MIPWA: Water managers develop their own high-resolution groundwater model tools

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Abstract The interests of the various parties involved in water management often conflict. The project "Development of a Methodology for Interactive Planning for WAter management" (MIPWA) is intended to resolve these conflicts. For the first time in The Netherlands, 17 water management stakeholders joined forces to develop a large-scale high-resolution decision-making tool for groundwater-related issues. It consists of a groundwater model database, an impulse-response database and the user-friendly interactive modelling tool *iMOD*. Each conceptual choice was made by the whole group of stakeholders themselves, based on the choices provided to this group by model experts of various research institutes and consultancies. This has strengthened the cooperation between the participating organisations enormously, and created a level playing field for environmental planning processes. Both technical and interactive consensus-building challenges had to be tackled in the MIPWA project. Numerous innovations have proven to be effective: grid-computing, up-scaling, large data storage, accessibility via the internet and interactive decision-making processes.

Key words groundwater modelling; decision-support; high resolution; scaling techniques; grid computing; graphical user interface

INTRODUCTION

Background

The "Development of a Methodology for Interactive Planning for WAter management" (MIPWA) project started in 2005. In this project, 17 water management parties in the northern part of the Netherlands (four provinces, three drinking water companies, six water boards and three municipalities) developed, together with two research institutes and two consultancy agencies a high-resolution regional groundwater decision-making tool for groundwater-related issues. In addition to technical goals such as the detailed scale (25 × 25 m) and an interactive graphical modelling environment, the project aimed at full support of the instrument by both hydrologists and decision-makers. This last goal changed the typical technical focus of model projects and required influx from social science, for example communication strategies and conflict handling techniques, to keep the group of stakeholders together in moving towards a technically high-standard, consensus groundwater model.

PROJECT AREA

The MIPWA project area in the northern part of the Netherlands (Fig. 1) is around 1 000 000 ha. It is a varied agricultural and natural area, with little urban development, and 44% of the area is below 3 m (above sea level) and a spread of small channels controlled by weirs and pumps dominates the water system. The area higher than 3 m (56%) has a more natural sloping drainage system, often modified by canalisation. Interaction between surface water and groundwater is

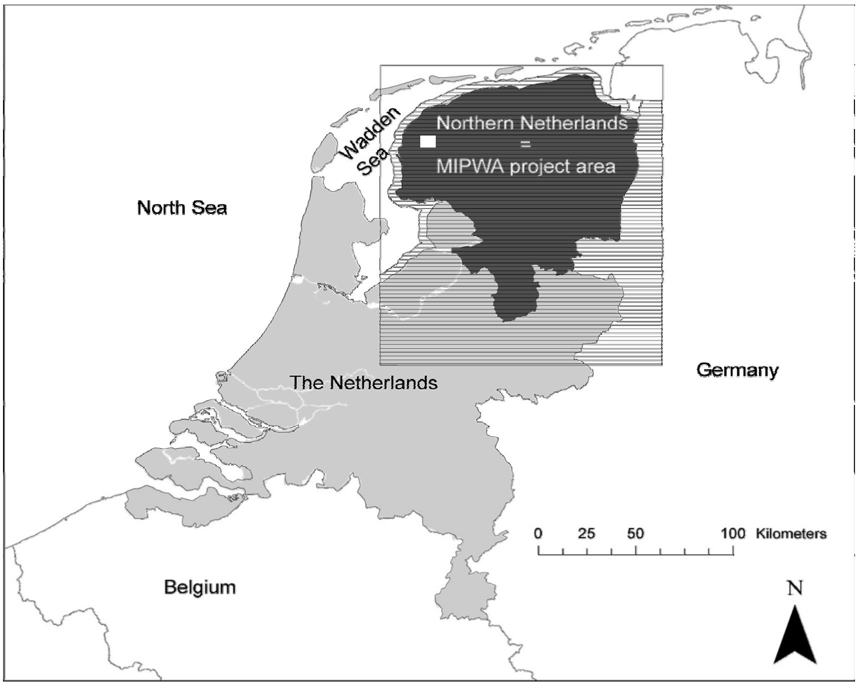

Fig. 1 Location of MIPWA project area (dark grey) and total model area (shaded).

strong in the MIPWA area. The total groundwater withdrawal for drinking water and industry is 380 million m^3 per year. Finally, seawater intrusion plays a role due to its location near to the Wadden Sea.

Water management issues

Responsibilities for water management in The Netherlands are divided over three parties; each having their own responsibilities. Provinces (four in the MIPWA area) are responsible for groundwater and spatial planning. Water boards (six in the MIPWA area) are responsible for surface water (stages and maintenance). The national government (unfortunately not yet involved in MIPWA) is responsible for all surface water bodies that are used for navigation other than recreational. The overlap between responsibilities complicates water management and policy making.

