EVALUATION OF THE GROUNDWATER CATCHMENT POTENTIAL IN THE VICINITY OF THE "DE CLOEDT" PIT AT KNOKKE, IN THE EASTERN COASTAL PLAIN OF BELGIUM

K. WALRAEVENS✉, K. MARTENS, M. COETSIERS and M. VAN CAMP

Laboratory for Applied Geology and Hydrogeology – Ghent University, Krijgslaan 281, S8, 9000 Gent, Belgium, E-mail: Kristine.Walraevens@UGent.be

Abstract

The municipal public water-supply company of Knokke-Heist is producing drinking-water from the dunes aquifer. However, the available resources are limited and overexploitation of the ecologically valuable dune aquifer system should be avoided. Therefore, the company has developed a new strategy for the future. An important component of this new strategy consists in the treatment of surface water by means of reverse osmosis, and remineralisation of the produced filtrate by means of groundwater taken from a new catchment around the "De Cloedt" pit, a former sand quarry, which is now inundated and recharged by surface water. The "De Cloedt" pit is situated in the polder area, just to the south of the dune border. In the polder area, saline groundwater occurs in depth, which may limit the groundwater exploitation potential. This paper deals with the hydrogeological investigations that have been performed of the area. This includes geophysical measurements, piezometric and surface water discharge measurements, groundwater sampling and analysis and modeling.

Keywords: groundwater catchment, hydrodynamic modeling, salt/fresh water distribution, geophysical characterization.

Introduction

During the last ten years, the vulnerable dune ecosystem has been receiving increasing protection and consideration by the public authorities in Flanders. Ecological values are largely dependent on hydrology, and the management of the dune aquifer system is thus high on the administration's agenda. A political option is to remove groundwater exploitation from the dunes. Whether such drastic measures will really be implemented, remains uncertain, but definitely water supply companies pumping groundwater from the dunes are urged to consider alternatives, at least for part of their needs.

✉ Corresponding author

The municipal water-supply company of Knokke-Heist has developed a new strategy for the future. They propose to use surface water from the Leopold Canal, which they will treat by means of reverse osmosis. The produced filtrate will be remineralized by means of groundwater taken from a new catchment near the "De Cloedt" pit. This is a former sand quarry, which is now filled by surface water from the polder area. A polder ditch is crossing the pit. The "De Cloedt" pit is situated in the polder area, close to the dune border. In the polder area, saline groundwater occurs in depth, which may limit the groundwater exploitation potential. In return for the new groundwater catchment in the polder area, less groundwater will be pumped from the catchment in the dunes.

Hydrogeological structure near the "De Cloedt" pit

The shallow groundwater reservoir is bounded to the bottom by the heavy clay of the Maldegem Formation (Bartonian, Tertiary) (Figure 1). It is found at a depth of around 27 m (ca –24 m TAW). The bottom of the aquifer consists of medium sand, frequently with shell fragments. This sediment can be attributed to the Moerkerke Deposit. Its hydraulic conductivity was determined at 13 m/d from a pumping test near the "De Cloedt" pit (Vermoortel et al., 1998). At about 18 m depth (ca –15 m TAW) it is followed by the Deposits of Damme and Eeklo, consisting of silty fine sand. The hydraulic conductivity of this layer was determined at 3.7 m/d. At the surface, the polder clay is found (Dunkirk Deposit), with a thickness of around 2 m.

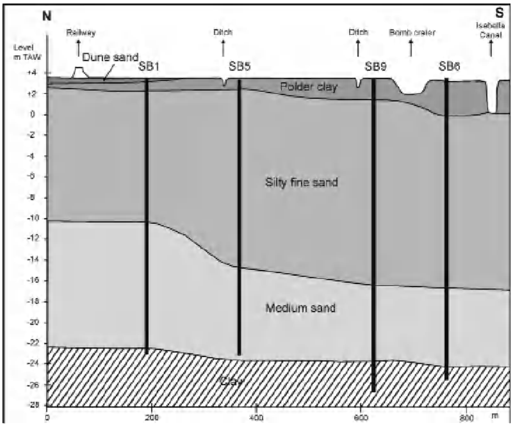


Figure 1. Hydrogeological structure.

