

HEAT LOSSES AND GROUNDWATER CHEMISTRY
OF THE UTRECHT UNIVERSITY ATES

A. Willemsen¹ and M.J.J. v.d. Weiden²

¹ IF Technology, Frombergstraat 1, 6814 EA Arnhem,
The Netherlands.

² Heidemij Adviesbureau BV, P.O. Box 264, 6800 AG Arnhem,
The Netherlands.

ABSTRACT

Storage of heat in aquifers has beneficial environmental effects (reduction of fossil fuel consumption), but also potentially negative environmental effects. The main potentially negative effects are the local change in temperature and the water quality in the store, and through losses, around the store. At Utrecht University an important local drinking water aquifer (the '2nd aquifer') is located above the storage aquifer (the 3rd aquifer). Between the two aquifers there is 80 m of clay and sand; through conduction this layer is gradually heated by the store (90°C storage temperature).

The lifetime of the store is assumed to be 20 years; calculations show that after 30 to 40 years from the start of the first storage cycle the temperature in the 2nd aquifer can rise by 2°C. The third aquifer contains brackish water and is not used by others. Therefore, it is considered less important that it will become warmer. Calculations show that the temperature in the store will be raised 5°C above its original temperature after 200 years.

Ca-Na exchange was chosen as water treatment against calcite scaling. A split treatment was decided upon. The split minimizes the salt consumption and the risk of clay swelling in the aquifer.

1 INTRODUCTION

The storage of heat in aquifers (ATES) has positive and negative environmental effects. The energy savings that can be reached with ATES have positive environmental effects: reduction of CO₂ and NO_x (and SO₂) emissions. The storage of heat in the aquifers also has potentially negative effects. Apart from the usual effects of withdrawal/injection of groundwater on the groundwater potential (and resulting settlements), ATES also has effects on the temperature of the groundwater and groundwater composition.

The methods to predict the effects of groundwater withdrawal/injection on the groundwater potential have been well established in the past decades and are applied all over the

world. This paper deals with the specific potentially negative environmental effects of the Utrecht University ATES: the increase of the temperature and the possible changes in water composition.

When heated water is injected into an aquifer, reactions occur between water and solid phase. These reactions result in a change in the composition of the water. The most significant reactions are dissolution of silicates and precipitation of carbonates. These reactions are reversed when the water is cooled down outside (or inside) the store. Changes in water composition which are the result of reactions to heating and cooling, are not considered to cause a significant deterioration of the water quality. This is not always the case for changes due to water treatment. Therefore, attention has been focused on the consequences of water treatment.

2 LOCAL SITUATION

The information on the hydrology and the hydrogeochemistry of the site is mainly obtained from a reconnaissance drilling (HA, 1989) and from the placement of production and monitoring wells (HA, 1989).

Information on the hydrogeochemistry was also gathered during the measurement program.

The soil profile at the ATES site is presented in Figure 1. In this figure, the schematic soil profile (fourth column) is accompanied by information concerning the following items: depth, stratigraphy, geological environment, lithography, geohydrological interpretation, permeability and anisotropy, filter placement and water type.

Heat will be stored in the third aquifer from 192 to 290 m below surface. The aquifer consists mainly of marine sands with shells from the Maassluis and Oosterhout Formations. The mean horizontal permeability is 4 m/d. The mean natural temperature is approx. 15°C. The 2nd aquifer is used locally for drinking water production. This aquifer has a high permeability and contains fresh water at a natural temperature of approx. 11.5°C. The 3rd aquifer is not used for other purposes, mainly because the water is brackish and the aquifer has a relatively low permeability, whereas better aquifers (the 1st and 2nd) are available.

The regional flow in the third aquifer is estimated to be 2 m/year. The influence of this flow on the thermal efficiency of the storage is negligible.

Filters have been placed in the production and monitoring wells from which water samples have been taken from. The water from the cold side (K1) will be heated to 90°C. The composition of this water was used for the calculations on water treatment.

