THE HST3D PROGRAM FOR SOLVING 3-D PROBLEMS RELATED TO ATES

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ABSTRACT

In the Netherlands the presence of fresh groundwater is limited, whereas the number of potential applications is considerable. One of the most rapidly growing applications is Aquifer Thermal Energy Storage (ATES). The interests of ATES can only be balanced properly against other groundwater applications if a sound environmental impact assessment can be made. A powerful tool for this is the 'Heat and Solute Transport in 3 Dimensions' program (HST3D). With the HST3D software, complex hydrothermal and hydrochemical problems in a three-dimensional groundwater flow system can be analysed. After a brief description of the program, an explanation will be given of two cases to which it was applied.

1. INTRODUCTION

With a population density of approx. 400 per km², the Netherlands is one of the world's most densely populated countries. As a consequence, development of the space available must be very conscientious. Though it is often not immediately realized, this has also become applicable to the subsoil space in recent years. The subsoil groundwater-filled sandy layers (aquifers) are exploited for several uses, such as: the extraction of drinking water by waterworks; the extraction of process and cooling water by industries; the extraction of groundwater within soil and groundwater remediation projects; the extraction of groundwater to drain construction pits; the maintenance or restoration of seepage flows on behalf of nature and agriculture.

The Netherlands Groundwater Act provides the framework for weighing up interests between the various applications. According to this Act, provincial authorities are in charge of policy-making and resource management. Resource management comprises the granting of licences and the allowance of certain operations. For authorities to weigh up interests correctly, it is necessary to have an environmental impact assessment made. Because of the complexity of geohydrology in the Netherlands with its multi-layer aquifer system and its high degree of interaction with surface water,

advanced geohydrological models are necessary for environmental impact assessments dealing with these aspects. .
Since 1985 a new way of using aquifers has been the Aquifer Thermal Energy Storage (ATES) . This technology is being used in the Netherlands at about 40 locations, and the principle is that residual heat or cold is stored in the soil to be utilized in a next season. Software used to calculate the effects of energy storage on the groundwater system shall be provided with several modules, including such with which the temperature field and the buoyancy flow due to temperature changes can be calculated. A suitable tool is the 'Heat and Solute Transport in 3 Dimensions' program (HST3D). This program is briefly presented, and two examples are explained in more detail.

2. THE HST3D-PC PROGRAM

The HST3D program was developed in the early 1980's by the US Geological Survey as an extension and improvement of the SWIP software (Survey Waste Injection Program) (Kipp, 1986). In the early 1990's Verbeek Consultant removed several bugs from the program, provided it with new input and output processors and adapted it to be run on personal computers (Verbeek, 1995).
HST3D simulates three dimensional groundwater flow and associated heat and solute transport. The three governing equations are coupled through the interstitial pore velocity, the dependence of the fluid viscosity on temperature and solute-mass fraction. The solute-transport equation is for only a single solute species with possible linear-equilibrium sorption and first-order decay. Finite-difference techniques are used to discretise the governing equations using a point-distributed grid. The basis source-sink term represents wells. A complex well-flow model may be used to simulate specified flow rate and pressure conditions at the land surface or within the aquifer, with or without pressure and flow-rate constraints. Boundary-condition types offered include specified value, specified flux, leakage, heat conduction, an approximate free surface, and two types of aquifer-influence functions. All boundary conditions can be functions of time.

3. CASE I: OFFICE, AMSTERDAM

3.1 Definition of the problem

Since 1988 an office in the center of Amsterdam has been using compression chillers, with the condenser cooling being effectuated by means of groundwater (see figure 1). Two wells are used to extract groundwater at a temperature of 12°C from the upper part of the second aquifer. After it has passed the cooling circuit and been raised in temperature by 4.5°C, the groundwater is re-injected into the soil through three injection wells placed in the lower part of the second aquifer. As, however, the extraction temperature had risen to 16°C, in 1993 it became necessary to close the existing extraction wells and put down a new one at a distance of approx. 150 m upstream from the previous ones. In 1995 the temperature in the new well appeared to have risen by another 1°C. Before renewed modifications were made, it was decided to apply the HST3D program to submit the system to a hydrothermal analysis. The analysis is to explain how this temperature rise could happen and to predict how the extraction temperature will develop in the future.