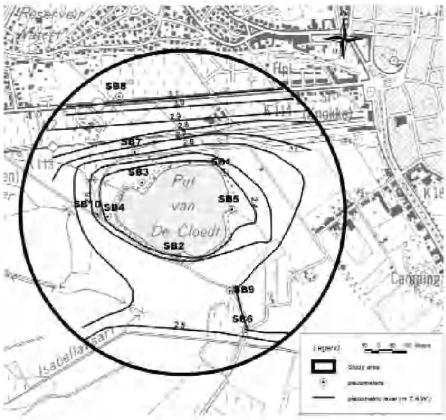


Figure 2. Observed fresh-water heads in the lower part of the aquifer (19/1/2003).

Hydrodynamical characterization

Measurements in piezometers around the "De Cloedt" pit have enabled to map the fresh-water heads in the groundwater reservoir. The lines of equal fresh-water head during the recharge period (for 19 January 2003) have been shown in Figure 2 for the lower part of the reservoir. The draining function of the pit is obvious. In the pit itself, the water level is at less than +2 m TAW. Groundwater flows towards the pit from all directions. The gradient is the highest to the north, at the dune border. To the south, there is a groundwater divide resulting from the presence of the pit: north of this divide, groundwater flows to the north towards the pit; south of the divide, the regional groundwater flow to the south, towards the Isabella Canal, is reestablished.

Within the aquifer, there is an upward vertical flow in the polder area. The vertical gradient increases starting from the dune border in the direction of the Isabella Canal. The fresh-water head differences reach more than 30 cm over 20 m depth.

The "De Cloedt" pit receives surface water from a polder ditch entering the pit from the northwest. Water leaves the pit at an outlet in the east. Actually, both waterways formed one polder ditch, which was cut by the digging of the sand quarry. The outlet leads the water to the Isabella Canal. At this outlet, discharge measurements were made, with the purpose of quantifying the water amounts that could be utilized for (semi-)natural infiltration by sealing the outlet, in the new situation of groundwater catchment by wells around the pit. The option of more active artificial recharge was abandoned because of the bad quality of the available water of the Leopold Canal, which would require treatment before infiltration. The discharge measurements at the outlet of the pit have been performed by means of a long-throated measuring flume (Bos, 1985). The results for the period July to December 2002 are represented in Figure 3. Peak discharges exceed 4000 m^3/day. However, during dry periods in summer, discharge may disappear completely.

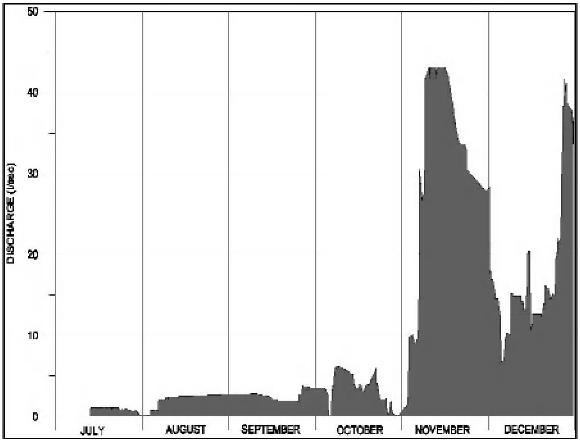


Figure 3. Discharge at the outlet of the "De Cloedt" pit during July-December 2002.

Simulation of groundwater flow

Groundwater flow was simulated by means of the MODFLOW code (McDonald and Harbaugh, 1988). The north boundary is the low water line at the shore (fixed head). To the south, the Isabella Canal was used as a fixed head boundary. The west boundary is a flow line perpendicular to the shore (no flow boundary). The boundary to the east is a water divide (no flow), which is further extended to the Isabella Canal. The cell size is 50 m x 50 m. Subdivision in layers for the polder area was done as discussed above. In the dunes, the dune sand is replacing the polder clay. As such, three aquifer layers have been distinguished: 1) the upper dune sands, 2) the silty fine sands and 3) the medium sand at the bottom. The "De Cloedt" pit was accounted for by locally introducing very high hydraulic conductivities into layers 1 and 2, resulting in equal calculated heads in all cells. The pit could not represent the input with fixed head, as the influence of groundwater catchment on the pit's water level must be calculated. The outlet was simulated by taking out 400 m^3/d on the average (disregarding the highest peak discharges).

