Operational Water Management, Refsgaard & Karalis (eds) © 1997 Balkema, Rotterdam, ISBN 90 5410 897 5

Safeguarding the Kristianstad Plain groundwater resource by using the MIKE SHE model

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ABSTRACT: This paper presents the application of a 3D distributed and physically based model, MIKE SHE, for safeguarding the Kristianstad Plain groundwater resource. With the Kristianstad Plain probably being the largest groundwater resource in northern Europe a plan has been needed for future protection. The protection of such a unique and invaluable resource implies an increased understanding of the geohydrological processes, particularly the long term effects of the human activities today and tomorrow. The major questions were: What are the limitations for future abstractions? How will long term threats, like leakage from agricultural land, impact from urban areas and waste deposit sites, affect the excellent groundwater quality of today? MIKE SHE has shown to be a very capable tool to enlighten these kinds of questions.

1 INTRODUCTION

The Kristianstad Plain is probably the largest groundwater resource in northern Europe. Its groundwater basin is formed in a depression of the crystalline basement filled up with Cretaceous sedimentary rock, covering an area of approximately 900 sq km. The Cretaceous sedimentary deposits are often more than 150 m thick in the central areas of the Plain and at some places more than 300 m thick. The lower strata is mostly made up of poorly consolidated glauconitic sandstone, which is covered by sandy limestone. The Quaternary deposits are usually 10-20 m thick but depths of more than 60 m have been observed.

The glauconitic sandstone is the major aquifer but also wells placed in limestone and in glaucofluvial deposits give considerable amounts of water. With the Kristianstad Plain being the breadbasket of Sweden the groundwater is mainly used for irrigation, municipal water supply and industries (one is actually the world famous Absolut distillery). The total extraction is approximately 20.5 million m3/year (irrigation 8 million, municipalities 8.5 million, industries 4 million). The yearly groundwater recharge is estimated to 85 million m3/year as an average.

Different extensive studies, concerning the groundwater basin of the Kristianstad Plain, have been carried out by the Swedish Geological Survey, a number of consulting engineering companies, universities, the regional state environmental authority and municipalities during the last six decades. This, of course, makes this area very well documented and there is good knowledge in the geological, hydrological, hydraulic and water quality conditions of the Plain.

The discharged groundwater from the Kristianstad Plain has excellent quality, but there are some severe long term threats, due to leakage from agricultural land, impact from urban areas including waste disposal sites, combined with locally quite large discharges. To be able to protect this unique and invaluable groundwater resource, there is still a need to increase the understanding of the geohydrological processes, particularly the long term effects of land use activities of today and tomorrow. This paper will focus on a study, still in progress, where the MIKE SHE model was applied to achieve this. The study was started in August 1995 and is planned to be completed in the fall of 1997.

The primary issue which is to be solved within the project concerns safeguarding the municipal supply of drinking water for the town of Kristianstad. The Kristianstad water supply station provides about 30.000 inhabitants, a number of large food industries and the regional hospital with drinking water. The drilled wells are 70-100 m deep. They are situated very close to the centre of the town and also very close to the municipal waste disposal site, still in use. The risk for groundwater contamination due to this situation is obvious. A new well field needs to be established somewhere else on the Kristianstad Plain, where there are no contradicting interests and no or very small risk that a similar situation as today will occur. The MIKE SHE model was chosen to be the decision tool for this work and forms a base of the entire project.

2 BRIEF MIKE SHE DESCRIPTION

MIKE SHE is a deterministic, distributed and physically based modelling system for simulation of geohydrological processes in the entire land phase of the hydrological cycle in a given catchment. The following components are encountered in the system: interception-evapotranspiration, overland-channel flow, unsaturated flow, groundwater flow, aquifer-river exchange, snow melt.

