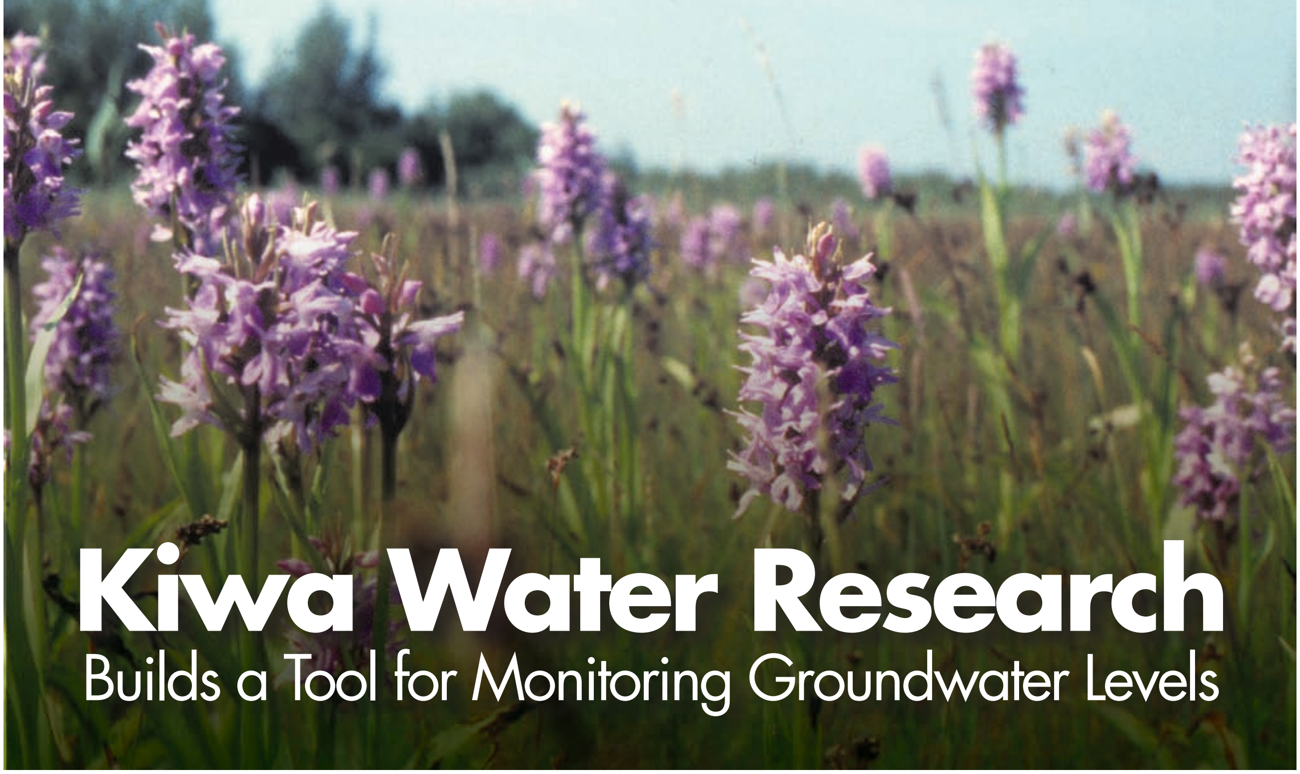

Kiwa Water Research

Builds a Tool for Monitoring Groundwater Levels

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Voorne's Duin is one of the most important nature reserves in Western Europe. Famous for its high diversity of plant and animal life, it is home to over 60% of all Dutch species of birds. It is also adjacent to Rotterdam, one of the world's largest sea ports, and to an industrial area called De Maasvlakte.

To relieve congestion in Rotterdam, the Dutch government is considering reclaiming a new area of land from the sea. The reclamation project would influence groundwater levels, with significant impact on the rare plants and animals in Voorne's Duin, such as the fen orchid and the narrow-mouthed whorl snail.

Jos von Asmuth and Kees Maas, researchers at Kiwa Water Research and the Delft University of Technology, were commissioned by the Ministry of Transport, Public Works and Water Management and the National Institute for Coastal and Marine Management to provide groundwater data that would help these groups determine how to safeguard the affected habitats.

In this article von Asmuth describes how he, Maas, and their team built Menyanthes, a MATLAB based monitoring tool that enables hydrologists and ecologists to use time series models to collect and interpret groundwater data.

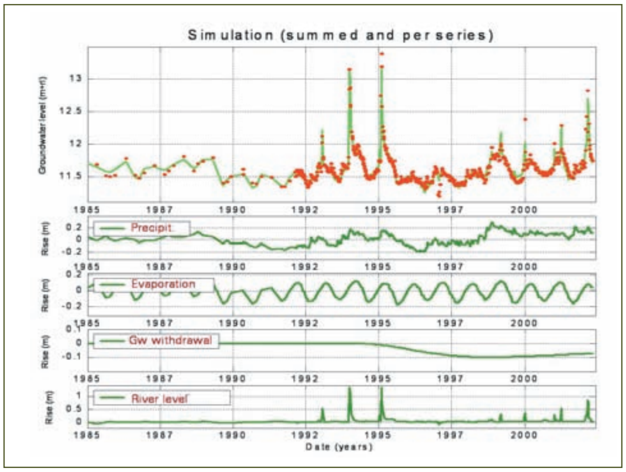

Figure 1. A time series model fitted on data with gaps in the observations. The four lower graphs show the effect of the different explanatory series on fluctuations in groundwater levels.