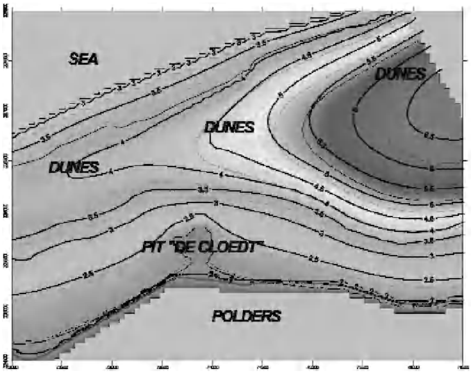


Figure 4. Hydraulic heads without pumping.

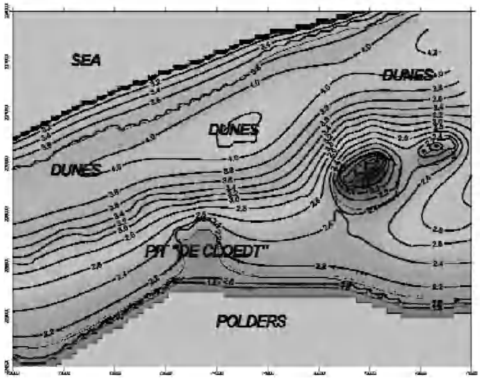


Figure 5. Hydraulic heads in the present situation: pumping of 800.000 m^3/year in dunes.

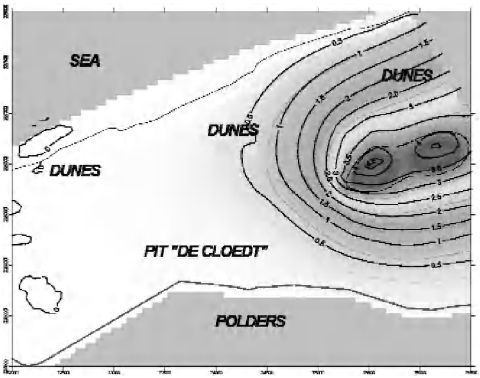


Figure 6. Drawdown in the present situation.

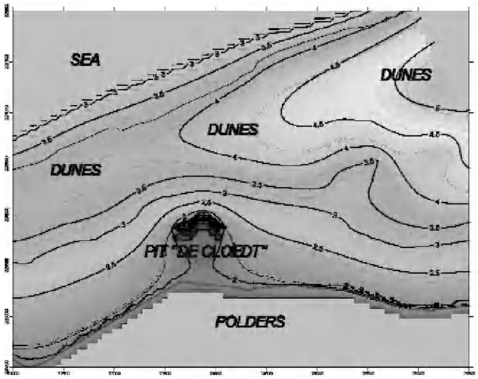


Figure 7. Hydraulic heads in the planned situation: pumping of 400.000 m^3/year in dunes and 320.000 m^3/year near "De Cloedt" pit.

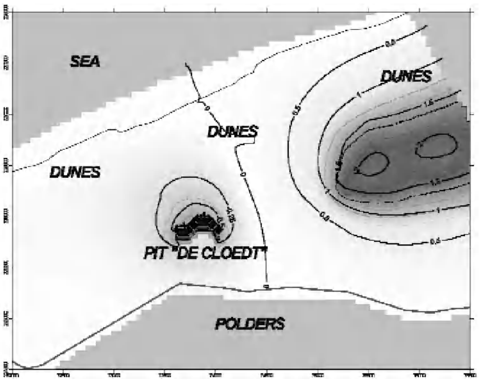


Figure 8. Rise of water table when pumping 400.000 m^3/year in dunes and 320.000 m^3/year near "De Cloedt", compared to present situation.