The main challenges for water managers in the MIPWA area are planning issues, the increasing need for domestic water, and the expected climate-induced increase in floods and droughts. Both Dutch and European legislation, GGOR (Dutch acronym for desired ground and surface water regime), Water management 21st century (anticipating on floods and droughts), and the European Water Framework Directive, regulate these challenges.

Besides the responsible governmental organisations other stakeholders play important roles in water management: drinking water supply companies, industry, agriculture and individual households. Over the last decade the participation of these stakeholders in decision-making processes has increased. In this arena communicational means are just as important as technical means.

MIPWA INNOVATIONS

Regional high resolution groundwater modelling

The geographic setting and the water management challenges require a detailed groundwater model on a regional scale that can be used for numerous groundwater issues. The primary focus in the MIPWA model was on spatial planning and water management, with possibilities for future extensions to other management issues.

The MIPWA model covers the area of interest plus a buffer area to decrease the impact of the model boundaries (145 km East–West and 167 km North–South). It is a MODFLOW model with 25 m grid cells. In total the model has 238 000 000 active model grid cells (Fig. 1) over seven quasi-3-D model layers. The model time step is 1 day. The model has been run for 13 years (1989–2001).

With its focus on planning, shallow groundwater processes are given high priority (Fig. 2). The unsaturated zone is modelled using the newly developed MODFLOW–SIMGRO on-line coupling (Veldhuizen *et al.*, 2006a). In the river package all individual surface water bodies, ranging from the smallest ditches to the largest lakes, are modelled. In this way the full nonlinear water system is modelled (Fig. 3).

Transmissivities and vertical conductances were calibrated in a stationary mode using the Representer method (Valstar *et al.*, 2004). For this purpose, 8171 measurement locations were used. The average residual (modelled minus measured groundwater level) for all layers was -0.07 m and the average absolute residual 0.35 m. River conductances, phreatic storage coefficients, capillary rise and storage in the root zone were transient calibrated using parallel PEST on time series of groundwater fluctuations.

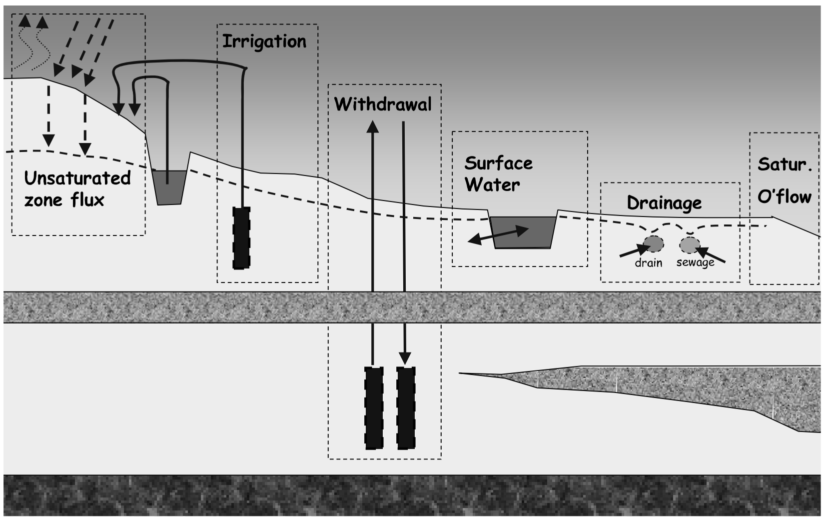

Fig. 2 Processes modelled.

Fig. 3 Representation of individual surface water bodies in the model (location is white rectangle in Fig. 1). Scale ranges from light grey to black, from small ditch to river.

