# Water management innovation for meeting Climate change effects and European Water Framework Directive targets: Pilot study Lankheet

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## ABSTRACT

The very wet conditions of recent years in Europe have made it clear that measures will have to be taken in this century to prevent flooding. The question is how to manage groundwater in order to reduce the anticipated increased hydrological risk. Furthermore the surface water quality in the Netherlands is insufficient to meet the standards of the Water Framework Directive. The required improvements are difficult to obtain because the diffuse loads of nutrients from agricultural use can not be reduced so easily. This demands for innovative solutions with respect to improve the surface water quality by means of purification in reed fields and use it as well to reduce the effects of the anticipated climate change. An experimental evidence on a practical scale is lacking and therefore in the woodland area of Lankheet in the eastern part of the Netherlands, 3 ha has been planted with reeds to purify the river water. The aim of the study is further to store the purified water in the groundwater in order to reduce climate change effects. For the hydrological situation a scenario study was set up, using a regional hydrological model to simulate the groundwater flow together with the water flow in a network of water courses. Possible measures have been analysed to reduce peak flows and to increase the lower flows in summer. The analysis will give knowledge on the multifunctional use of such a system.

## INTRODUCTION

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 following the drainage of peat bogs and their conversion to farmland 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. The very wet conditions of recent years in Europe have made it clear that measures will have to be taken in this century to prevent flooding. As indicated in the recent published IPCC report (IPCC 2007), the anticipated climate change will have a crucial effect on groundwater and surface water. The question is how to manage groundwater in order to reduce the anticipated increased hydrological risk.

The objectives of the European Water Framework Directive (WFD) focus on sustainable water use by protection and improvement of the surface and groundwater, using the river basin as the focal point. In a tentative study, the consequences of the WFD for agriculture in the Netherlands was carried out for  nutrients and pesticides in fresh water ecosystems (Bolt & Leenders 2004). The results indicated that the surface water quality in the Netherlands is insufficient to meet the standards of the Water Framework Directive. The possible consequences of the Directive are considerable, in larger parts of the Netherlands arable land should be taken out of production, because the diffuse loads of nutrients from agricultural use cannot be reduced so easily (Bakel 2006). This situation demands for innovative solutions with respect to reduce the anticipated effects of climate change, and to improve the surface water quality on meeting the WFD targets.

In this paper we report on a project which is presently carried out in the Eastern part of the Netherlands. It's an experimental set-up in order to improve the water quality of the surface water and to reduce the effects of the anticipated climate change.

## METHOD

The effects of climate change and meeting the target for the WFD demands for innovative solutions. In an experimental set-up the purification of the water in reed fields is monitored and investigated, together with the reduction of peak flows. A schematic layout of the set-up, the so-called model Vereijken, is shown in Figure 1. An experimental evidence on a practical scale is lacking and therefore in the woodland area of Lankheet in the eastern part of the Netherlands, an area of 3 ha has been planted with reeds to purify the river water. Reed is able to take up nutrients and phosphorus, it is known that uptake of P is in the order of 50 kg per ha per year. The purified water can be stored in designated areas. Further benefit is to replenish the groundwater in order to recover the terrestic ecosystem from too dry conditions. Also the water can be retained in the reed fields and in the forest to prevent flooding downstream. A promising measure is also to periodically harvest the reeds to be used as bio fuel.