The water in the 3rd aquifer is fresh at the top, and brackish below. The mixed water, as produced from K1 has a

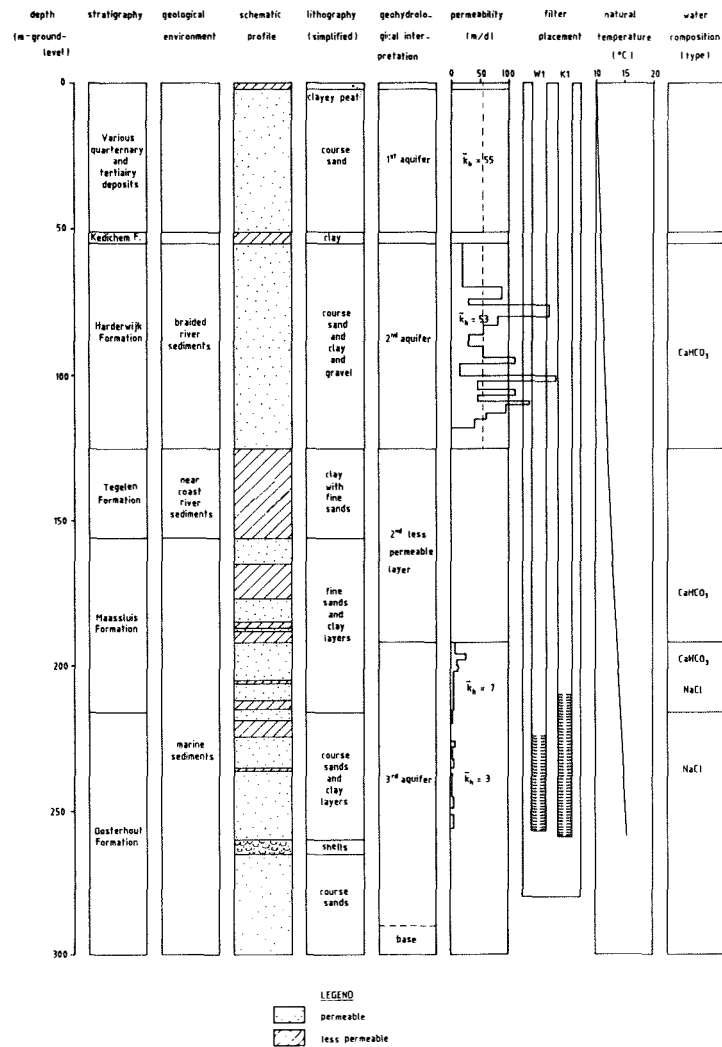


Figure 1. Schematic geohydrological profile

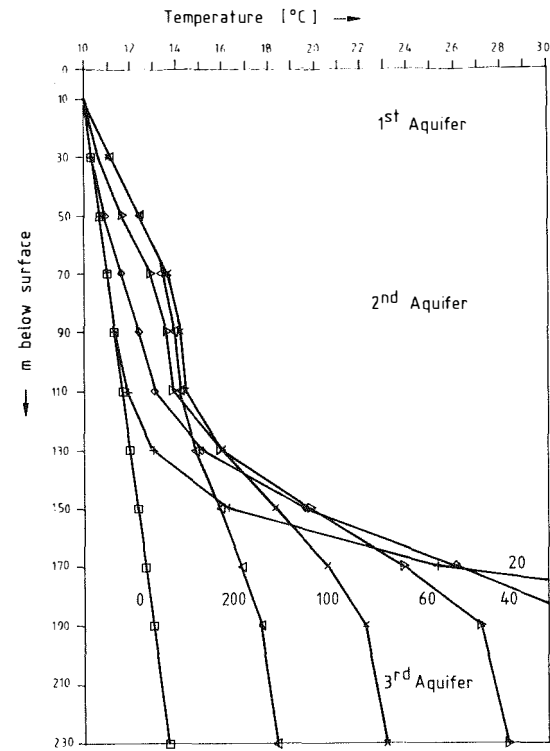


Figure 2. Calculated temperature profiles, 0; 20; 40; 60; 100 and 200 years after the start of the storage.

moderate alkalinity and is of the NaCl-type. The contents of dissolved gases are low. The water is reduced and contains little iron (0.31 mg/l). The calculated total absolute gas pressure at 90°C is approx. 2 bar. The system design is described by Van Loon and Paul (1991).

3 HEAT LOSSES

Calculations have been performed with SWIP (Intercomp, 1976) to assess the long-term temperature effects of the store on the surroundings. Special attention has been directed to the possible heating of the '2nd aquifer'. The heating of the 3rd aquifer is considered to be of minor importance.

It has been assumed that the heat store will function for 20 years. During the last cycle, the store is unloaded until the production temperature has fallen below 45°C. The temperature in and around the store have been calculated for a period of 380 years after this last cycle. The calculated temperature profiles after 0, 20, 40, 60, 100 and 200 years are given in Figure 2. During those years the temperature in the third aquifer drops from 45° (after 20 years) to 18°C (5°C above natural).