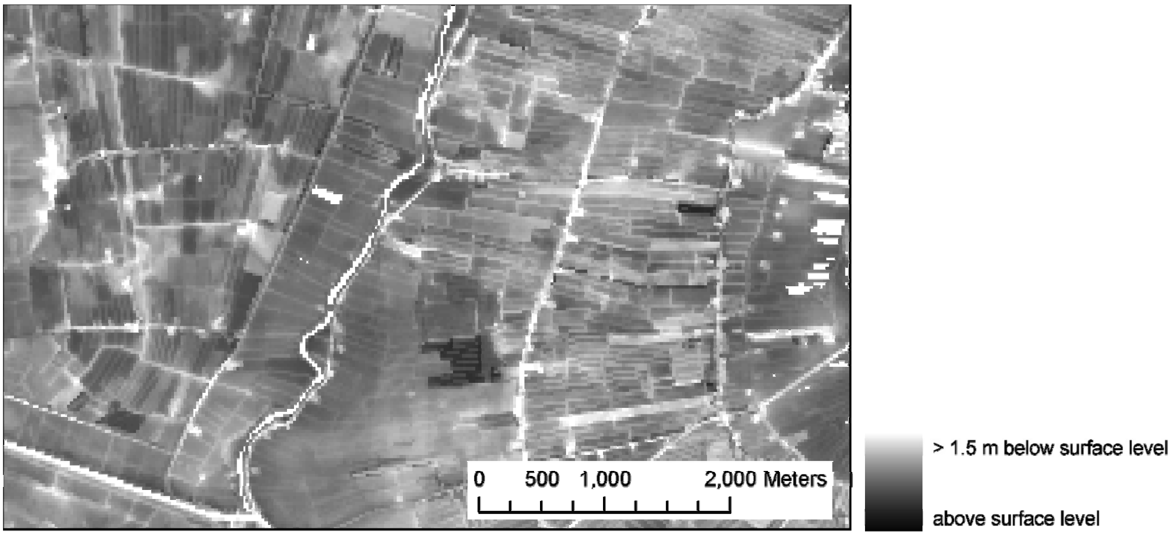

Fig. 4 MIPWA model result: average highest yearly groundwater level (location is white rectangle in Fig. 1).

The MIPWA model results consist of maps and time series of groundwater levels, head and fluxes. An example of the detailed model results is shown in Fig. 4.

In order to run this huge numerical model and store all results, much effort has been put into scaling techniques and grid computing. Scaling of the nonlinear surface water system is of major importance here. We applied the proposed Cauchy correction methods from Vermeulen *et al.* (2006a) in an iterative manner. The Cauchy corrections are calculated as the difference between fine scale heads of a previous run and current coarse-scale heads. During both stationary and non-stationary calibration, the model was scaled to 250 × 250 m grid cells. A forward run of the high-resolution model was done by splitting the model into 473 sub models. Grid computing was used to distribute jobs over around 150 computers. In this way, 16.6 years of CPU time for calibration and forward runs was realised within 1.5 years.

Impulse–response database

In order for the MIPWA model to really support decision making in spatial planning processes the concept of impulse–response (IR) databases was developed. In an IR-database the effects of a variety of possible measures on the water system are collected. This database can be consulted in two ways: what effect will this measure have? and what measures can be used in order to achieve a certain effect? Using *iMOD* (see next paragraph) the database can be consulted very quickly. When consulting the database the effects are simply added, ignoring nonlinearity. An example is given in Fig. 5. The IR-database therefore gives an estimation of the possible total effect (quick scan) and is only applicable for selected measures, based on prior linearity analysis.

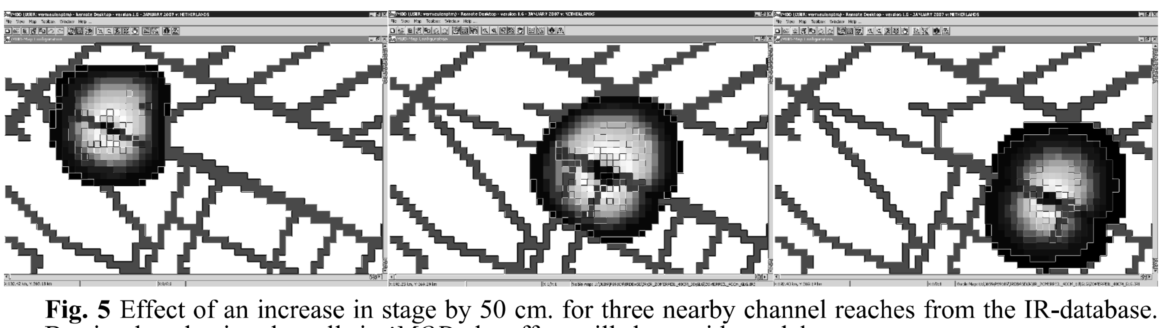

Fig. 5 Effect of an increase in stage by 50 cm. for three nearby channel reaches from the IR-database. By simply selecting the cells in *iMOD*, the effect will show without delay.

To collect the effects the model was run once for every measure on a possible location. For example, for the measure "new abstraction well" the effect of a new abstraction well is calculated for 24 215 possible locations, every 1 × 1 km^2, i.e. the model has been run 24 215 times. In total 27 measures, e.g. increasing surface water levels or ending additional water supply in summer, were added to the IR-database.