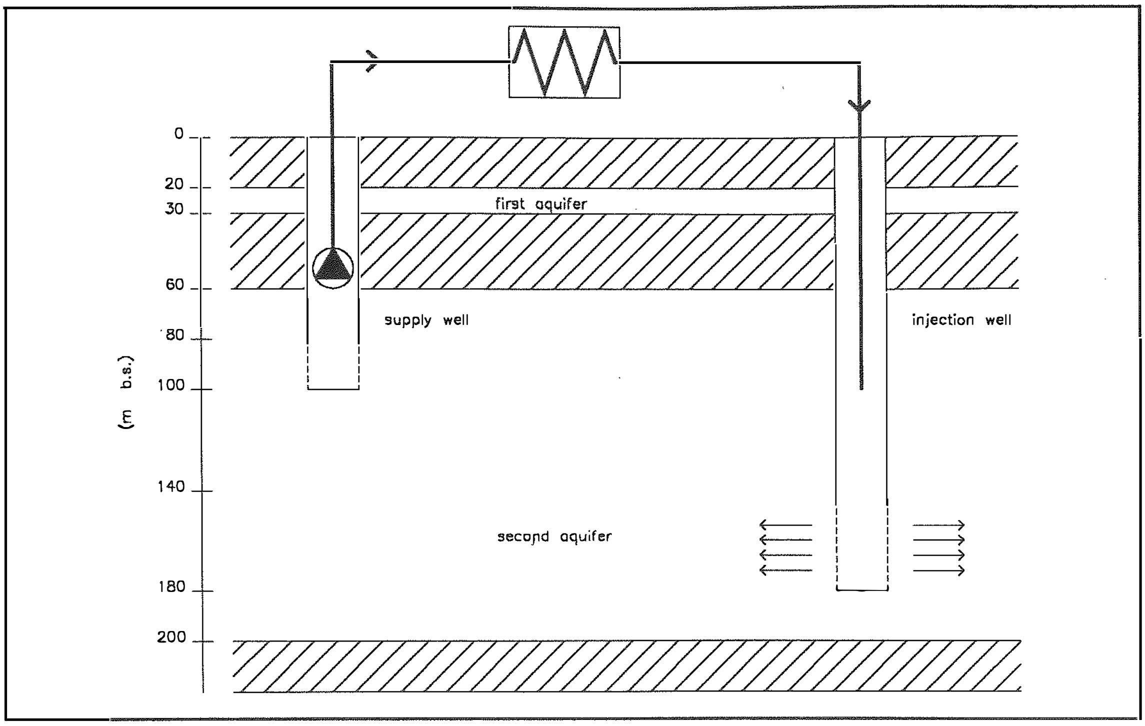

Fig. 1: Principle flow sheet groundwater cooling system Amsterdam

3.2 Simulation

The simulation was started while developing an HST3D model calibrated to the extraction temperature values measured in the period from 1988 to 1993. Figure 2 indicates that the model allows for the extraction temperature to be calculated to an accuracy of 0.5°C. In the calibration process it has become clear that the vertical permeability of the aquifer is equal to its horizontal permeability. As this is not in line with current geohydrological principles, part of the re-injected water is suspected to have flown upward through the gravel pack of the wells.
Subsequently, the calibrated model was used to make calculations for an additional period of 10 years. It has appeared that the extraction temperature is to rise to 14°C in the period from 1995 to 2003.

3.3 Conclusion

The calculations reveal that an underestimation of the effect of buoyancy flow on the distribution of re-injected warm groundwater resulted in a condition that thermal breakthrough could occur faster than expected. The system would have had a better performance if the injection wells had been placed in the higher part of the aquifer and the extraction wells in the lower part.

The 1993 modification of the system was based on the assumption that there would not be a temperature rise if the extraction well was sufficiently far away upstream from the injection wells. When this modification was made, however, one was unaware of the extent and location of the warm water zone that had built up in the five previous years. On the basis of the calculated temperature rise the user is of the opinion that no modification is necessary in the near future.

