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# Water management measures in two lowland basins to reduce flooding

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*In the northern part of the Netherlands some years ago flooding took place and there were very serious threats of flooding densely populated areas. Therefore a project has been carried out in an area of 1200 km$^2$ with a number of brooks to assess the possible retention of water in the upper parts of the river basins in order to reduce the threat of flooding more downstream. The physically-based groundwater and surface water model SIMGRO was used to gain insight in the hydrology of the basins. The model was calibrated using discharges and groundwater levels. Scenarios were defined to represent measures to assess the possible retention of water in the upper parts. One measure is the retention of higher discharges using culverts or gates, the other is to make the brooks shallower, which means reduce the stream flow and the adjacent banks of the river will be flooded. Holding water in the upstream parts of the basins proved to be feasible. The reduction of the peak flow is significant.*

*Keywords: Drainage basin; rainfall; evapotranspiration; groundwater; surface water; modelling; river basin; scenario*

## 1 INTRODUCTION

Worldwide there has been an increase in the number of floods and droughts, effecting large number of people and this results in enormous economic losses. In the period 1990 to 1998 the number of recorded flood disasters was higher than in the previous three and a half decades (EEA, 2001). From such a situation it is clear that measures have to be taken to reduce the impact of these extreme hydrological events. To analyse such extreme events and possible mitigation measures, tools were used to evaluate them in terms of eco-hydrological impact and the effect on agriculture.

The Netherlands was originally a marshy delta formed by the rivers Rhine and Meuse. A rise in sea level, coupled with subsidence of the ground level means that more than half the country is now below sea level (the low-lying part); the remainder is only slightly above sea level. Throughout the country the water table is shallow (between 0.3 and 2.5 m below the soil surface) and a dense network of engineered watercourses is needed to drain the land. During recent flood events in the northern part of the Netherlands there was damage caused by flooded polders and a serious threat of flooding of densely populated areas. The high rainfall resulted in a situation that the system could not cope with the amount of run off. The water flow from the upper part of the basins could flow down very quickly, because in the last 40 years the brooks have been enlarged to discharge more water.

After a Dutch national study “Water Management in the 21st Century” a policy has been adopted to retain more water in the upper part of river basins in order to avoid flooding in the downstream part. For this national study measures were analysed in six basins across the Netherlands (Querner, 2002). Understanding the hydrology in these basins gave a proper basis for decision making on feasible measures. To analyse complex Dutch (engineered) river systems it requires the use of a combined groundwater and surface water model and predict the effect of measures on a regional scale. For such situations the SIMGRO model was used. The model simulates the flow of water in the saturated zone, the unsaturated zone and the surface water. The model is physically-based and therefore suitable to be used in situations with changing hydrological conditions. The model is a tool to find the feasible management solutions both from an ecological and agricultural point of view.

In order to give solutions for an integrated river basin management plan for the northern part of the Netherlands, one of the problems to solve is how to reduce the peak discharge. The question is

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how to retain more water in the upper parts of basins. In this paper we report on a project carried out to assess the possible retention of water in the upper part of a river basin. It describes very brief the SIMGRO model, the schematisation of the study area, the input data and then the scenarios and results.

## 2 SIMGRO MODEL

SIMGRO (SIMulation of GROundwater and surface water levels) is a distributed physically-based model that simulates regional transient saturated groundwater flow, unsaturated flow, actual evapotranspiration, sprinkler irrigation, stream flow, groundwater and surface water levels as a response to precipitation, and groundwater abstraction. To model regional groundwater flow, as in SIMGRO, the system has to be schematised geographically, both horizontally and vertically (Figure 1). The horizontal schematisation allows input of different land uses and soils, in order to model spatial differences in evapotranspiration and moisture content in the unsaturated zone. For the saturated zone various subsurface layers are considered. For a comprehensive description of SIMGRO, including all the model parameters readers are referred to Querner (1997) or van Walsum et al. (2004).