The catchment is discretized in the horizontal plane by a grid square network which is used both in the overland flow component and the groundwater flow component. These are linked by a vertical column of nodes at each grid representing the unsaturated zone. Water movements in the catchment are modelled by a numerical solution (finite difference) of the partial differential equations describing the processes of overland and channel flow, unsaturated and saturated subsurface flow, interception, evapotranspiration and snow melt.

The model is applicable to a wide range of water resources and environmental problems related to surface water and groundwater systems and the dynamic interaction between these. MIKE SHE has shown to be a very capable tool when the effects of human interference, e.g. pollutant loading from waste disposal sites, changes in land use, is to be assessed. A detailed description of the MIKE SHE model is presented in DHI (1993) and DHI (1995).

3 THE KRISTIANSTAD PLAIN MODEL

The entire catchment area is approximately 2 400 sq km limited by the natural watershed. It contains the entire area of the Kristianstad Municipality but also parts of three other municipalities, Hässleholm, Bromölla and Sölvesborg.

3.1 *Input data*

A large amount of information has been collected, put together and digitised into the MIKE SHE model.

The model limit was chosen to coincide with the watershed to simplify the setting of the boundary conditions The model area only cuts the watershed in two discrete points (the rivers Helgeån and Skräbeån). The boundaries in these two points were set to measured time series of the river flows.

The topography was described with contour lines from the national topographical map with 5 meters level interval. The surface characteristics were described by parameters for roughness, distribution codes for landuse and crops. The main rivers through the catchment were described with cross-sections, bank levels, roughness and river bed lining characteristics.

The geological model has been built with a typical precision of 200 meters. In total 8 geological layers were defined, starting from top with Peat, Sand, Clay, Gravel, Till, Limestone, Sandstone, and finally as bottom layer, the Bedrock. See example of cross-section in Figure 1. The upper soil characteristics (i.e. porosity and hydraulic conductivity) were described for each type of soil profile relevant for the unsaturated zone. The hydraulic parameters for the saturated zone were among others estimated from a large number of pumping experiments, later on verified through model runs. The saturated zone was discretized by five vertical simulation layers, more or less corresponding to the major geological layers.

The actual water abstractions from the different aquifers, in total more than 600 municipal, industrial, private and irrigation discharges, were described as time series for the chosen simulation period, 1980 to 1990. In addition, a number of larger embankments were described, being the largest source of discharge from the top layers.

Finally, a number of climatological variables were described by continuous time series, covering 1980 to 1990. The daily precipitation were given as input from fifteen stations, distributed according to the typical annual precipitation. Temperature were taken from two stations representing the typical

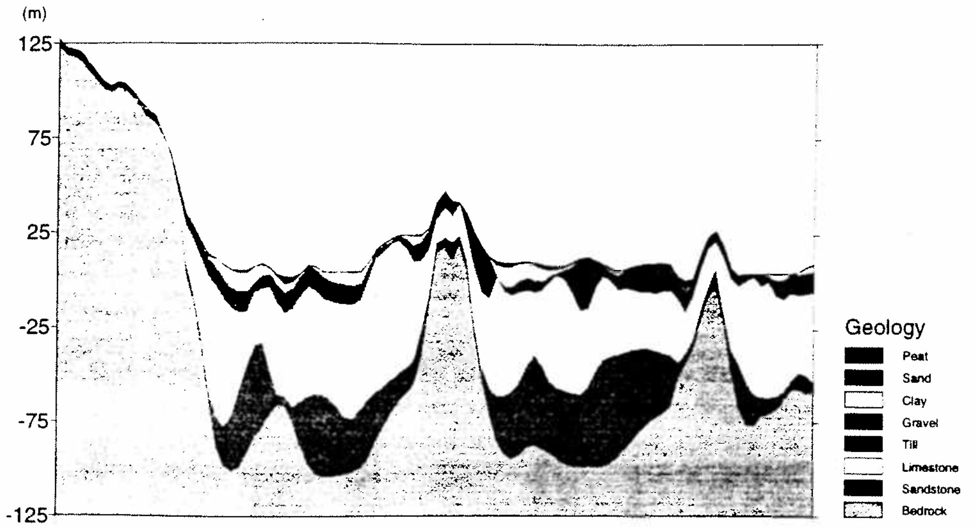

Figure 1. Cross section showing the geological layers through the town of Kristianstad.