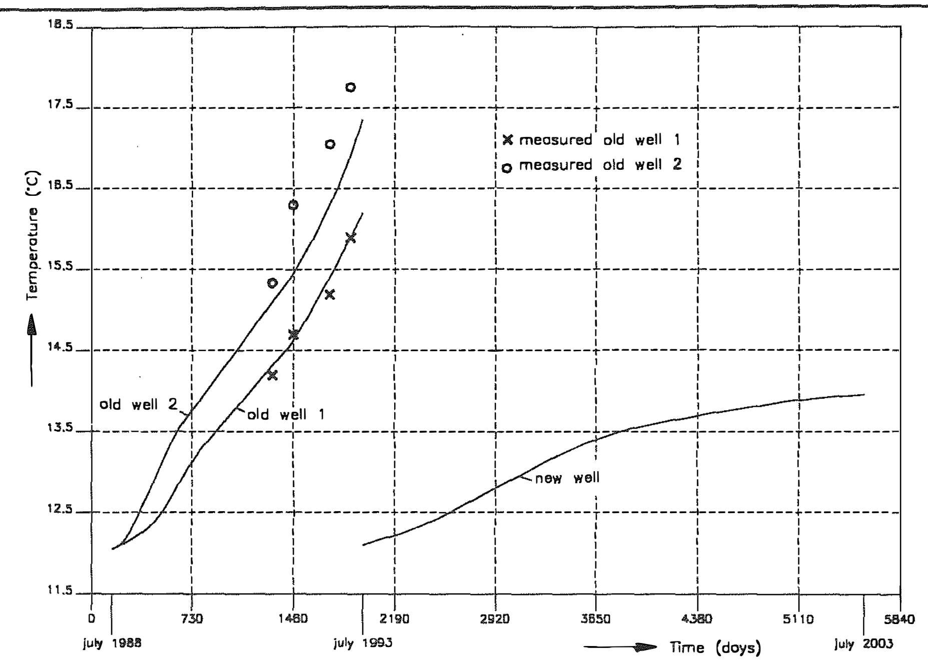

Fig. 2: Calculated and measured extraction temperatures.

4 CASE II: OFFICE, THE HAGUE

4.1 Definition of the problem

To renovate the present cooling system (1997) of an office in The Hague, use will be made of a cold storage system with four wells. The best prospects for cold storage are offered by the second aquifer. This aquifer is at a depth between 30 and 80 m below the soil surface. At a depth of 65 m there is a distinct interface between fresh (300 mg/l) and salt (5000 mg/l) groundwater. The licensing authority does not allow the aquifer to become salinated. To prevent salination, there are two well configuration options. The first option is based on placing the filters (20 m long) in the upper part of the aquifer (figure 3), whereas the second one is based on placing the filters in the lower aquifer part (figure 4). An analysis using HST3D shall indicate which well onfiguration will result in the lowest possible degree of salination.

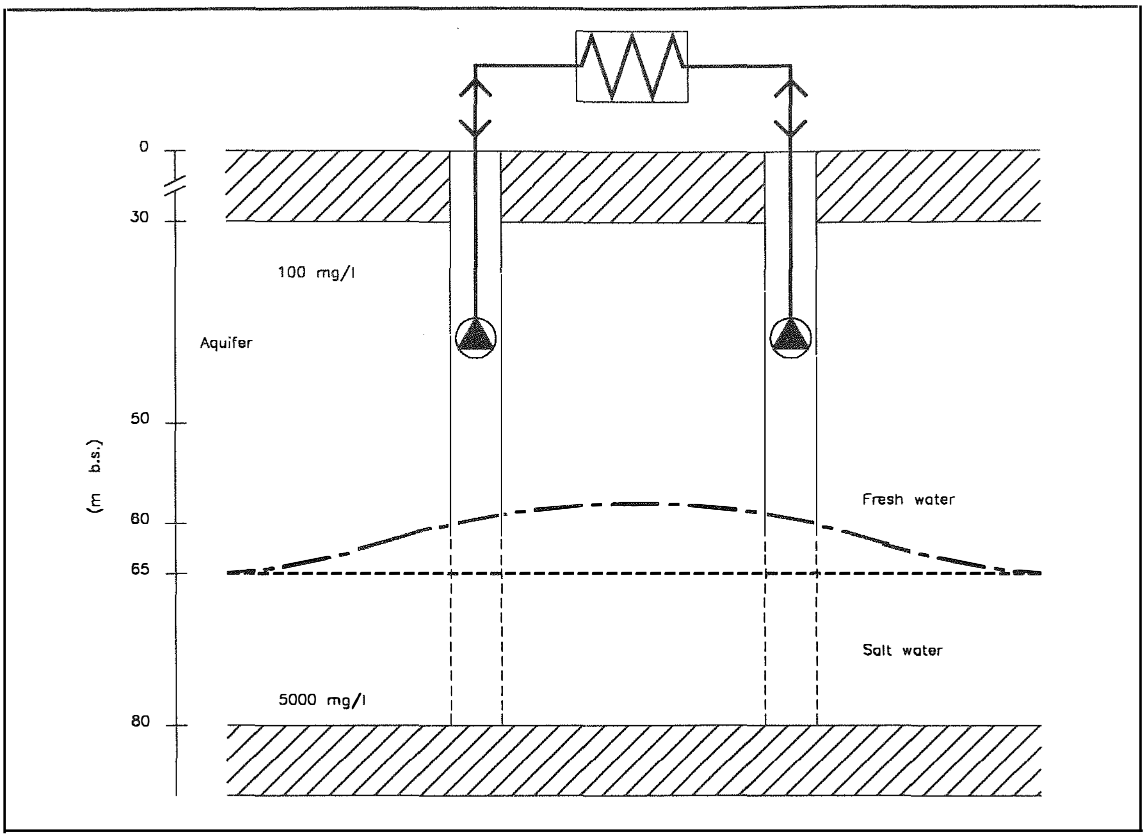

Fig. 3: Option 1: screens in upper part aquifer. Reference situation and situation after ten years cold storage.