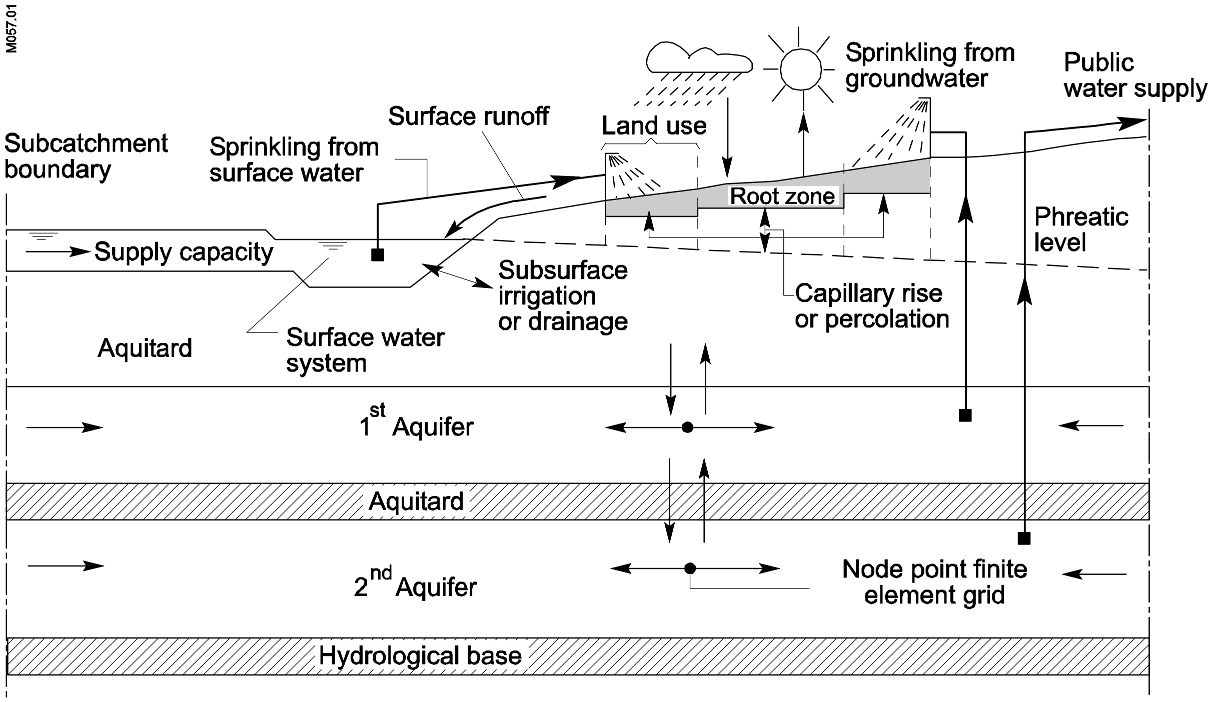

**Figure 1** Schematisation of water flows in the SIMGRO model (Querner, 1997).

### 2.1 Groundwater flow

In SIMGRO the finite element procedure is applied to approach the flow equation which describes transient groundwater flow in the saturated zone. The unsaturated zone is represented by means of two reservoirs, one for the root zone and one for the underlying soil. The calculation procedure is based on a pseudo-steady state approach. If the equilibrium moisture storage for the root zone is exceeded, the excess water will percolate towards the saturated zone. If the moisture storage is less than the equilibrium moisture storage, then water will flow upwards from the saturated zone (capillary rise). The height of the phreatic surface is calculated from the water balance of the subsoil below the root zone, using a storage coefficient. Evapotranspiration is a function of the crop and moisture content in the root zone.

## 2.2 Surface water flow and drainage

The surface water system is often a dense network of watercourses. The water course are converted for the model to a network of reservoirs. The inflow of one reservoir may be the discharge of the various watercourses, ditches and runoff. The outflow from one reservoir is the inflow to the next reservoir. The water level depends on surface water storage and on reservoir inflow and discharge. In the model, four drainage subsystems are used to simulate the interaction between surface water and groundwater. This interaction is calculated for each drainage subsystem using a drainage resistance and the difference in level between groundwater and surface water.

## 2.3 GIS interface AlterrAqua

The SIMGRO model is used within the GIS environment Arcview. It gives the possibility of using digital data, such as a soil map, land use, watercourses, etc., to serve as input data and to show results. It is also a tool for analysis and discussion, because interactively data and results can be presented.