We used MATLAB® to process and analyze our groundwater level observations—from acquiring the measurements to visualizing the modeling results. With the high-level functions and application development and deployment tools in MATLAB we combined all the functionality that we needed into one application.

Dealing with Real-World Data

We acquired our groundwater data from zipped bundles of ASCII files generated by the large national geohydrological database called DINO (Data and Information of the Subsoil in the Netherlands). The MATLAB `unzip` function came in very handy for this. We also used data from manual measurements in observation wells in the field, as well as meteorological data from the Dutch Royal Meteorological Institute.

Working with large amounts of manually collected field data, with its errors, gaps, and observations of irregular frequency, was one of our biggest challenges. To handle this problem we devised a method of time series modeling that operates in continuous time. With the continuous-time approach, observation frequency was no longer present in the model equations. This meant that the model could handle and filter all the available data, regardless of its frequency (Figure 1).

Developing Time Series Models

Time series models are easy to construct and have a high degree of accuracy. Our time series models represent the course of the groundwater table at a single point in three-dimensional space. They use groundwater level observations and incorporate factors that influence the groundwater level, such as precipitation, evapotranspiration, and hydrological interventions.

Our data comprised 76 groundwater level series obtained from observation wells, as well as precipitation measurements and estimates of the potential evaporation (the evaporation of a grassland optimally provided with water, which can be obtained from meteorological stations).

We used this data to create time series models of all groundwater level series. These models enabled us to:

- Quantify the influence of factors or measures on the groundwater level
- Detect and quantify trends in the groundwater level
- Filter, lengthen, or fill up short or messy series of groundwater level observations
- Pre-process groundwater level data
- Forecast groundwater dynamics resulting from stresses such as recharge, pumping, or stream levels

Visualizing the Results

We interpolated the modeling results to create maps of the groundwater level dynamics in the area (Figure 2).

MATLAB visualization techniques helped us quickly process all the time series while maintaining an overview of the data and the modeling results. For example, we used the `pcolor` function, surface plots, and patches to visualize the

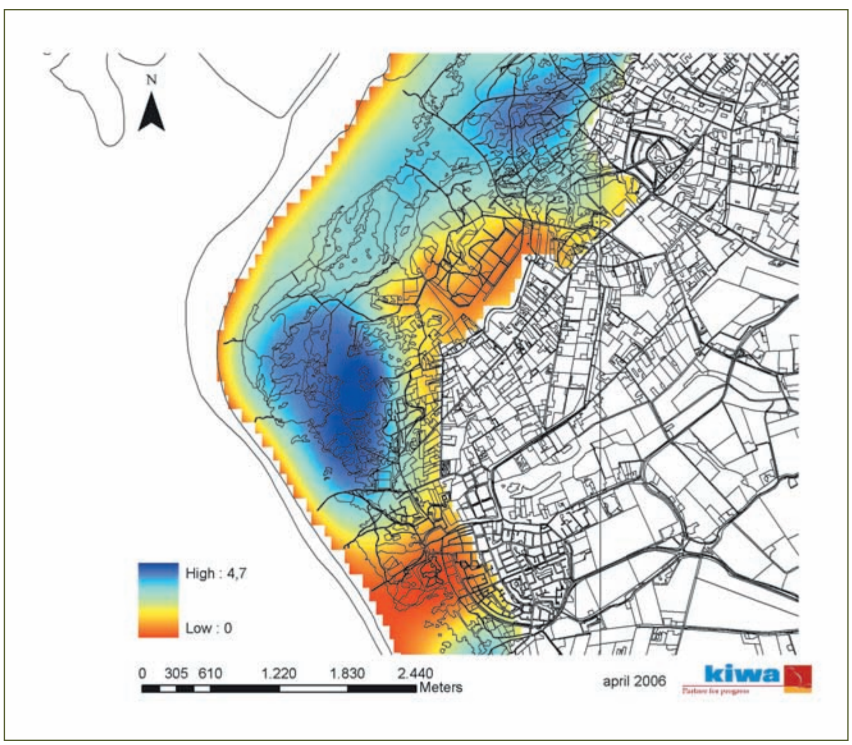

Figure 2. Groundwater level dynamics in the Rotterdam area.

cross-sections, a map with GIS functionality to keep track of the location of the data, and time series and bar plots to visualize the time series data. The MATLAB `linkaxes` function helped us visualize related time series.

It was stimulating to find that such a modest effort yielded insight into the hydrological conditions of the area. For example, our MATLAB visualization revealed the effect of fresh water floating on heavier salt water—an observation that otherwise would have required extensive ground–water modeling (Figure 3).