However, in the second aquifer the temperature increases during the first 100 years and will only start to drop 100 years after the store has started to function. The calculated temperature just below the 2nd aquifer is shown in more detail in Figure 3, only the change in temperature with respect to the natural temperature is given. The maximum ΔT amounts to 4 K after approximately 80 years. In these calculations with SWIP no regional flow has been assumed. However, over a period of 80 years regional flow will contribute significantly to heat transport in the 2nd aquifer. If it is assumed that the water in the 2nd aquifer, which is heated by the store, is refreshed thermally every 13 years, then the calculated corrected temperatures are as given in Figure 3. These corrected temperatures in the 2nd aquifer show a maximum increase of 1.5 K after 30 years.

A license is required for the heat store from the Province of Utrecht in connection with the 'Groundwater Pollution Act'. The Province of Utrecht has decided to allow a maximum temperature of 14°C in the 2nd aquifer above the store. If a higher temperature is measured the license will be withdrawn. Considering the calculations it is very unlikely that this maximum will ever be reached.

4 WATER TREATMENT

When groundwater is heated, the solubility of Calcite decreases. This can be expressed in a saturation index of the water that is produced and heated.

$$SI_{cc} = \log \left(\frac{(Ca^{++})(CO_3^{--})}{K_{cc}} \right)$$

Where:

- SI_{cc} = Saturation Index for Calcite
 (Ca^{++}) = Activity of the free Ca^{++} -ion
 (CO_3^{--}) = Activity of the free CO_3^{--} -ion
 K_{cc} = Solubility constant for Calcite according to Plummer and Busenberg (1982).

Figure 4 shows the calculated SI_{cc} for the groundwater from well K1 at different temperatures.

The SI increases from 0.47 at 15°C to almost 1.0 at 90°C. Calcite scaling is likely to occur at these SI-values (it is however, uncertain, see Appelo et al, 1990).

A reduction in SI_{cc} can be achieved by conventional water treatment prior to heating. Ca-Na exchange was chosen.

The choice for Ca-Na exchange implied that the risk of clay swelling had to be considered more closely. The marine deposits that form the 3rd aquifer have a significant clay content which might partly consist of swelling clays (smectites). These clays tend to swell if the Na-content increases or the salt content decreases.

In soil science, the SAR (Sodium Adsorption Ratio: $Na/(Ca+Mg)^{1/2}$ in mmol/l) is used to assess the risk of clay swelling (see Appelo, 1988). In petroleum engineering on the other hand, the percentage of Ca and Mg in the total amount of cations (all in mg/l) is used (Jones, 1964).

The SAR should be kept lower than 11 to prevent swelling. According to Jones (1964), water with more than 10% (Ca+Mg) can safely be injected.

Table 3 lists the calculated SAR's and (Ca+Mg) percentages for different 'splits', where the split is the portion of water going through the ion-exchanger.

Table 3. Calculated SAR (Sodium Adsorption Ratio: $Na/(Ca+Mg)^{1/2}$ in mmol/l) and percentage (Ca+Mg) of the total amount of cations present (in mg/l), for different split percentage of Na-exchange treatment.

Split (% of water treated)	SAR	% (Ca+Mg)
0	4.7	27
50	8.5	15
60	10	13
70	12	10
80	15	6.8