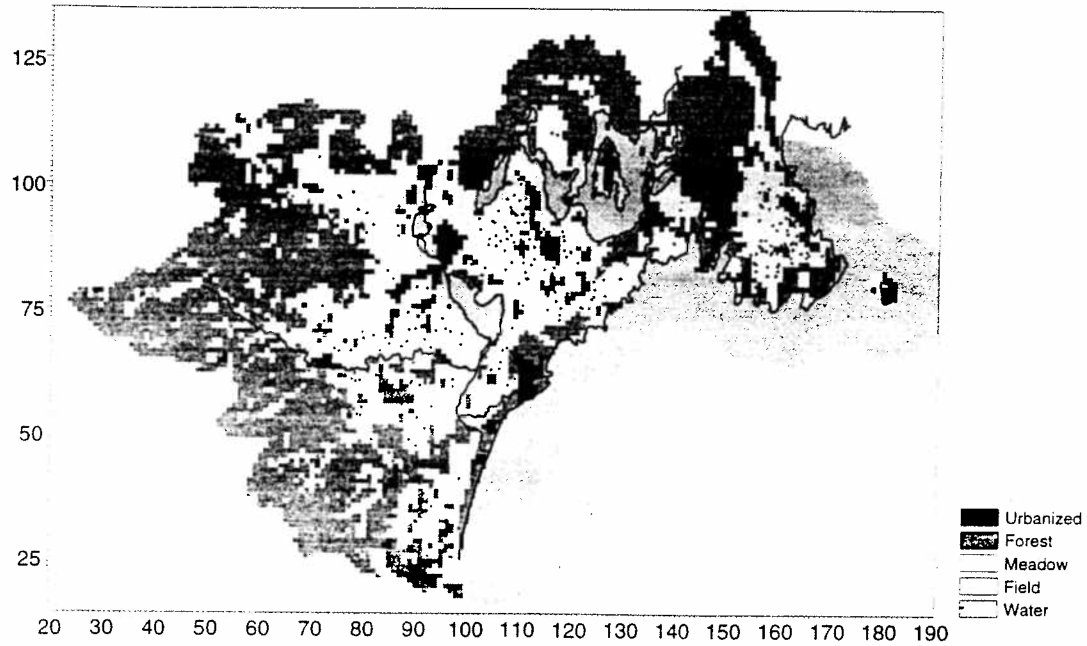

Figure 2. The figure shows the landuse for the entire area modelled. The thin line is representing rivers and coastal lines. The small dots indicate the major abstraction wells.

difference between the lower Plain and the ridges. In addition, the evaporative demand was described by typical monthly values of potential evaporation from four weather stations, and leaf area index and root depth for the different types of vegetation and crops within the area.

3.2 *Verification of the model*

Hydraulic parameter values were initially set to values based on overall experience and a large number of pumping tests carried out during the last decades. Generally, the initial values for the various layers, were given as lumped values for large sub-areas. By comparing the simulated

