# Model of the effects of a flood in the Dender catchment, based on a risk methodology

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*Even if all the dikes are heightened to resisting maximal historical flood, there will always be a certain danger for flooding near the navigable waterways in Flanders. Considering that, we believe that an approach of protection against inundations cannot be a protection against high water levels any more. In the future, the consequences of a flood must be taken into account by introducing a value for the damage. This damage calculation is used as an essential element in the risk calculations. This risk level is calculated by means of an equation which contains the summation of the frequency of the observed inundation multiplied by the value of the damage caused by that inundation. In other words, the supplementary value caused by a flood with a specific return period is calculated by comparing it with the value of the damage caused by a flood with a smaller return period. The use for society of the risk model is that an objective comparison of the impression of security can be made by means of a mathematical method that can be used in the different hydrographical catchments. Another advantage is the possibility to calculate the risk in the present situation and compare it with future scenarios when the morphology and the bathymetry of the fluvial system (due to dredging, heightening of dikes ...) or the land use of the inundated land are changed.*

**Keywords:** risk, flood, damage, Flanders, GIS

## Introduction

Regularly, parts of Flanders (Belgium) are flooded due to the overflow of dikes. There have been, for example, 3 floods in the Dender catchment during the last 10 years: in 1995, 1999 and 2002-2003. Figure 1 shows a plot of the maximum annual discharge at Lessines, upstream of Flanders in Wallonia.

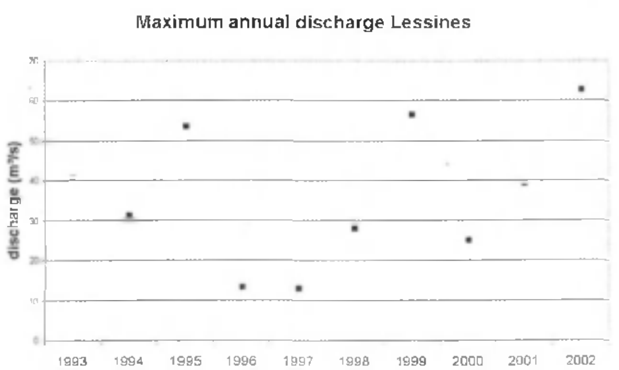


**Figure 1 Maximum annual discharge ($m^3/s$) in Lessines**

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In the past, the solution to avoiding the flood problem was evacuating the water downstream as fast as possible and heightening the dikes along the river border. Experience showed that is not the ideal situation. In the governmental note of "Mobility and Public works 2000 - 2004" the Flemish minister responsible launched the idea of another approach. The idea was not to keep trying to avoid all floods but to avoid serious damage. It is not a protection against water levels any more but a protection against the damages caused by the water. In certain areas, the effects of inundations are rather limited, in certain zones, for example in nature conservation zones, inundations can have positive effects. The opposite is true in densely populated areas or in areas with important industrial installations. In those areas extra efforts to avoid flooding have to be taken.

During an inundation there is a short term storage of big volumes of water that can be allowed in certain areas to control the discharge as much as possible. This approach makes defining controlled overflow zones necessary. This policy supposes a uniform approach of risk analysis in the different hydrographical catchments.

In this context, the study explained has several objectives:

- the development of a methodology for the uniform calculation of damage and risk for the whole of Flanders;
- calculation, using the same methodology, of changes in risk and damage due to local heightening of dikes or / and changes in land use;
- a definition of the needs for GIS data and GIS programs necessary for running the equations.

In the first place, it is the Waterways and Marine Affairs Administration (AWZ) who is responsible for all navigable waterways in Flanders and who wants a scientific tool by which the impact of decisions can be calculated in the future. In such an approach, it is necessary to work with data that have a uniform accuracy and precision for the whole of Flanders. After drawing up an inventory of the available data, a calculation model for the "risk" is defined and implemented in GIS. The results presented here are those for the Dender catchments (see figure 2). But as told before, they can be used for the other Flemish catchments as well. The Dender enters Flanders in Geraardsbergen and after a trip op 48 kilometres it enters Dendermonde where it flows into the Scheldt.


**Figure 2 View of Flanders with the 11 principal hydrological catchments (Dender catchment in grey)**

## Different types of damage

Different types of damage can be distinguished. From a financial point of view, damage can be distinguished in monetary damage and non- monetary damage. For the moment, this study does not take non-monetary damage into account, which is the domain of the emotional damage.