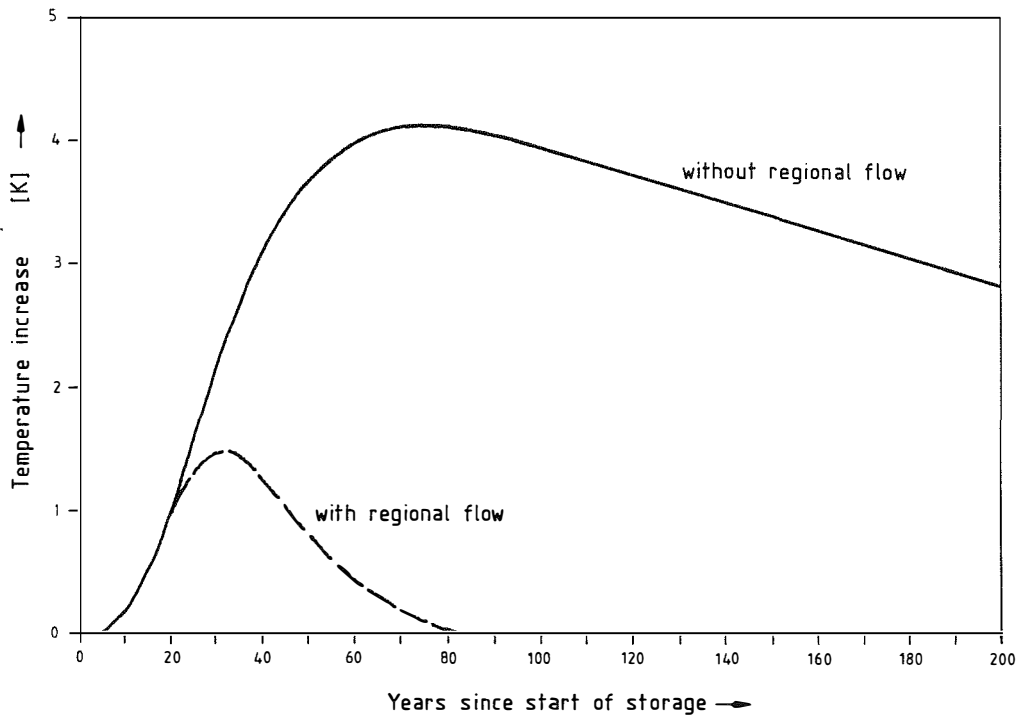


Figure 3. Calculated increase in temperature in the 2nd aquifer.

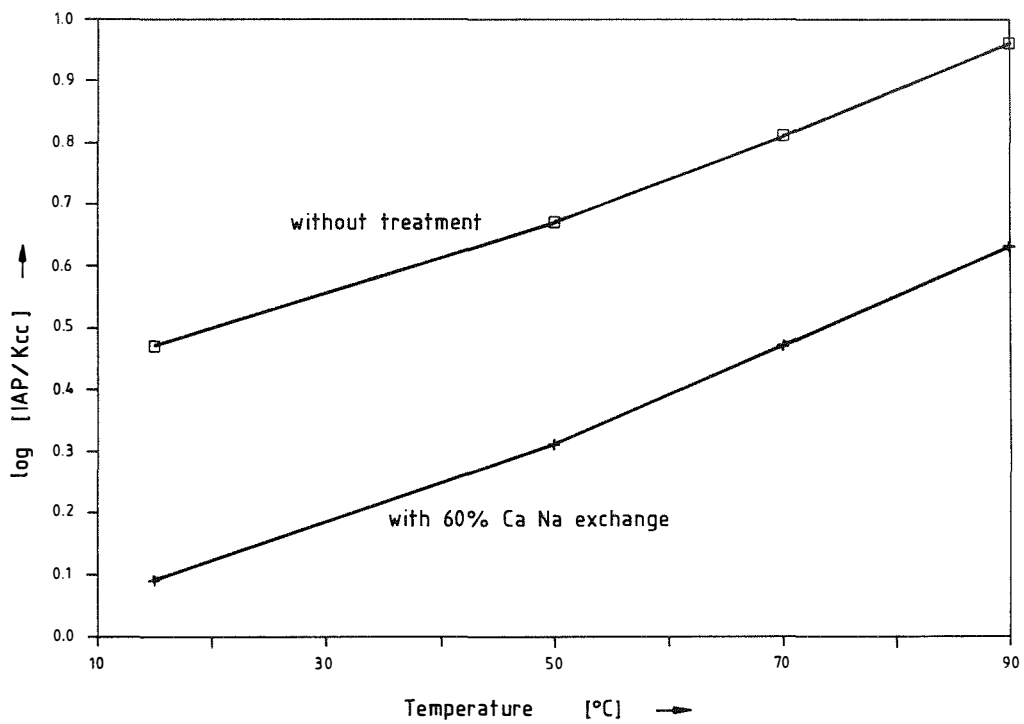


Figure 4. Calculated saturation index with respect to calcite (cc) as a function of temperature.

From Table 3 it can be seen that a split of 60% is the maximum value that can be used safely without risk of clay swelling.

The question now is whether a split of 60% reduces the SI_{cc} enough to prevent calcite scaling. Figure 4 shows the calculated SI_{cc} , assuming 60% exchange of Ca, Mg and Fe to Na. If it is assumed that the original SI_{cc} of the produced water represents a kind of metastable composition, then calcite scaling will probably not occur until the SI_{cc} rises to more than 0.3 above this value (so from 0.47 to 0.77). As can be seen in Figure 4, this value will not be reached with a split treatment of 60%.

During the 2nd cycle and later, the produced water will contain more Na already. This means that the risk of clay swelling might increase with cycles. However, because the water will also become less hard, the split can be reduced in future cycles, reducing the Na-increase with cycles.

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