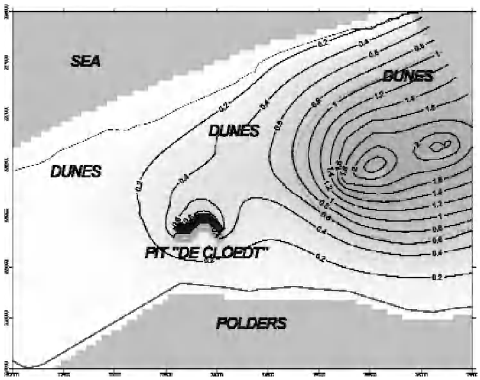


Figure 9. Residual drawdown of water table in planned situation, compared to situation without pumping.

The calculated hydraulic heads in the situation without groundwater exploitation are shown in Figure 4. A groundwater divide is observed in the center of the dunes. North of it, groundwater recharged in the dunes flows out towards the sea; to the south, it flows to the polder area.

Simulation of the present situation

In the present situation, no groundwater catchment exists around the "De Cloedt" pit. In the dunes, 800.000 m^3/year may be pumped according to the license. The hydraulic heads in the present situation are shown in Figure 5. Heads have decreased, and in the east, where the dune catchment is situated, the water divide has moved to the north. The drawdown as a result of groundwater exploitation in the dunes is shown in Figure 6. In the dune catchment area, the drawdown reaches more than 4 m.

Simulation of the planned situation

Several alternatives have been explored for the planned situation. The one presented here is as follows: the dune catchment is reduced to 400,000 m^3/year, near the "De Cloedt" pit, 320,000 m^3/year is pumped. The outlet of the pit is now closed, so no water is taken out in the simulation. The pumping wells near the pit are situated to the north of it only, because of the presence of saline water in the aquifer to the south. The calculated hydraulic heads are represented in Figure 7. The rise of the water table compared to the present situation is shown in Figure 8. In the dune catchment area, the rise amounts to 2 m, as a result of the reduction of the pumping to 50 %. Near the "De Cloedt" pit, the "rise" is negative, because here we see a net drop of the water table. Figure 9 shows the residual drawdown of the water table in the planned situation, compared to the situation without pumping. A residual drawdown of more than 2 m persists in the dune catchment area. Near the "De Cloedt" pit, drawdown remains fairly restricted, apart from the immediate surroundings of the pumping wells.

The groundwater model as for now is dealing with steady state conditions. The next step will be to develop a transient model, in order to account for seasonal variations, which obviously are important with respect to the protection of groundwater-bound ecological values in the area.

Salt/fresh water distribution near the "De Cloedt" pit

The "De Cloedt" pit is situated in the polders just south of the dunes. It is sitting on the limit of the presence of salt groundwater in the reservoir, as can be observed on the map showing the depth of the fresh/salt water interface (Figure 10), which was mainly based on geo-electrical prospecting (De Breuck et al., 1974). Salt groundwater is absent in the dunes, and the salt groundwater starts to rise from the dune border to the south, in the area where the pit is situated.

The "De Cloedt" pit has quite steep slopes, and a depth which for the major part is less than 12 m. However, in the central part, a steep deepening occurs to depths of around 19 m. The maximum depth measured was 21.0 m. The resistivity of the water was measured in the pit at depth intervals of 50 cm (Vermoortel et al., 1998). The results are shown in Figure 11. Water resistivity is in between 5 to 8.5 ohm·m, corresponding with moderately brackish to weakly fresh water. However, at 15 m depth, an abrupt decrease down to 0.6 to 1.5 ohm·m indicates the presence of very brackish water.