Another possibility is to distinguish between internal and external damage. Internal damage is defined as the damage caused in the inundated zone itself. external damage occurs at places that are not flooded. External damage occurs when suppliers or client markets are flooded. Because companies can react in many possible ways when suppliers or customers are flooded ( they can for example change stocks, buy or sell products from / to rival companies), only the internal damages are taken into account.

The third way is to distinguish between direct and indirect damages. Both are taken into account using the following definitions:

- direct damages are those affecting buildings, furniture, stocks, installations, crops …;
- indirect damages are defined as the loss due to a period without production and all costs concerning cleaning up activities (Griggs et al 1976).

The value of "goods" used for damage calculation is the replacement value and not the purchase price.

## Damage

When general calculation methods for the risk in Flanders are used, it is impossible to incorporate all the potential damage of one household individually. Insurance companies are principally interested in the potential damage that has to be assured, as detailed as possible, to calculate insurance premiums. The approach in this project is based on the use of grouped spatial data such as the mean housing value per village, the average value of crops per agricultural area, the number of houses in a statistical sector (more or less a district, a part of a community) … The spatial resolution of all these data is different. This has to be kept in mind when combining them in one project. There are also (rather big) differences in semantic and thematic reliability.

The following principles concerning an acceptable damage level have to be observed:

- whatever the price of someone's house, everybody runs an equal risk of inundation.
- for each land use, the data with the best accuracy and precision (available for the whole of Flanders) are used on a level as detailed as possible;

Due to the algorithms, the problem is that a statistical sector with rather expensive houses can run a big risk. But a statistical sector with cheaper houses can be flooded more frequently concerning lower damage. The mathematical consequence is that the area with the more expensive houses has to be protected first, which creates the problem that those areas are becoming more and more expensive (because of a good protection) and the difference from areas with cheaper houses becomes bigger and bigger (De Maeyer et al 2003). To avoid that, it is not only necessary to calculate the damage and (as defined later) the risk but also an index for "social correction".

In practice the first thing that is calculated is the maximum damage or the potential damage in each area for each land use and the creation of flood maps. The next step is combining both to make maps of the real occurring damage by use of relationships between the damage and water level. The relationship between both is not linear: figure 3 shows some graphs of the damage functions for different land uses and table one explains which function is used for the different types of land use.

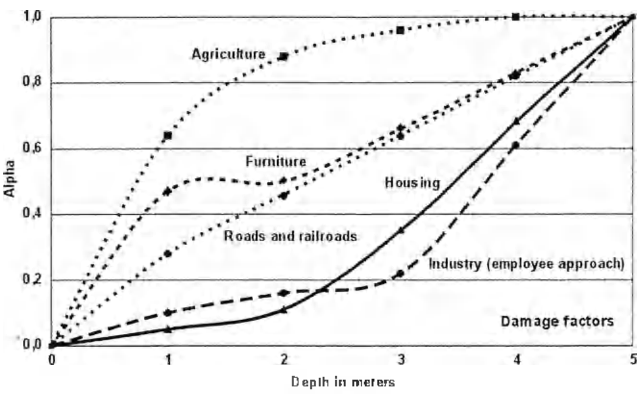


**Figure 3 Damage functions: real damage as a function of water depth**

The calculation of the replacement values for houses is explained as an example.

| Damage Classes | Damage Function |
|---|---|
| Housing, real estate | Housing |
| Housing, furniture | Furniture |
| Cars | Cars |
| Industry | Industry (surface approach)<br>Industry (employee approach) |
| Infrastructure | Industry (surface approach) |
| Airports (infrastructure) | Industry (surface approach) |
| Airports (other parts) | None |
| Recreation | Recreation |
| Arable farming | Agriculture |
| Pasture | Agriculture |
| "Nature" | None |
| Forest | None |
| Water | None |
| Roads | Roads and Railroads |
| Railroads | Roads and Railroads |

**Table 1: the damage functions used for the different damage classes**

In every statistical sector, the number of houses and the built surface is known. There are three classes of density for built surfaces which can be defined by means of a distribution code that calculates the density of houses, the basic data of which can be combined into a data layer with the number of houses per surface in each statistical sector and for each building density class. The average value of all sold houses can be found in the "Guide of the real estate values" (Fortis Bank). The product of the density of houses and the average value of a house gives the average value per surface. Insurance companies were contacted for the average value of furniture. All values they gave were about 50% of the value of the building. Due to the fact that there are different damage curves for houses (building) and furniture, those two values cannot be summated.