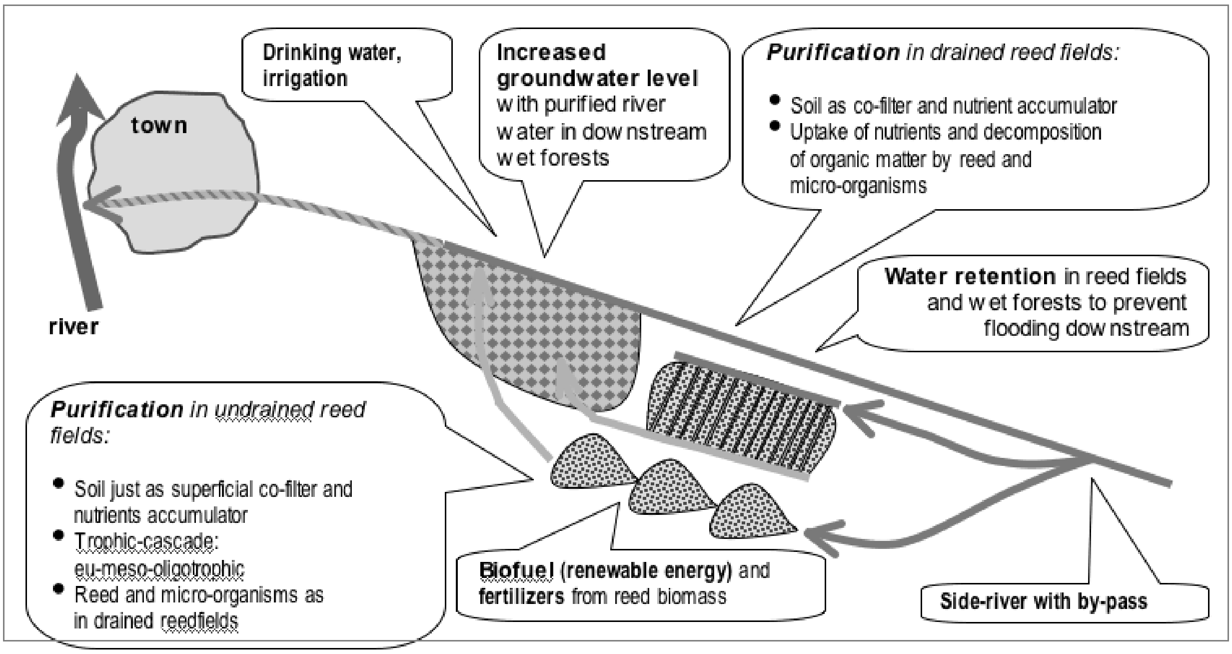


**Figure 1**. Schematic layout of the experimental site (Vereijken and van der Werf, 2007)

Climatologists anticipate that the climate in the near future, say around 2050, will be warmer and wetter. The Dutch Royal Meteorological Institute predicted a set of climate change scenarios, based on moderate warmer or warmer conditions, using the data and methods given in the 4$^{th}$ IPCC report. The average temperature will rise for the two scenarios one or two degrees respectively. Furthermore it is expected that the air circulation could change. For a temperature rise of two degrees, including the change in air circulation, the so-called W+ scenario, the average annual rainfall will decrease in summer by 19% and increase in winter by 14% (Hurk et al. 2006). The annual potential evapotranspiration will increase by 15%. It is further expected that the rainfall in a period of 10 days will increase by 12% in winter and 10% in summer. Based on these predicted changes historical meteorological data on a daily base was transformed into a new series applicable for the period around 2050. Fife years of meteorological data on a daily basis were selected for the simulations with the hydrological model, being the period 1994-1999. The year 1998 was extreme wet, resulting in an average annual rainfall for this period of 863 mm, for the climate change scenario this increases to 897 mm per year (increase of 4%). The average potential evapotranspiration for grass was 539 mm per year and for the climate change scenario it increases to 620 mm. In the 5 years high intensity rainfall events of 30-40 mm/d occurred 6 times and events of 40-50 mm/d occurred 2 times.

## THE COMBINED SURFACE AND GROUNDWATER FLOW MODEL SIMGRO

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 rainfall, reference evapotranspiration, and groundwater abstraction. To model regional groundwater flow, as in SIMGRO, the system has to be schematised geographically, both horizontally and vertically. The horizontal schematisation allows input of different land uses and soils per subregion, in order to model spatial differences in evapotranspiration and moisture content in the unsaturated zone. For the saturated zone various subsurface layers are considered (Fig. 2). For a comprehensive description of SIMGRO, including all the model parameters readers are referred to Querner (1997) or Walsum et al. (2004).