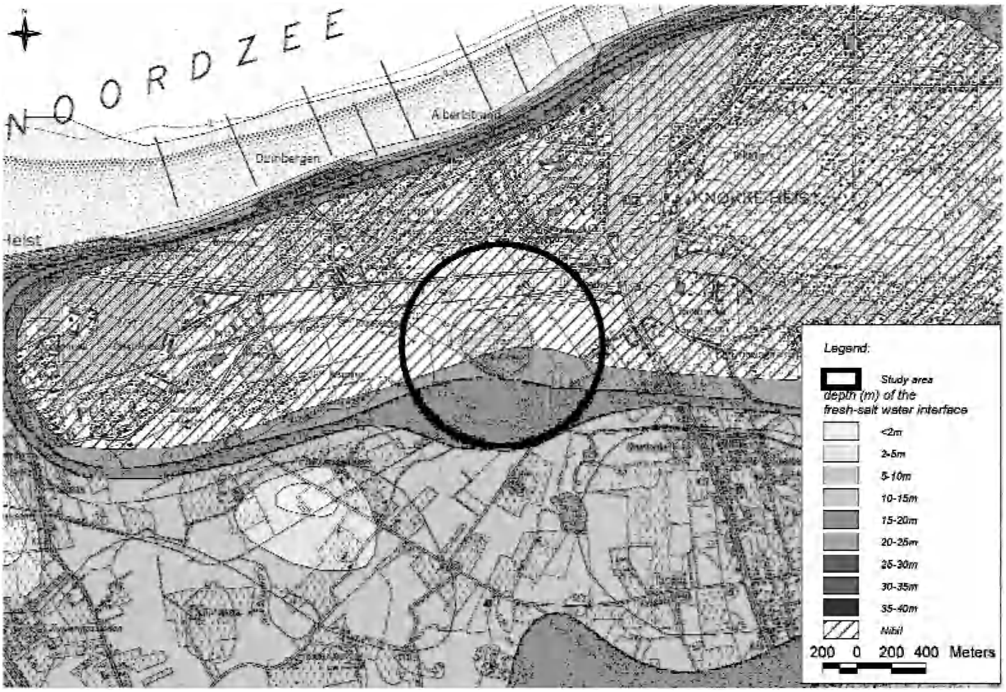


Figure 10. Depth of the fresh/salt water interface (De Breuck et al., 1974).

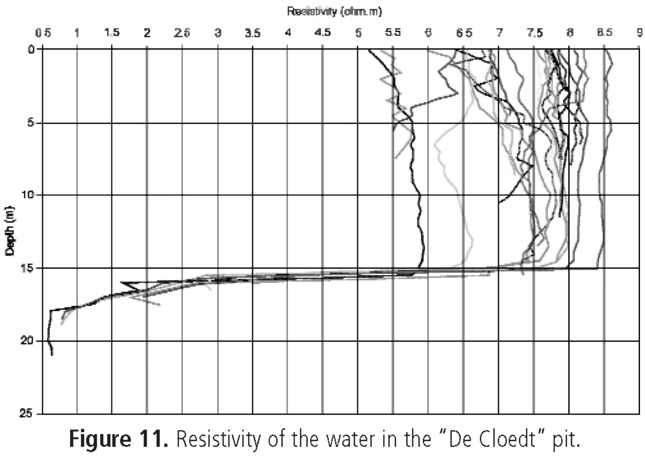


Figure 11. Resistivity of the water in the "De Cloedt" pit.

An important concern will be to avoid attracting saline water towards the pumping wells. Therefore, the fresh/salt water distribution was investigated in greater detail, by means of geophysical measurements and chemical analyses of groundwater sampled from piezometers.

Electromagnetic prospecting

Three parallel N-S profiles of electromagnetic prospecting have been measured. They are situated in the immediate surroundings of the "De Cloedt" pit. The measurements were made with the instrument EM34-3 by Geonics Ltd. The lines of equal apparent ground conductivity for the three profiles, measured with horizontal dipoles at an intercoil spacing of 40 m, are represented in Figure 12. The presence of the "De Cloedt" pit is clearly causing a rise of the salt water interface to the south of it.

For profile EM1, the measurements were performed with three different intercoil distances: 10 m, 20 m and 40 m (all horizontal dipoles), corresponding to estimated maximum penetration depths of 7.5 m, 15 m and 30 m, for the assumption of a homogeneous subsoil. They are shown in Figure 13. It is clear that at shallow depth, the apparent ground conductivity only starts to rise at the end (in the south) of the profile, close to the Isabella Canal, whereas at larger depth (S = 40 m), a rising conductivity is observed already from the "De Cloedt" pit on, towards the south.