Aiming at reducing computing time for the IR calculations the MIPWA model was reduced in space and time. In space the so called "amoeba principle" was used. First, an initial sub model is selected with constant head boundaries. Next the effect is calculated. If the effect reaches the sub model boundary, a new, larger, sub model is run. If the effect stays within the sub model, the effect is stored.

In time, the 1-day resolution was reduced to a quarter-year model. The reduction in time was possible because the focus is on effects on groundwater levels only and not on the full range of model results. Although, this reduction can result in large model errors, the errors on the calculated effects area are relatively small (on average 10%). This error is very acceptable with respect to the purpose of the IR-database.

Process guidance and policy support

The detailed groundwater model offers the water authorities in the northern Netherlands technical support. But technology is not the language in the policy arena and certainly not in the realm of administrative decision-making. To ensure that the model is indeed fully supported by all parties and that the technology properly embeds in the various organisations, the MIPWA project has devoted a great deal of attention to process guidance and policy support. The project started with an analysis of the actors and influences to ensure that the project goals were suitable. Within a period of 2 years, 20 workshops have been held. During these workshops the 17 stakeholders jointly decided upon model conceptualisation and parameterisation and they contributed their area-specific knowledge. The hydrologists from the research institutes and consultancy agencies prepared these workshops together with policy professionals. These workshops were very well attended. Everyone was well aware of the value of the workshops in strengthening the cooperation and creating broad support for the groundwater model.

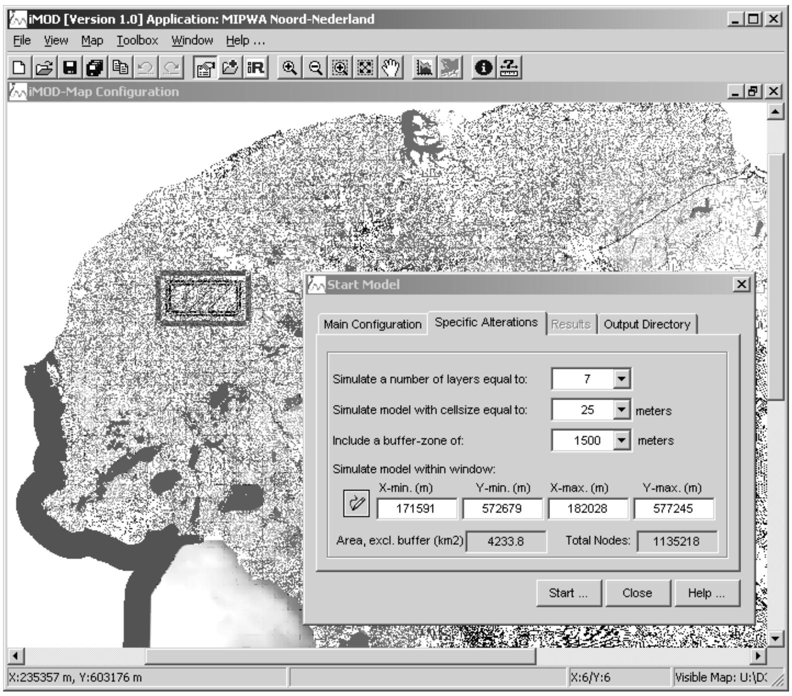

Fig. 6 Screendump of *iMOD* in model run mode.

Another part of the policy support was the development of the user-friendly interactive modelling tool *iMOD* (Vermeulen *et al*., 2006b). *iMOD* offers analysis and query tools for the input and output of the regional groundwater model and the impulse–response database and it offers tools to run (Fig. 6) and analyse model scenarios. The above-mentioned scaling techniques were implemented in *iMOD* to ensure correct calculations. During the model building *iMOD* was also used to discuss model input and results. All participants could use *iMOD* via the internet for analysing the model input and they could leave digital notes ("the seepage pattern in this area is not correct") on model maps.

CONCLUSIONS

In the MIPWA project a variety of innovations, both technical and policy oriented, have proven to be very valuable. Without the technical innovations the detailed model scale would not have been feasible. The support of all stakeholders for the model would not be as strong without the policy oriented innovations.

The IR-database concept is new in both the technical and policy arena. It is a powerful, promising technique to reduce the distance between decision-making and technical groundwater information. The IR-database concept is limited at the moment by the linear addition of effects. We expect improvements in the near future from model reduction theory. Actual effects may then be calculated with quick reduced models, instead of consulting a database.

The MIPWA project has shown that technicians and policy makers can understand each other. However, translators are necessary, either in person or in technical tools. Concerning the technical tools we believe there is a still lot of work for policy-sensitive technicians.

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