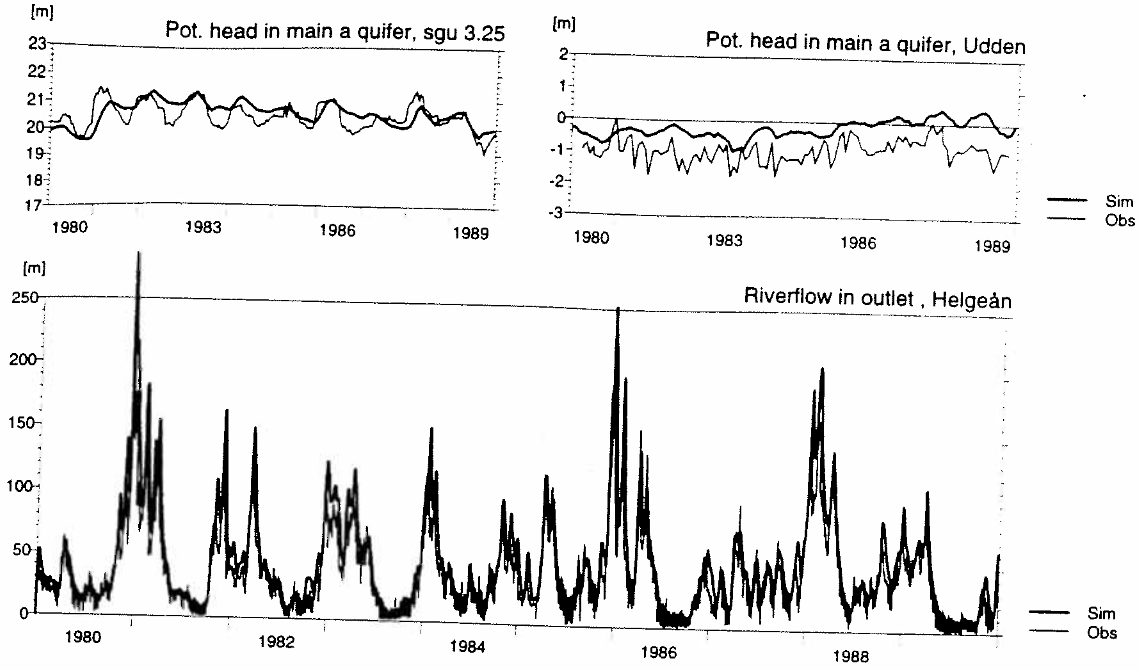

Figure 3. Example of verification results at two important groundwater observation sites in the main aquifer, and the main river outlet from the watershed - Helgeån.

hydraulic head pattern with observed ones, the hydraulic parameters were adjusted until satisfactory comparison was achieved. About 50 different groundwater level observation sites were used to verify the groundwater model.

In addition, a number of river flow stations were used to verify the overall water balance, as well as the exchange flow between the aquifers and the river network. The water balance shows that approximately 14% of the yearly precipitation leaves the catchment area through rivers and more than 70% evaporates. This leaves 16% for infiltration of which only 2% percolates all the way down to the limestone and sandstone.

The model is at this stage verified with a grid size of 1000 by 1000 meters. Some examples are shown in Figure 3. The process of validating the model results with a grid size of 500 by 500 meters is right now in progress. So far, the results look as promising as for the 1000-grid model. The work with a number of sub-models with finer grid size (e.g. 250 and 50 meters) are in progress. These will be verified accordingly.

4 MODEL APPLICATIONS

Many different scenarios can be, have been and are to be simulated, based on both historical events and future expected and exceptional conditions. In especially interesting areas, sub-models will be created using results from the entire model as boundaries.

One sub-model, covering 200 sq km, has already been established for more detailed studies of the area around the town of Kristianstad. The grid size for this model was set to 250 by 250 meters, and the applications of the model range from detailed hydraulic analyses to overall risk analyses from different sources of contamination. A sub-model with a grid size of as little as 50 by 50 meters, dedicated for detailed transport studies of the Kristianstad waste disposal site, is right now being built. For this model a much finer raw data precision is used, especially for topography and geology. The limits of the sub-models already established or in progress, as well as some landmarks and the main aquifer, are illustrated in Figure 4.

The scenarios studied this far, except for present conditions (verification), comprise:

- Natural conditions, meaning no human interference. Among others, the simulation results show that, without any extraction from the aquifer, the potential head would be just below the ground level in the centre of Kristianstad. These results have been verified against information from the beginning of this century (before the extensive discharges started). At present conditions the groundwater depletion is approximately 5 meters.
- Alternative locations of a new well field for the Kristianstad municipal water. Three alternative locations have been briefly analysed. The most interesting alternatives will be studied closer in a more detailed sub-model.