There are two approaches for industry. One is based on the surface, the other uses the number of employees as a key to calculate the value of industry. Because none of the methods is perfect to deal with the damage, the maximum value of both calculations is chosen in the final risk models. It is surely possible that this is an overestimation of the real damage, but overestimating is socially more acceptable than an underestimation of damage and risk.

An important concept in this approach is the "doorstep level". It is the height above the ground level that defines the zero level for damage. Under the "doorstep level" the damage is set to zero. For industry and housing, this doorstep is a physical reality. For roads the idea behind the concept is that a small water height doesn't cause any damage in a short term period. In practice, the water levels are grouped into classes of 25cm in a conservative way. That means that all water levels in the flood map are changed by the next multiple of 25cm. For housing, there is a doorstep of 25cm and for roads and industry there is a doorstep of 50cm. For all other classes of land use, the doorstep level is 0cm, which means that the damage occurs from the moment there's water. This doorstep level is included because the damage curves that are used are adaptations of the curves in the Netherlands and during calibration people were asked how high the water was above the doorstep.

Like explained before, there is a maximum (replacement) value for every class of land occupation per surface ($m^2$) or per distance unit (m). These values are variables in space and time. That is why average values of housing or agricultural production in the smallest territorial unit available are used in this project. In several cases existing approaches were adapted to the specific situation of the Flemish territory. Most of the sources of this knowledge come from the Netherlands (see e.g. Vrisou van Eck et al 1999, Van de Sande 2001) and the adaptations are described in Vanneuville et al (2002).

In an inundation zone the real damage caused by an inundation with a certain water height can be calculated by summating all unique surface entities and by using the water depth and the land use. Mathematically, this can be described like equation 1.

**Eq 1:** $$S_w = \sum_{unique\ entities} \alpha \times S_{max} \times N$$

Where:

| | | |
|---|---|---|
| | $S_w$: | real damage in a zone |
| | $S_{max}$: | maximal or potential damage in a certain land occupation |
| | Á: | coefficient expressing the elation between water depth and damage (see figure 3) |
| | N: | number of entities (linear or surface) |

Because it is by far the most important reason of floods in the Dender catchment, only overflow of dikes is taken into account.

## Fresh water versus salty water

For some land uses, an inundation with salt water will cause more damage then an inundation with fresh water. There are two ways to bring this into model.

The first way to handle the extra damage due to salt water is creating new damage curves which show the relation between water depth and fraction of the total damage. This is done for houses (buildings) and cars. In this case, damage calculation is based on inundations where the flood zones are inundated for a long time, in comparison to the data of Penning-Rowsell et al (2003). The maximal damage caused by floods of fresh or salt water respectively remains the same, but the damage curve increases faster (Vanneuville et al 2003a).

Another possibility is to change the potential damage value. This is done for agriculture and recreation. This can be done because there is a change in soil structure, which results in lower agricultural yield in the years following the flood. How long the effect of a flood can be seen in the agricultural production differs strongly for different soil types (Wösten 2002). Adding lime to the soil is an additional cost when arable land is flooded by salt water.

## Victims

During an inundation, the danger of having mortal victims always exists. From time to time courts of justice decree the value of a human life but in this project full distinction is made between the economic damage model and the victim model. The political consequences and policy options can be different when it is decided which effects are allowed.

Floods can occur on every moment: during day or night, week or weekend … and concentrations of people change over time. That is why in this model all people are assigned to their homes with the same density code as buildings (see before). The rest of the calculations are rather equally as for economic damage but drowning depends from the maximum water level and the maximum increasing level of water as expressed in equation 2.

**Eq 2:**

$$N = f_d * f_w * A$$

where:

| | | |
|---|---|---|
| N: | number of victims |
| $f_d$: | drowning factor as a function of water depth |
| $f_w$: | drowning factor as a function of incremental rate |
| A | number of people per surface ($m^2$) (Vrisou van Eck, 1999) |

The same "doorstep level" as for buildings (25cm) is used in calculation $f_d$:

**Eq 3:** $$f_d = \exp(1{,}16 * d - 7{,}3)$$

Where: d: water depth (in metre)

The drowning factor based on incremental rate $f_w$ is defined as:

**Eq 4:**

$$\begin{cases} f_w = 0 & \text{if } w \le 0{,}3 \\ f_w = 0{,}37 * w - 0{,}11 & \text{if } 0{,}3 < w < 3{,}0 \\ f_w = 1 & \text{if } w \ge 0{,}3 \end{cases}$$

where: w: incremental rate (m/hour) (Vrisou van Eck, 1999)

## Risk

The risk is an expression of the statistically expected damage for one year in a limited zone. The risk function takes into account the chance of the occurrence of a flood with a certain water level. This chance is expressed by the use of the concept of the return period. Risk must be expressed by a composed summation of the occurring damages of a flood that statistically occurs once a year and a part of the damage of a flood with a return period of two years (the extra damage, not happening when a flood with a lower chance of occurring is passing by), plus etcetera. This can be expressed mathematically as in equation 5.