# 3 STUDY AREA AND MODEL SCHEMATISATION

The modelling area, in size 1200 km$^2$, is located in the northern part of the Netherlands (see Figure 2). The interest area is approx. 750 km$^2$, covering the basins of the river Drentsche Aa and Peizerdiep. The ground surface slopes from about 24 m above NAP (reference level in the Netherlands) in the south to about -1 m in the north. The area consists of sandy soils in the upper parts with clay and peat in the brook valleys and the lower part. Land use is predominantly agricultural and forest; about 42% is pasture, 24% is arable land, 18% is woodland, 11% residential and 5% is other. For the meteorological input data 5 stations spread over the area were used (Querner et al., 2005) .

For the SIMGRO model the groundwater system needs to be schematized by means of a finite element network. The network, comprising 49050 nodes is spaced in the interest area about 200 m, but in the brook valleys it is spaced 75 m. For the modelling of the surface water the basin is subdivided in 5625 sub-basins. The difference in height of about 25 m means that 570 weirs were constructed in the past to control the water level and flow. Most of the weirs are adjustable, so that the target water level in summer can be raised. The lower part near or below sea level requires 58 pumping stations and 41 inverted siphons.

The geology of the area is quite complex, due to influences from the ice ages, permafrost, tectonic movements and influences from wind and water. From great influence on the groundwater flow is the resistance layers formed by boulder clay, resulting in large areas with perched water tables. In the model the groundwater system is build up of 4 aquifers and in between these 3 less permeable layers. The second layer consists of the boulder clay. The interaction between groundwater and surface water is characterized by a drainage resistance. This resistance is derived from hydrological parameters and the spacing of the water courses.

The Simgro model was at first not able to simulate the perched water tables, caused by the boulder clay (model layer 2). In large areas this resulted in too low groundwater levels. The model was adjusted, that on the basis of the hydraulic head below and above the boulder clay, the vertical resistance is corrected to simulate the flux through this clay layer correctly. Also the storage coefficient above and below the clay layer is changed during the calculations depending on the presence of the perched water table.

# 4 RESULTS OF SIMGRO MODELLING

## 4.1 Present situation

The simulations have been carried out for a period of 10 years (1989-1999). The results were compared with measured river discharges (9 locations) and groundwater levels (about 800 piezometers). For 3 main gauging stations, as shown in Figure 2, Table 1 gives the measured and

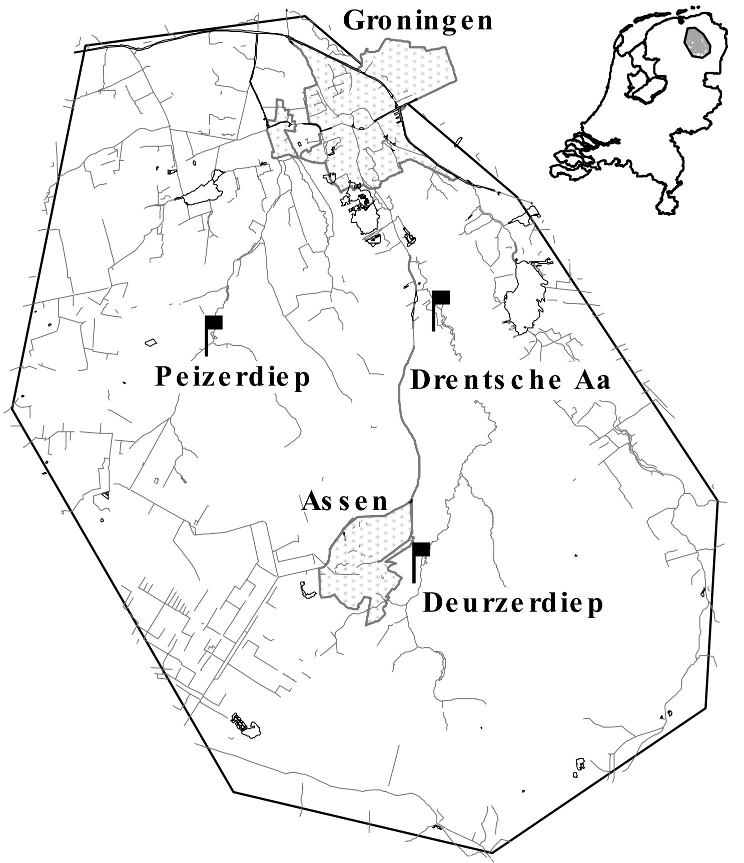

**Figure 2** Location of the modelling area and the main water courses in the northern part of The Netherlands (Rakhorst, 2005).

calculated discharges. The discharges are given for a recurrence interval of once in 5 years to 5 times per year. For the Drentsche Aa the calculated discharge is a bit higher than measured, but for the other two brooks the differences are very small. When comparing hydraulic heads, for more than half the total number of piezometers, the difference in measured and calculated head is less than 0.25 m. Comparing only the phreatic levels: for the 332 phreatic piezometers there are 239 with a difference less than 0.5 m and 145 with a difference less than 0.25 m. These differences between measured and calculated results were regarded as small, so it was concluded that the model can be used to analyse possible measures to hold water in the upstream part of the basin.