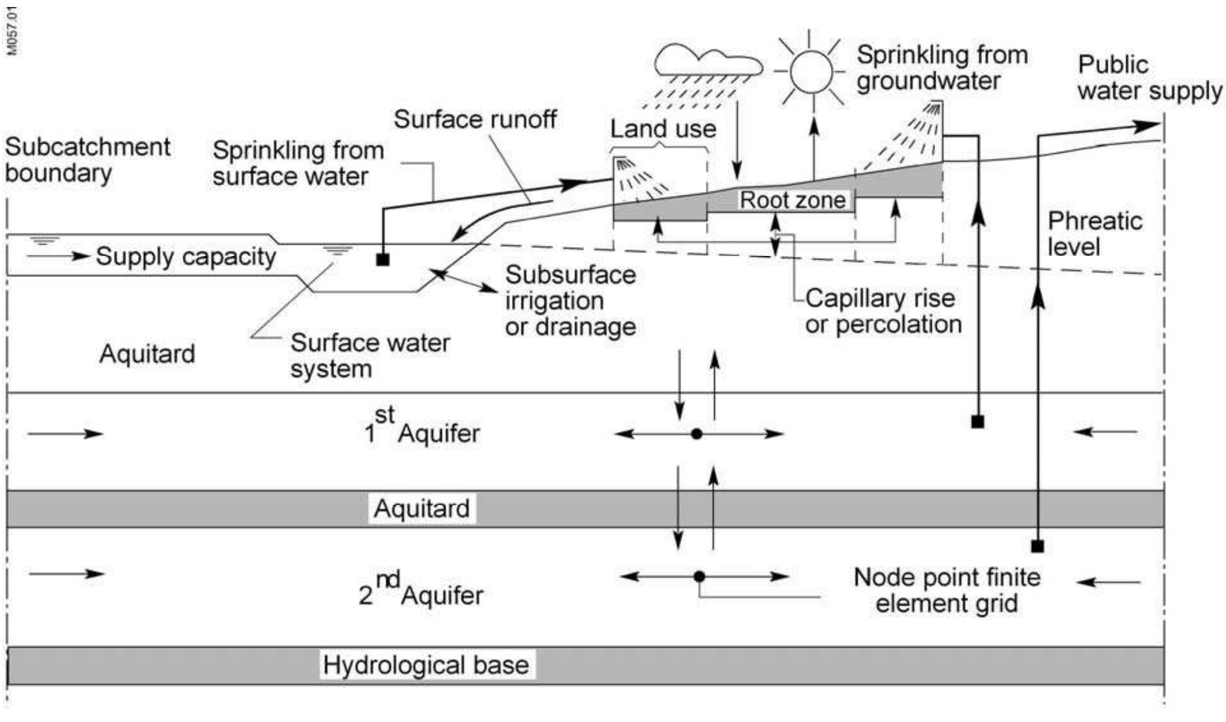


**Figure 2.** Schematization of water management in the SIMGRO model. The main feature is the integration of the saturated zone, unsaturated zone and surface water systems (Querner, 1997).

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 (Fig. 2). The calculation procedure is based on a pseudo-steady state approach, using generally time steps of up to one day. Evapotranspiration is a function of the crop and moisture content in the root zone.
In the model, four different categories of ditches (related to its size) are used to simulate the drainage. This interaction between surface water and groundwater is calculated for each category using a

drainage resistance and the difference in level between groundwater and surface water (Ernst 1978). The surface water system is modelled as a network of reservoirs. The outflow from one reservoir is the flow entering the next reservoir, and surface water levels depend on the amount of storage and discharge from a reservoir.

## STUDY AREA AND SCHEMATIZATION

The modelling area is located in the eastern part of the Netherlands and covers 125 $km^2$ (see Fig. 3) Also shown is the area of main interest, the Lankheet estate, being approximately 5 $km^2$. The ground surface slopes from about 31 m above NAP (reference level in the Netherlands) on the east side to about 22 m in the west side. The difference in height of about 9 m means that weirs were constructed in the past to control the water level and flow. The area consists of sandy soils in the upper parts with some clay in the stream valleys. Land use is predominantly agricultural and forest. About 29% is in pasture, 10% is arable land, 55% woodland and 6% other.
For the SIMGRO model the groundwater system needs to be schematized by means of a finite element network. The network, comprising 16000 nodes, is spaced at about 25 m in the interest area and spaced at 300 m at the boundary of the model. For the modelling of the surface water the basin is subdivided into 990 sub-basins. 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 groundwater system in the model consists of a single aquifer with under laying Miocene clay. For the saturated zone the transmissivity varies between 25 and 300 $m^2$/d.