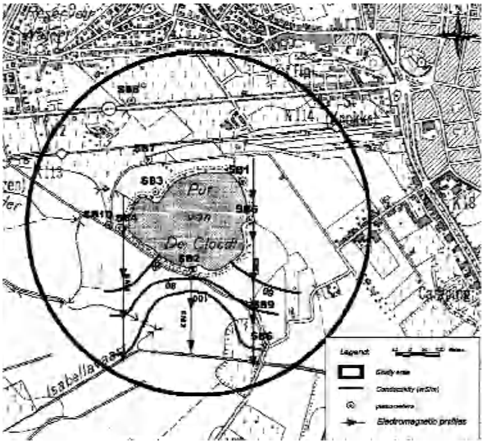


Figure 12. Apparent ground conductivity near "De Cloedt" pit.

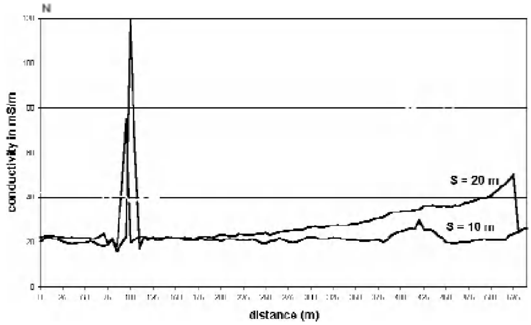
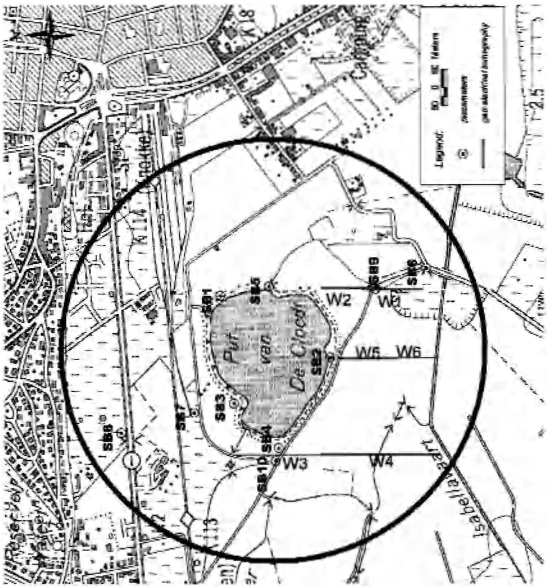


Figure 13. Electromagnetic measurements along profile EM1 with different intercoil spacings (S).

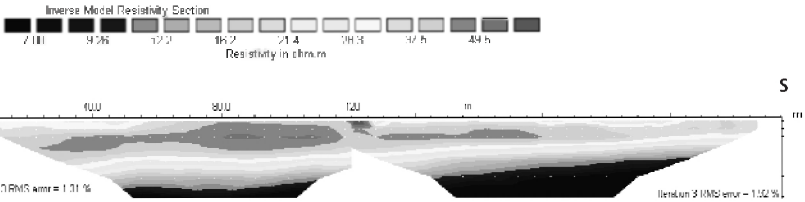
Electrical tomography

Electrical tomography was performed by means of the Syscal R2 equipment by Iris Instruments (Figure 14). The results of the electromagnetic prospecting campaign are confirmed, but additionally, these measurements provide quantification of the true formation resistivities, both laterally and vertically.

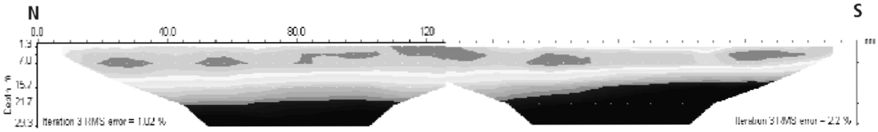


a. Location of profiles measured with electrical tomography.