4.2 Simulation

The HST3D model developed for this problem has been made on the basis of a groundwater flow model (Micro-Fem). The distribution of the chloride content has been entered in the model as an initial condition. The model has been applied to both configurations to make calculations for a period of 10 years.
With the first configuration, the upconing of the salt front appears to be such small that this does not affect the chloride content of the extracted groundwater. This is mainly caused by the fact that the salt groundwater is heavier and tends not to flow upwards. Consequently, there is only a slight salination of the aquifer (figure 3). This is different from the results for the second option (figure 4). The presence of the filter near the fresh/salt water interface will cause a considerable mixing of fresh and salt groundwater.

4.3 Conclusion

According to the calculations, it is the best solution to place the filter in the higher part of the aquifer. The calculations have given the licensing authority adequate insight into the behaviour of the fresh/salt water interface in reaction to cold storage. They will issue a positive licensing recommendation.

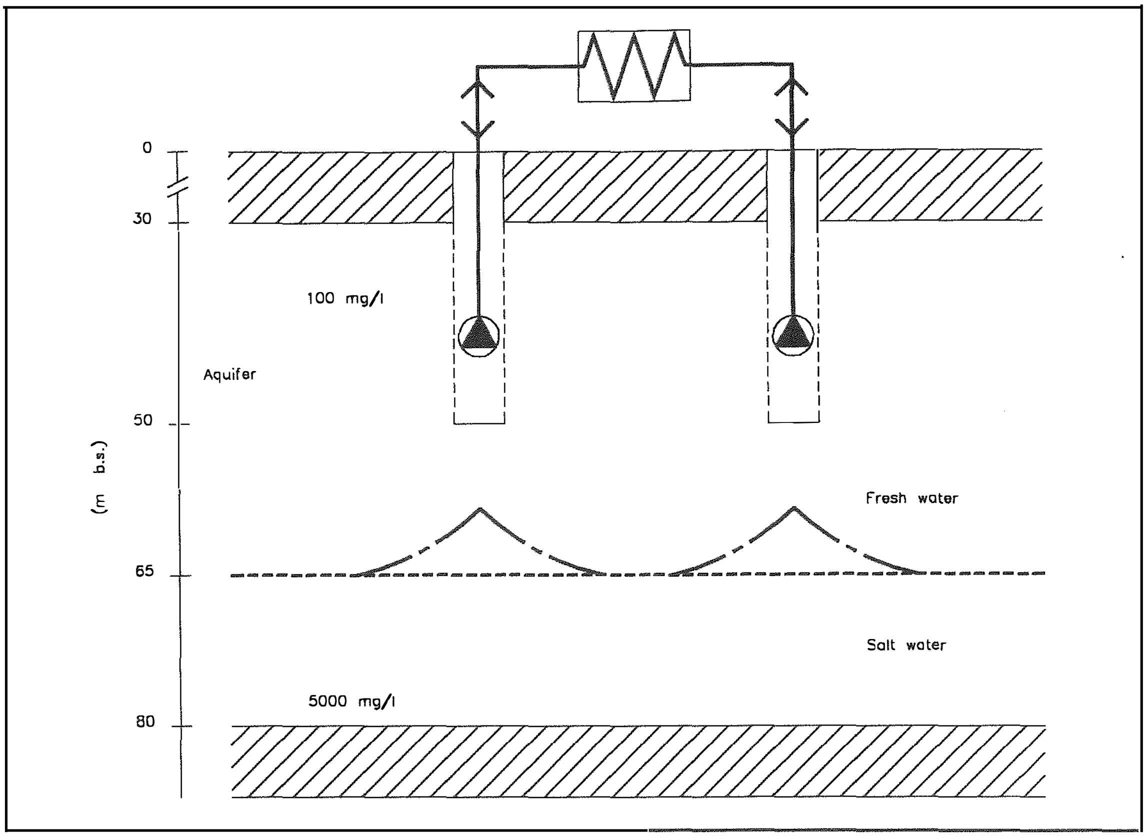

Fig. 4: Option 2: screens in lower part aquifer. Reference situation and situation after ten years cold storage.

5 CONCLUSION

HST3D is a powerful tool for analysing three-dimensional groundwater situations, e.g. where problems with buoyancy flow are involved. Such analyses will allow for making better designs for energy storage and/or groundwater cooling systems. Furthermore, these analyses give better insight into the effects of an ATES system on the groundwater system. This makes it possible for the licensing authority to balance the positive effects of ATES on the emission reduction of CO_2, SO_2 and NO_x against any potential adverse effects on the groundwater system.

6 LITERATURE

Kipp, K.L., 1986. HST3D, A computer code for simulation of heat and solute transport in three-dimensional groundwater flow system. US Geological Survey, Water-Resources Investigations Report 86-4095.

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