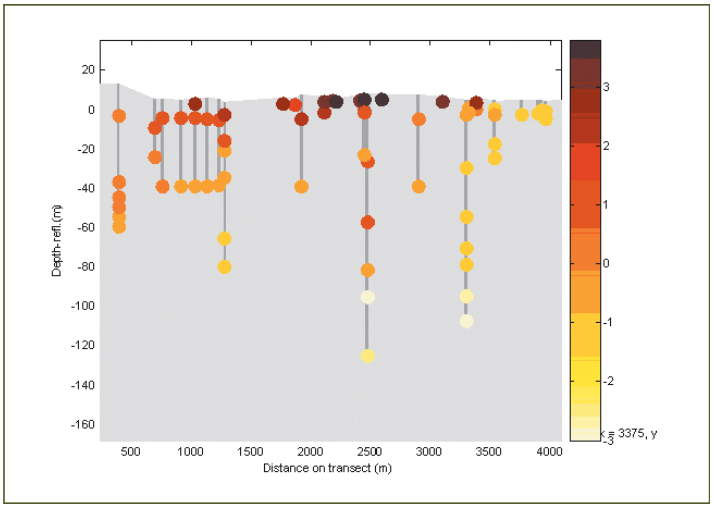

Figure 3. The drainage base estimated by the time series model. The convex evolution of the values in the upper filters reveals that fresh water in the upper soil floats on the salt water in the subsoil.

Developing Menyanthes

We implemented our research methods and data in Menyanthes (Figure 4), a tool that hydrologists and ecologists can use to manage and process groundwater data and to create maps and 2-D or 3-D cross-sections of the results.

Menyanthes supports a variety of tasks, including filtering and lengthening limited time series, estimating geohydrologically relevant parameters, and assessing the influence of a specific factor, such as the withdrawal of groundwater for drinking purposes, tide- or stream-level fluctuations, or hydrological measures.

We wanted Menyanthes to provide an efficient alternative to the widely used transfer-function models of Box and Jenkins. While Box and Jenkins models provide a good solution for systems whose dynamic behavior is erratic, they have several drawbacks. For example, they are complex and require knowledge of the statistical theory behind them. Menyanthes includes information on the behavior of groundwater systems in the model.

With Box and Jenkins models, each time series must be modeled separately using a heuristic model identification procedure. The time series models within Menyanthes are standardized and completely automated. Box and Jenkins models require data that is regularly sampled (if in the time domain). Menyanthes lets researchers screen for and correct errors in the data and perform data manipulation, such as resampling or interpolation operations.

Extending Our Results

We are currently integrating our MATLAB time series models with deterministic groundwater flow models that we developed using an analytic element model built in Python.

In a time series analysis, the relationship between an input series, such as recharge, and an output series at an observation well, such as groundwater levels, is determined using a stochastic method with no physical foundation. Hence, a time series model can be used to forecast the effect of changes in the input series at the observation well but not at other points, and it cannot predict the effects of new stresses or physical changes in the aquifer.

Integrating time series models with deterministic groundwater models will enable us to extend the results over the entire aquifer. We will also be able to forecast the effect of changes in the hydrological system.

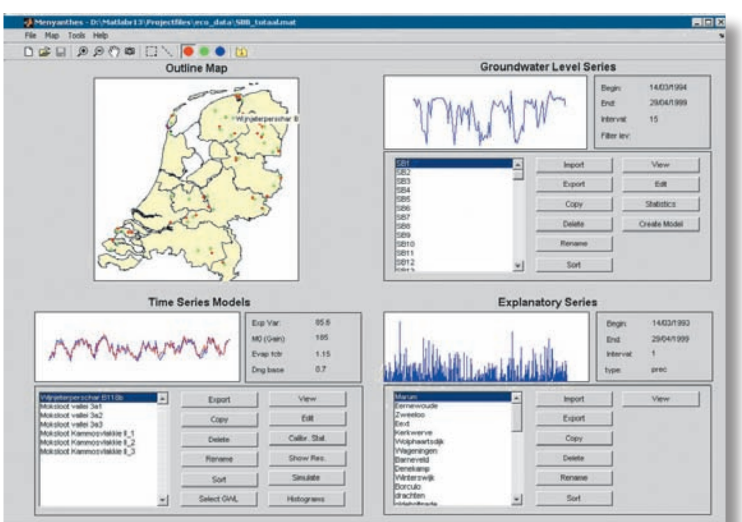

Figure 4. The main window of Menyanthes contains a map showing the locations of the observation wells, a quadrant containing the groundwater level series and explanatory series data, and a quadrant where the time series modeling results are stored.

Kiwa Water Research *is the leading Dutch research institute for drinking water and related ecological and environmental resources. Kiwa Water Research collaborates closely with universities and consultancy organizations to serve water companies, government, and business sectors worldwide.*

RESOURCES

- **Kiwa Water Research**
  www.kiwa.nl
- **Menyanthes**
  www.mathworks.com/res/menyanthes

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