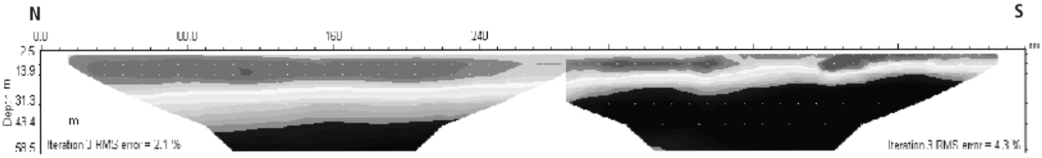
Legend:



b. Interpretation of electrical tomography along profile W2W1.



c. Interpretation of electrical tomography along profile W5W6.



d. Interpretation of electrical tomography along profile W3W4.

Figure 14. Interpreted formation resistivities in profiles measured with electrical tomography.

Well logging

Resistivity logging with the long-normal array has allowed to obtain formation resistivities, from which the groundwater resistivities and groundwater quality groups were approximated, on the basis of Table 1. For profile SB1-SB5-SB9-SB6, the distribution of water resistivities is represented in Figure 15. In the north of the profile, near the "De Cloedt" pit, the major part of the reservoir is filled with moderately and weakly fresh water, although more saline groundwater starts to appear near the bottom of the reservoir. Towards the south, the saline water interface is quickly rising, and a large part of the reservoir is filled with brackish to salt water.

Table 1. Relation between formation resistivity and groundwater quality.

Groundwater quality group	TDS (mg/L)	Groundwater resistivity ρ_w (ohm·m, 11°C)	Formation resistivity ρ_t (ohm·m, 11°C)
Very fresh (VF)	< 200	> 50	> 200
Fresh (F)	200 – 400	50 – 25	200 – 100
Moderately fresh (MF)	400 – 800	25 – 12.5	100 – 50
Weakly fresh (WF)	800 – 1600	12.5 – 6.25	50 – 25
Moderately brackish (MB)	1600 – 3200	6.25 – 3.13	25 – 12.5
Brackish (B)	3200 – 6400	3.13 – 1.56	12.5 – 6.25
Very brackish (VB)	6400 – 12800	1.56 – 0.78	6.25 – 3.12
Moderately salt (MS)	12800 – 25600	0.78 – 0.39	3.12 – 1.56
Salt (S)	> 25600	< 0.9	< 1.56

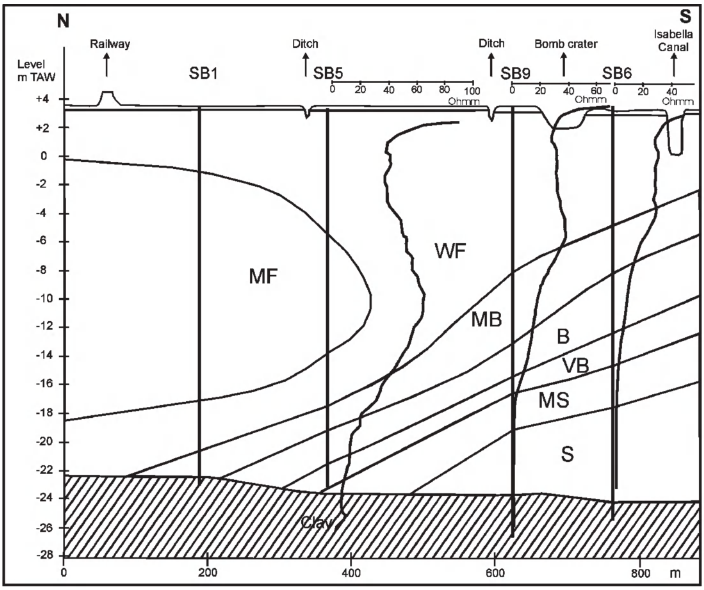


Figure 15. Resistivity profile obtained from well logging (for symbols, cfr. Table 1).