**Table 1** Measured and calculated discharges for 3 gauging stations ($m^3/s$).

| Gauging station | | Discharge for a recurrence interval | | |
|---|---|---|---|---|
| | | 5 year | 1 year | 5x/year |
| Drentsche Aa | Measured | 11.02 | 8.91 | 6.97 |
| | Calculated | 13.63 | 11.57 | 7.58 |
| Deurzerdiep | Measured | 14.45 | 11.52 | 6.34 |
| | Calculated | 14.05 | 11.59 | 6.24 |
| Peizerdiep | Measured | 13.64 | 10.45 | 6.57 |
| | Calculated | 13.44 | 10.47 | 5.97 |

## 4.2 Mitigation measures and the impact

Mitigation measures were defined that would reduce the peak discharges to acceptable volumes. In this research the following measures were analysed:

1. Restrict peak discharges
   Peak flows can be restricted by installing sluice gates or culverts of such a dimension that only the higher peaks are reduced. In the simulations, the opening of these constructions was such that the flow will be restricted when the flow is higher than occurring once a year.
2. Make the brooks shallower
   Reducing the depth of the water course will result in water overtopping the side banks and that will be stored on the flood plain. The storage of the water on the over banks will reduce the flow propagations and thus reducing the peak flow.

In Figure 3 the upstream part of the Drentse Aa is shown, were measures were considered. At 8 locations the flow was restricted and over a length of 29 km the brooks were made shallower. In Table 2 the results are shown for the 2 sub basins; it gives the discharge for the reference situation, the two measures and the change in flow. The impact of the first measure (restrict peaks) is more than the second (shallower brooks). Limiting the flow by introducing gates or culverts, means a decrease in peak flow in the order of 25-50%. The large variation depends on local conditions and the number of structures in a brook. Limiting the flow has very little influence on groundwater levels, because only for a number of days or weeks the water flow is obstructed. Local flooding may occur and thus groundwater levels rise. This small and short rise, often in winter time, has no effect on agriculture or nature. When the brook is made shallower, this results in reduction of peak discharges in the order of 5-20% (Table 2). The consequence of this measure is higher water levels, also in dry periods. The flow reduction is mainly caused by the water overflowing the river banks and flooding the valley. Also the groundwater levels adjacent to the brook will be higher. In general the higher levels have a positive influence on nature.