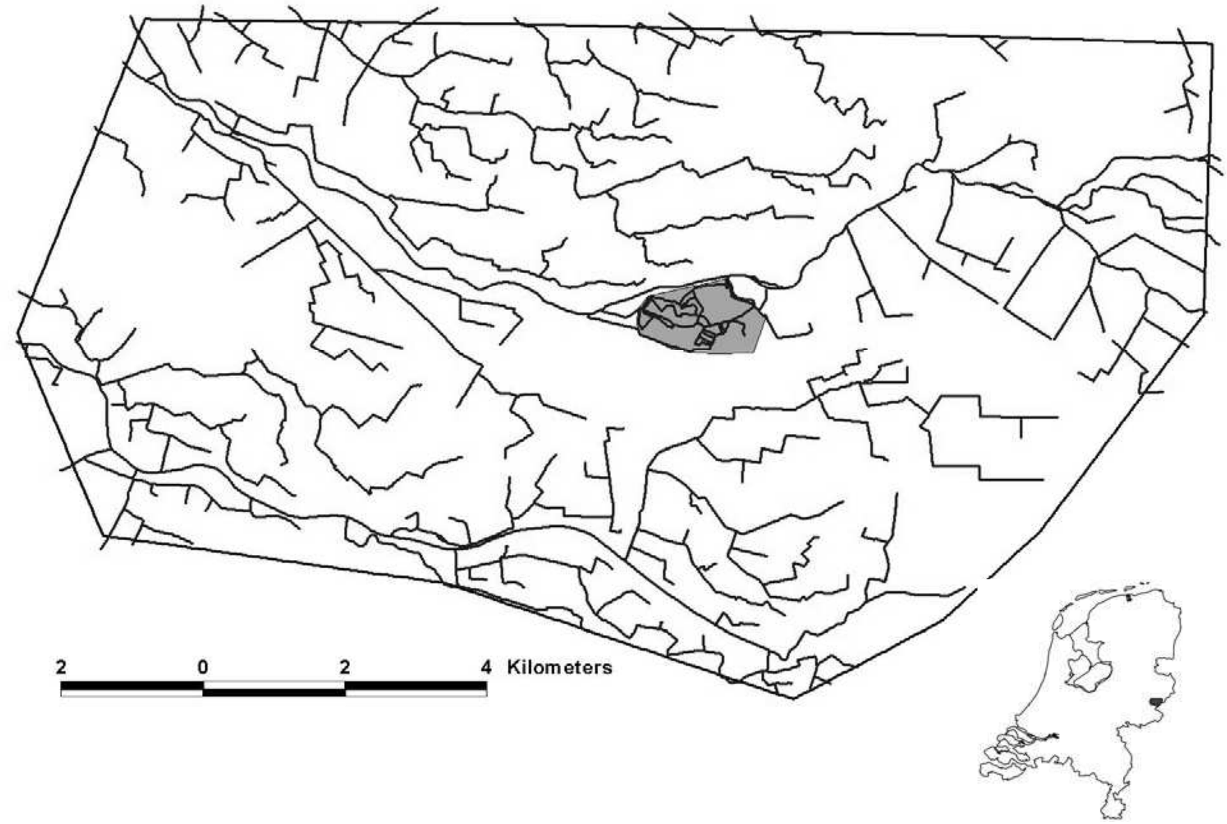


**Figure 3**. Location of the modelling area and the main water courses in the eastern part of The Netherlands. The shaded area is the Lankheet estate.

## RESULTS

Running the model for the present situation and the climate change scenario gives differences in stream flows. For a closed sub-basin within the modelling area these are shown, for the years 1994 and 1995, in Figure 4, together with the change in stream flow. In winter the stream flow is higher, but in summer the flow is much smaller due to the reduced rainfall and the increased evapotranspiration. The dryer conditions in the climate change scenario results in higher water storage capacities in the ground, resulting in an attenuation of the stream flow.
The stream flows were also analysed in terms of frequency of exceedance, for the highest peak in this 5 year period the increase in flow was 15%. For 5 occurrences in this period the increase was 8-10%. In summer the low flow, Q95, occurring less than 5% of the time will be around 6 to 8% lower. Because of the relative short duration of the simulations (5 years) the calculations give a rough order of the changes in flow pattern, but a longer calculation period is needed to give a more precise answer. Simulations of basin response to climate change in the Netherlands reported some years ago (Querner 2002), gave increases in peak flows in the order of 20 to 30%, based on the previous set of climate change scenarios. In the present scenarios there is a lower increase in precipitation and the assumed evapotranspiration is higher.
For the extreme peak flow occurring in November 1998 it was estimated that the increase in flow for the climate change scenario lasted around 6 days and this increase was estimated for the sub-basin to be 4 mm of water. This amount of water can be retained in the reed fields and in the wet forest.

The effect of the climate change on groundwater levels in the modelling area was moderate. In summer the lowest groundwater levels, averaged over the 5 years, are in the order of 6-15 cm lower, and in winter the high groundwater levels around 5 cm higher.