Groundwater analyses

Groundwater samples were taken from all available piezometers, and the analytical results were classified according to the Stuyfzand (1986) classification (Figure 16). The more freshened groundwaters in the northern upper part of the aquifer show a F-$CaHCO_3$+ type. The final stage of freshening is expressed by the positive cation exchange code, indicating a surplus of marine cations. Towards the bottom of the reservoir, brackish B-NaCl+ water is present in the north. But to the south of the "De Cloedt" pit, the brackish or more saline groundwaters occupy more than half of the reservoir thickness. In the upper part, fresh-brackish F_b-$NaHCO_3$+ water is present, with depth evolving towards salt S-NaCl0 water. In the deep filters of SB6 and SB9, salinity is almost as high as seawater (TDS ≈ 30 g/L).

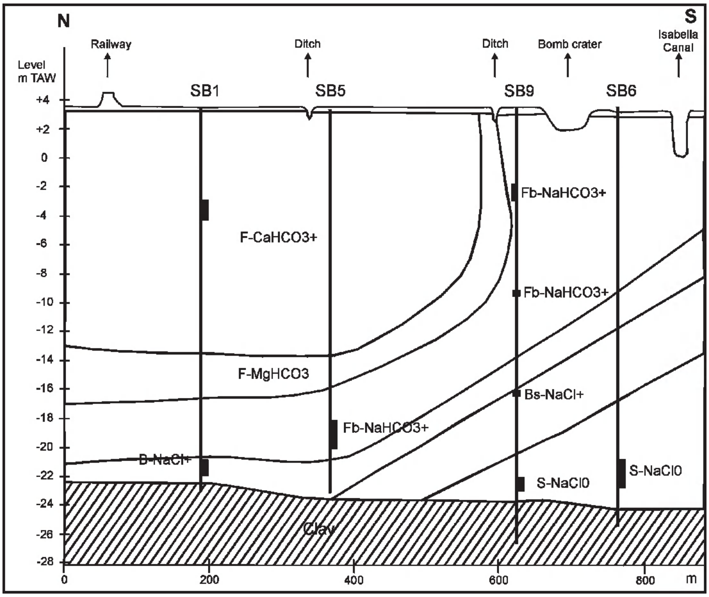


Figure 16. Groundwater types based on chemical analyses.

Conclusion

Groundwater flow modeling of the natural, the present and the planned situation has allowed to predict the rise of the water table as a result of the reduction of the catchment in the dunes. The new catchment near the "De Cloedt" pit will compensate for this reduction. However, because of its localization in the polder area, and the presence of saline groundwater to the south, an important concern will be to avoid attracting saline water towards the pumping wells. The fresh/salt water interface has been studied in detail by geophysical measurements and chemical analyses on groundwater sampled from piezometers. In the future, the characterized fresh/salt water distribution in the reservoir should be taken into account in the groundwater model, simulating the effect of the new catchment near the "De Cloedt" pit.

Acknowledgements

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References

BOS, M.G. (1985). *Long-throated flumes and broad-crested weirs.* Martinus Nijhoff / Dr. W. Junk Publishers. Dordrecht. 141 p.

DE BREUCK, W., DE MOOR, G., MARÉCHAL, R. and TAVERNIER, R. (1974). *Depth of the fresh-salt water interface in the unconfined aquifer of the Belgian coastal area (1963-73).* Map 1:100.000. Military Geographical Institute, Brussels.

MC DONALD, M.G. and HARBAUGH, A.W. (1988). A modular three-dimensional finite-difference groundwater flow model. *Techniques of Water-Resources Investigations of the U.S. Geological Survey.* Book 6. Chapter A1. 586 p.

STUYFZAND, P. (1986). A new hydrochemical classification of watertypes: Principles and application to the coastal dunes aquifer system of the Netherlands. *9th Salt Water Intrusion Meeting, Delft 1986. Proceedings* 641-655.

VERMOORTEL, Y., GAUS, I., DE SMET, D. and DE BREUCK, W. (1998). *Hydrogeological study of the catchment potential in the municipality of Knokke-Heist – Hydrogeological characterisation of the surroundings of the "De Cloedt" pit.* Report TGO94/37. Laboratory for Applied Geology and Hydrogeology. Ghent University. 40 p.