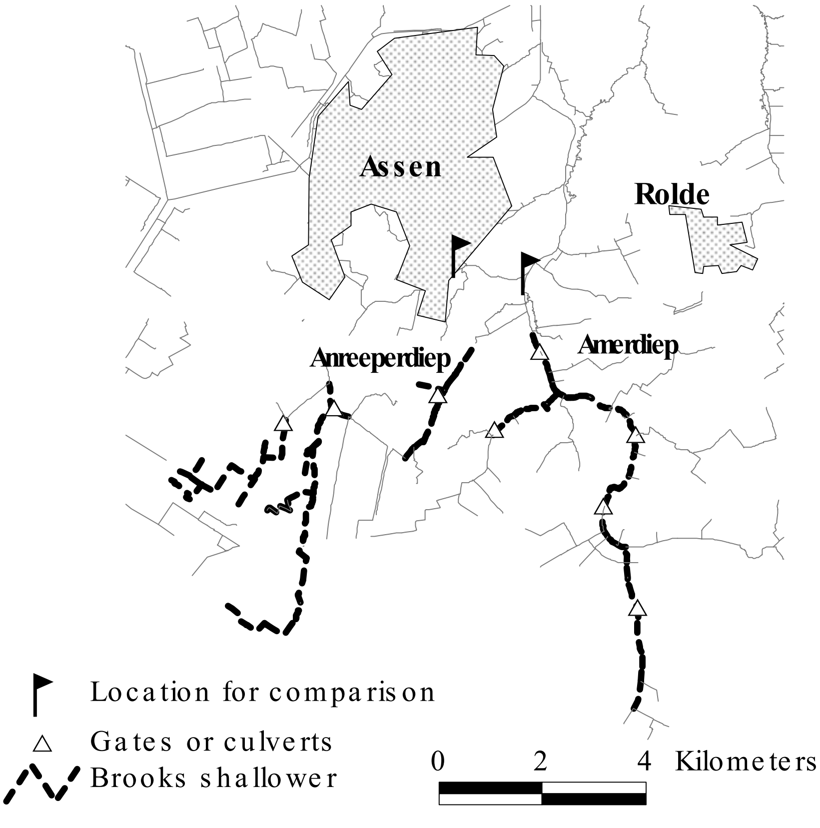

**Figure 3** Location of the mitigation measures carried out in the upstream part of the Drentsche Aa.

**Table 2** Change in discharges ($m^3/s$) for 2 sub basins and the two measures as shown in Figure 2.

| Location | Scenario | Discharge for a recurrence interval | | | |
|---|---|---|---|---|---|
| | | 10 year | 5 year | 1 year | 5x/year |
| Amerdiep | Reference | 13.180 | 9.620 | 5.418 | 3.078 |
| | Gates | 5.321 | 4.980 | 4.603 | 3.138 |
| | Reduction (%) | 60 | 49 | 15 | -2 |
| | Brooks shallower | 10.078 | 9.056 | 4.994 | 3.071 |
| | Reduction (%) | 24 | 7 | 8 | 0 |
| Anreeperdiep | Reference | 9.121 | 5.807 | 3.379 | 1.939 |
| | Gates | 6.973 | 3.741 | 3.019 | 1.972 |
| | Reduction (%) | 24 | 36 | 8 | -2 |
| | Brooks shallower | 8.475 | 5.526 | 3.438 | 1.929 |
| | Reduction (%) | 7 | 4 | 2 | 1 |

## 5 DISCUSSION ON MEASURES FOR EXTREME RAINFALL EVENTS

In the present situation extreme rainfall extreme events would cause flooding in the low laying areas, which are often densely populated. This situation occurred as well in the autumn of 1998, when in the upper part of the brooks intense rainfall occurred for a number of days. This caused high stream flows and in the lower parts, in the city of Groningen (see Figure 2), very serious threats of flooding occurred. In this analysis it has been demonstrated that it is feasible to restrict peak flows when they are higher than the discharge occurring once a year. Another approach could be as well to reduce the peak flows which occur once in 10 or 50 years. Take these measures in the upper parts of the basin, thus storing water in extreme events in areas which are not so densely populated. In that way the choice is explicitly accepting local flooding in the upper parts of a catchment where mostly agricultural land is situated, instead flooding high densely populated areas more downstream.

## 6 CONCLUSIONS AND DISCUSSION

Physically-based models are able to simulate stream flow in basins with different land use and climate conditions. The model calibration was limited, but the simulation results show that the model give satisfactory estimates of the discharges and groundwater levels. The model is therefore an adequate tool to simulate stream flow, and have a potential to assess the impact of measures to reduce flooding. This research may be seen as a support tool for decision-makers who are responsible for a management plan. One of the main results of this research is the model itself, as a tool for finding the best possible management options both from an ecological and agricultural point of view. The research clearly showed that an integrated hydrological approach, gives results that can be used in the evaluation of the effects of water management measures. These results can also be the basis of a more comprehensive and profound study that takes into account other factors such as constraints and costs of the different measures and public participation.

This study has shown that ecosystems of lowland catchments where the groundwater levels have been lowered by extensive land drainage can be restored by restricting the flow from the upper parts. Holding water in the upstream parts of the basins is feasible. The delay of the peak flow is significant. Limiting the flow by introducing gates or culverts, means a decrease in peak flow in the order of 25-50%. To make the brook shallower results in reduction of peak discharges in the order of 5-20%.

For extreme situations as occurred in October 1998, it is also possible to use measures to reduce only the extreme peak flows, like flows with a recurrence of say once in 10 or 50 years. In that way the choice is explicitly accepting local flooding in the upper parts of a catchment where mostly agricultural land is situated, instead flooding high densely populated areas more downstream.

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