**Eq 5:**

$$R = \sum_{i=1}^{n} \frac{1}{i}(S_i - S_{i-1})$$

where: $S_i$ the damages related to a flood with a return period of i years.

The calculation of damages implies the knowledge of exceptional water levels in the waterway and their chance of occurring. Also the propagation of extreme water levels in the waterway into the flood zone must be known as detailed as possible. The calculation of the chance of occurring is done by composite hydrographs. These are synthetic hydrographs used as an upstream boundary condition. They have the advantage that in every point of the waterway (and in the flood zones) the calculated water levels have the same return period. Only one calculation for every return period is enough, which results in faster risk calculation models. Because the creation and the validation of composite hydrographs is a time- consuming job, only a few are created. To calculate the risk in practice, it is assumed that there is a linear interpolation between two known return periods as expressed in equation 6.

**Eq 6:**

$$R = \sum_{i=x_i} \left[ \left( \frac{\frac{1}{x_{i-1}+1} + \frac{1}{x_{i-1}+2} + \ldots + \frac{1}{x_{i-1}+(x_i - x_{i-1})}}{x_i - x_{i-1}} \right) \times (S_{x_i} - S_{x_{i-1}}) \right]$$

## Application of the Dender catchment

The model of risk calculation was first tested on the Dender catchment. During this project, all necessary data were collected for the whole of Flanders to make sure that a uniform calculation for all hydrographical catchments is possible. Except from the hydrological data necessary for the return period calculations, there must be a detailed Digital Elevation Model (DEM) with an altimetric precision of less than a decimetre. A DEM with these characteristics is made for the whole of Flanders by the Waterways and Marine Affairs Administration (AWZ) together with the Environment, Nature, Land and Water Management Administration (AMINAL).

There are two land use maps available for the whole territory: Corine Land Cover (CLC) and the Small scale land use map of Flanders and Brussels. Both are derived from Landsat TM and Spot images so the resolution is too rough to see all linear structures such as waterways, roads and railroads. Those linear elements are well described in the topographical maps of the National Geographic Institute and there is made an overlay of the three data sources.

The general derivation scheme of the risk map is made visual in figure 4.

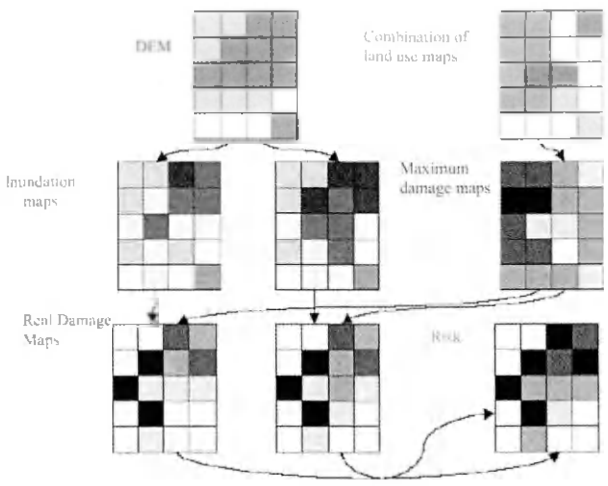


**Figure 4: General derivation scheme of risk maps**

Like explained before, in practice there is a limited number of return periods used. In the study project of the Dender, composite hydrographs of 1, 2, 5, 10, 25, 50 and 100 years were available. In this case equation 6 can be rewritten:

**Eq 7: and Eq 8:**

$$R = \frac{1}{1}S_1 + \frac{1}{2}(S_2 - S_1) + \frac{\frac{1}{3}+\frac{1}{4}+\frac{1}{5}}{5-2}(S_5 - S_2) + \frac{\frac{1}{6}+\frac{1}{7}+\frac{1}{8}+\frac{1}{9}+\frac{1}{10}}{10-5}(S_{10} - S_5) + \ldots$$

$$R = 0.5000 \times S_1 + 0.2389 \times S_2 + 0.2320 \times S_5 + 0.0700 \times S_{10} + 0.0315 \times S_{25} + 0.0135 \times S_{50} + 0.0130 \times S_{100}$$

## Calculation models

Starting with land use maps and flood maps, all steps to create risk maps are separated in sub models based on raster GIS. When the calculations in raster and vector were compared, GIS did not result in big differences of precision and accuracy but the calculation times in raster GIS are much faster. The small differences in accuracy and precision can be explained because the land use maps are derived from satellite images (raster) and the flood maps are made by using a raster DEM. The storage capacities on computer are much bigger for raster but can be compressed.