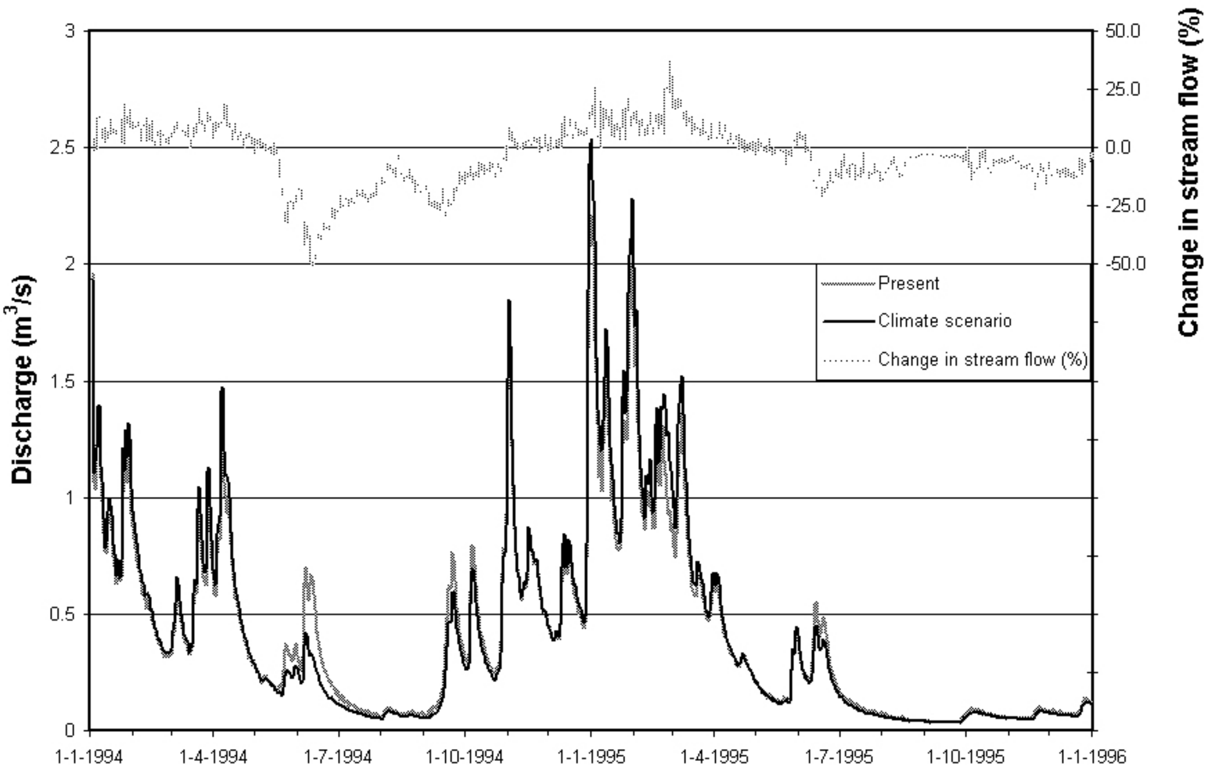


**Figure 4.** Effect of climate change on stream flow for a sub-basin of 31 km$^2$.

## DISCUSSION AND CONCLUSIONS

The climate in Europe is expected to become warmer and wetter during the next century, the temperature rises, and stream flow from regional water systems reduces in summer, but peak flows in winter will increase. Therefore the anticipated climate change results in more frequent flooding and mitigation measures are necessary to cope with the hydrological risk. For the Lankheet region a scenario study was conducted to quantify the increased risk, using a regional hydrological model to simulate the groundwater flow together with the water flow in a network of water courses. The analysis shows that peak flows in winter will increase by 10 to 15%. The low flows in summer will decrease by 6 to 8%. This study shows that to adequately simulate the effect of climate change the model must be comprehensive and integrate surface water and groundwater, because the changes in precipitation and evapotranspiration will have a great effect on shallow groundwater conditions and on surface water levels.

The European Water Framework Directive can have enormous consequences for agriculture in the Netherlands. In parts of the country agriculture should be taken out of production because the nutrient loads to the surface water system are far too high. Using reed fields is a possibility to improve the water quality and these areas can be used as well for water retention in order to prevent flooding downstream. The analysis carried out gives knowledge on the multifunctional use of such a system and tools will be developed for the hydrological feasibility of water storage and purifying reed lands in other parts of the Netherlands.

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