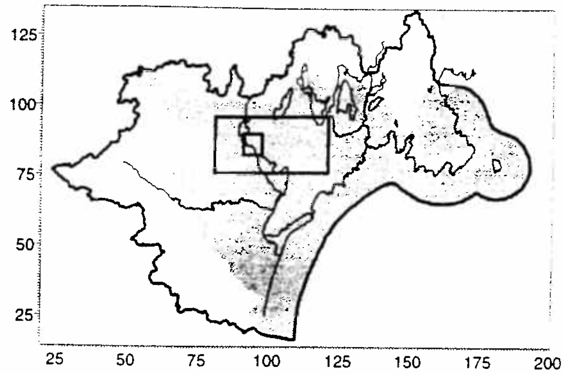

Figure 4. Example of sub-models (rectangles) with finer grid size. The grey area indicates the limits of the main aquifer.

In addition to these "water movement" studies, a number of contamination scenarios are interesting to study. These simulations will be carried out with a pure advection/dispersion approach, which simulates the detailed transport and spreading of dissolved conservative solutes. In the first step these simulations will only be applied on the saturated zone. Additional input data for these simulations include: effective porosity, longitudinal and transversal dispersion parameters, and the concentration of the contaminating source. Studies already started or planned comprise:

- Risk analysis of the municipal waste disposal site contaminating the groundwater wells within the town limits of Kristianstad. An overall analysis with the 250-grid model has already been carried out. The results from this study can however only be used as a very rough indication of the contamination risk. The final risk analyses will be carried out with a much more precise description, i.e. the 50-grid model. Only to illustrate possible results from such simulations, the transport of pollutants from the waste disposal site is shown in Figure 5 and Figure 6.
- Risk analysis of contamination from tank truck accidents.
- Mapping of the age of the water at different locations in the aquifer. This interesting analyses will be managed by a newly developed add-on module to MIKE SHE, Refsgaard et al (1995).

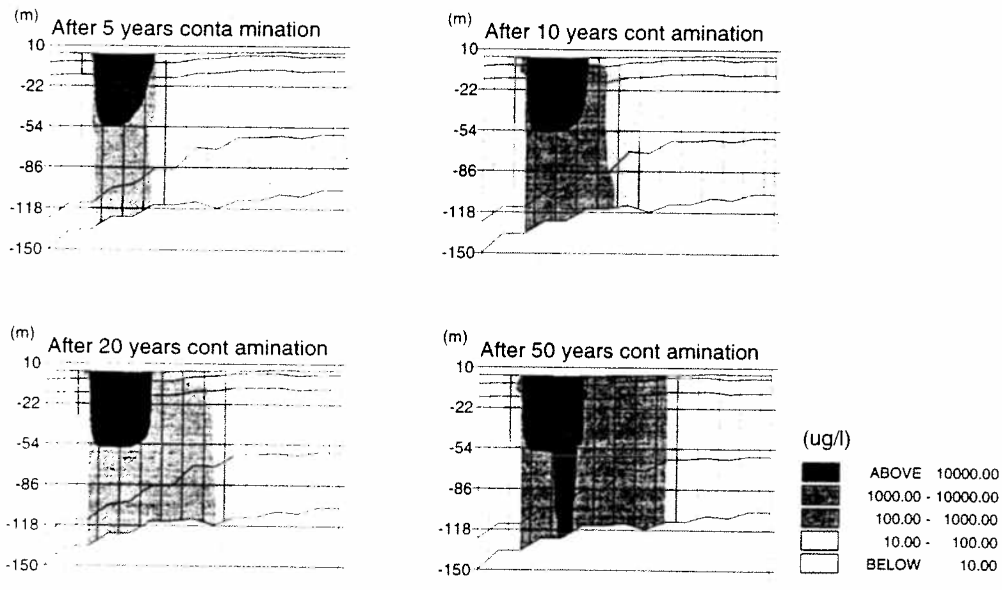

Figure 5. Transport and spreading of the contamination from the waste disposal site shown as a cross-section (south-east to north-west) through the waste disposal site and the centre of the well field.