A widespread misconception is telling that raster GIS is out of date. The choice between raster and vector GIS must be made by looking at the type of the available data and the kind of analyses. Another thing to keep in mind is the interchange possibility with other GIS or spatial data used in an organisation. So conversion must be possible.

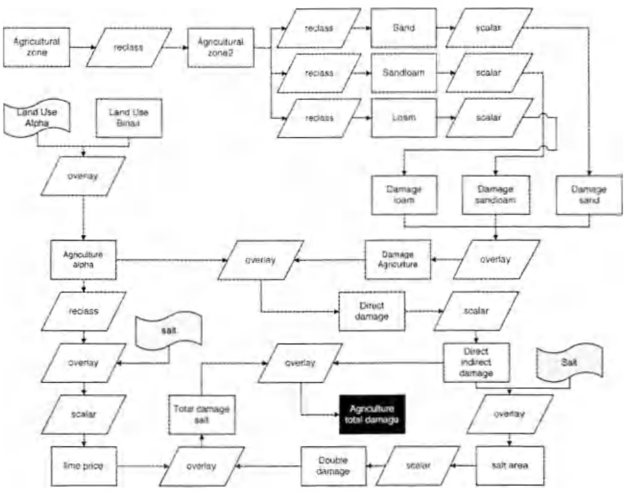


**Figure 5: Agricultural Damage, flow chart based on an Idrisi132R2 sub model**

Raster GIS is more flexible to use for dynamic phenomena. Changes in time are visualised in different data layers of which only the basic structure (number of columns and rows, grid size) is identical. Continued phenomena can be handled in vector GIS by the use of isolines or contours. They are useable for visualization but not efficient for numeric modelling or the study of spatial interactions. When continuous variables are used, 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. (Burrough & McDonnell 1998)

Once a system of models is built and specifications are defined, it is difficult to implement actions to increasing quality. But future evolution in flood risk management cannot be foreseen totally. Working with separated Idrisi models is flexible and allows future changes in a relatively simple way without too many costs (time and money) and without big concessions in quality.

For each class of land use the total damage is calculated into separated sub models. Figure 5 is a screen dump of the Idrisi Model Builder (Eastman 2001) and gives an example of the sub model of agricultural damage (direct and indirect) when areas are flooded with salt or fresh water. All these damages are brought together to create total damage maps for every return period. For the 7 return periods used in this Dender project 14 damage maps are created (2 ways of calculating industrial damage, see above). Each group of 7 damage maps is results in a risk map and the maximum value of each pixel in the risk maps results in the final risk map. This process is described in detail in Vanneuville et al (2003b).

When scenarios are calculated, changing the input files (new land use, changed topography, other flood maps ...) results in new damage and risk maps that can be easily compared to earlier calculations in order to select interesting policy alternatives.

## Conclusion

The total risk in the Dender catchment includes an ascendancy of the risk of houses and industry. The risk is highly influenced by some parts that are flooded frequently. As seen in the risk formula for the Dender catchment (equation 5), the floods with a small return period have a susceptible influence on the total risk. Also the contribution of agriculture to the total risk cannot be ignored. The damage per surface is much smaller than for industry and housing but the flooded areas are much bigger. The risk model allows simulations where land use and topography are changed. Due to the uncertainties in the basic data and the assumptions made for building the model, the results cannot be interpreted absolutely. This means that it is impossible to use the results for insurance, but they do give a very good idea of the order of size when bigger regions are compared. That makes it possible for monetary budgets to be spent on a more efficient and objective base because there is a scientific base for calculations.

Not only the benefits (decreased expected annual damage) but also the costs of new infrastructure, expropriation ... must be taken into account. Some of these actions do not only have construction or execution costs but also maintenance costs. The economic optimum is where the sum of all costs (remaining damage and cost of policy actions) is the lowest. Perhaps the economic optimum is not the policy optimum and therefore the number of mortal victims is taken out of the economic evaluation.

To make the right conclusions, precise and accurate basic data for the specific aims of a project are needed. A cartographic representation of numerical model output is a very useful method to exanimate the origin of outliers and to evaluate the overall effect of planned actions.

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