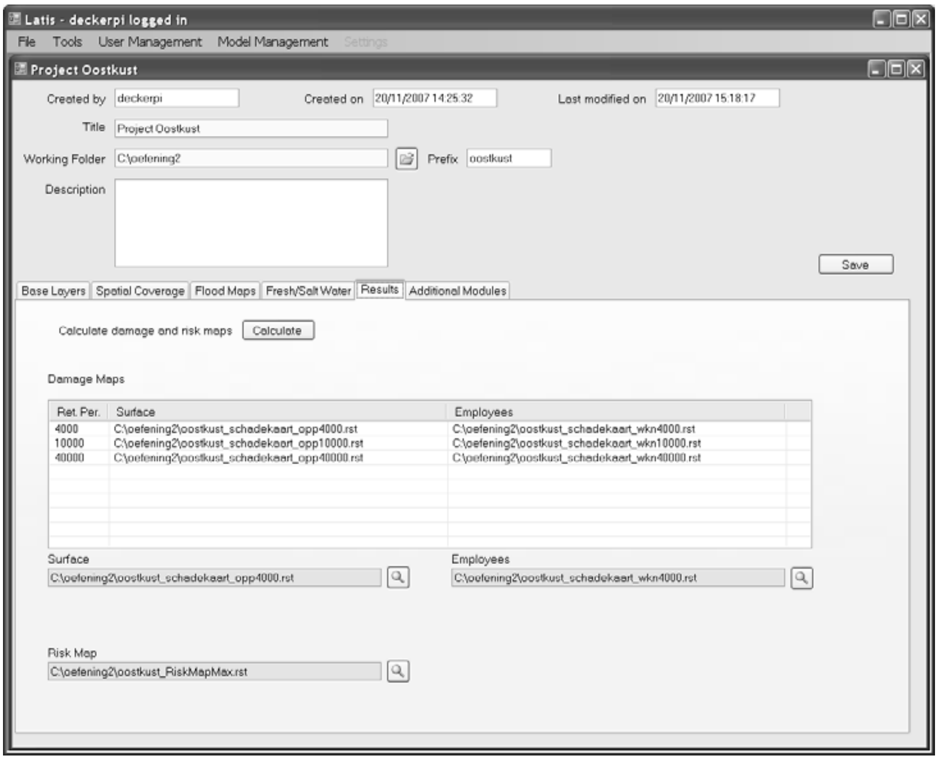

Figure 3: Screen dump LATIS (window for the results of the basic damage and risk model)

On of the first projects where the *LATIS* tool is used is for calculating the effect of climate change scenario's in Flanders. These climate change scenarios are based on regional climate models for different emissions scenarios. Based on potential evolutions in rainfall and potential evapotranspiration a high, mean and low scenario is defined for summer and winter period in Flanders. In general drought problems will probably increase during summer time, while the evolution during winter time is quiet unsure (strong increase in flooding in the high scenario till slightly decrease in the low scenario).

Hydraulic model runs are executed based on the climate change scenarios for Flanders and the available measurement series for water level, discharge and evaporation to derive flood maps with different return periods in the catchments. Besides the extension of the flooded area, the water depth is used in this project as a main factor to derive damage. First the flood maps for the current situation are recalculated with the most recent socio-economic data available. They are used as a reference to be compared with the flood maps of the climate change scenarios. For all four simulations, the flood risk is based on the same series of return periods for the flood map calculations.

A relative small increase or decrease in water level can cause large differences in damage and risk. Some vulnerable sites in landscape that are only flooded once a century can be flooded more frequently and increasing the risk seriously. At the other hand is a serious increase of water depth on agricultural land not causing a large increase in damage and risk. Once the crops are rotten the water depth is not that important any more.

Those economic damages are calculated in general for housing, industry, agricultural etc. but special attention is given to local objects in landscape creating an extreme high damage (e.g. power supply installations, museums) or sites that are important in case of emergency as a control centre (e.g. fire brigades, police stations) or due to evacuation reasons (e.g. hospitals, elderly houses).

On this moment large land use changes are not taken into account, but where it makes sense the difference is made between fresh and salt water and the borderline between them can be changed.

Interpretation of the results of the damage and risk maps from the climate change scenarios has to be done (like for all other risk scenarios) in a relative way and not for each map pixel (in this case 5*5 metres). Comparison of the risk maps of the scenarios with the risk map of the actual situation is in this case the most advisable relative value. In the example of the river Dender catchments below the values are summarized in between two successive sluices and locks. In the master plan for these catchments – where the studies are already going on – the location and dimensioning of the sluices will be evaluated and adapted. The proposed measures also have to be sustainable under the conditions of climate change, so the evaluated scenarios can be reused.

3. Conclusions

At present, the risk-based methodology and risk assessment tool *LATIS* are used as part of social cost-benefit analyses. Both are decision support tools to evaluate scenarios considering economic social safety, health, etc. These analyses are done for several river and coastal management plans.

Further development of the *LATIS* tool will allow us to fulfil the demands of the European Flood Directive. In the following months some additional modules will be added to provide additional maps. Most of the questions in the EU Flood Directive are dealing with drawing up an inventory of many objects in the potentially flooded zones. At the same time the potential damage and likelihood due to flooding will be evaluated. If the damage is important or largely different from its environment it will be added to the damage and risk calculation modules too.

The advance of *LATIS* now with these future developments is data availability (all data in one file format) and data management (base data only stored once) together with a user friendly interface that allows the same map layout for all catchments for all questions in the EU flood directive.

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