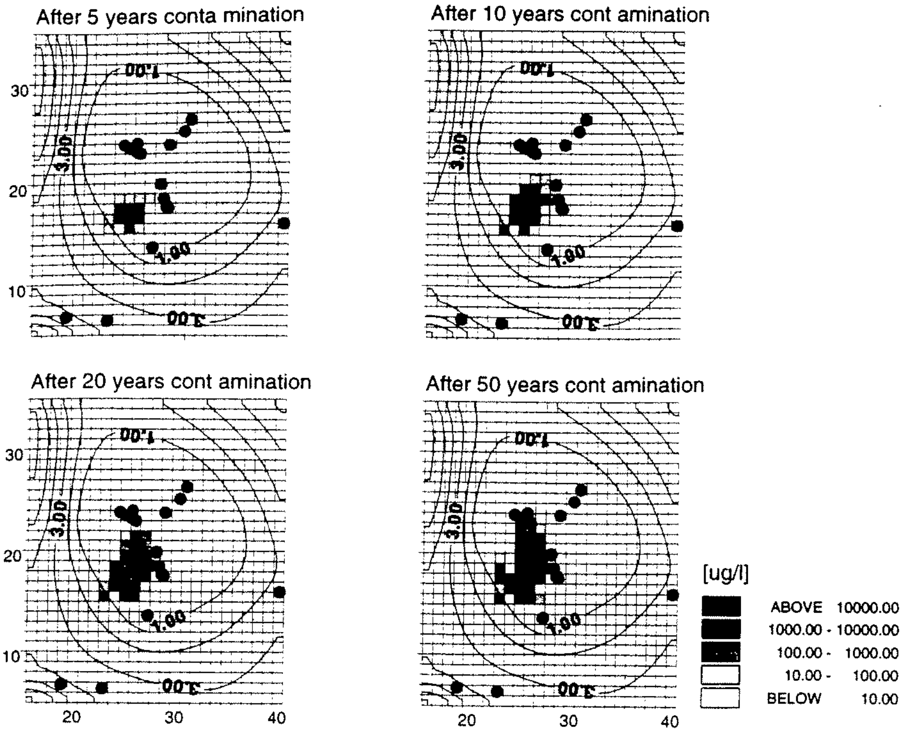

Figure 6. Transport and spreading of the contamination in the main aquifer from the waste disposal site close to the centre of Kristianstad (based on indicative simulations with a 250-grid sub-model).

5 CONCLUSIONS

Integrated mathematical models describing the interaction between surface and subsurface water systems in a physically correct way are valuable tools when analysing the effects of human interference on the hydrological cycle.

The presented work, which only constitute the first step of the planned studies on the Kristianstad Plain, have clearly demonstrated that MIKE SHE successfully can be applied for analysing regional surface water bodies and sub-surface groundwater systems, as well as the interaction between the two.

Through the establishment of the geological model and the calibration of the hydrological model a great knowledge about the geometry of the sub-surface environment was obtained and stored in the database of the modelling system. Due to the flexibility of the database, it is easy to improve the geological interpretation through new borings, etc., and consequently easy to incorporate changes in the hydrological model in the future.

With the verified model, some initial successful studies have been carried out to evaluate alternative well fields, and in general increase the understanding of the sub-aquifers and their interaction.

The three-dimensional modelling of contaminant transport in the groundwater due to waste disposal sites has been illustrated by use of a combined regional and local model approach, where time-varying boundary conditions for a local model with fine discretizations are generated by a regional (flow) model with a more coarse discretization.

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