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IMPACT OF A WATER CATCHMENT IN THE DUNE AREA ALONG THE FRENCH-BELGIAN BORDER

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Abstract.The western Belgian coastal plain, along the French-Belgian border, consists of shore, dunes and polders. A water catchment creating a valuable nature reserve is present in the dunes. In recent years, the water catchment has problems with salt water intrusion from the polder. The aim of this study is to model the influence of the water catchment. Special attention goes to the evolution of the salt water intrusion from the polder and from the sea in the dunes along the French-Belgian border. Therefore, a 3D density dependent groundwater flow model was made of the shore, dunes and part of the polder using the MOCDENS3D code.The heterogeneous groundwater reservoir was schematised in the model based on numerous drillings descriptions and geophysical measurements, and the simulations were calibrated using hydraulic heads and water quality observations. It was shown with the model that the salt water intrusion is restricted to the immediate surroundings of the water catchment, does not cross the border and does not inf1uence the nature reserve.

Key words: salt water intrusion, water catchment, dunes, modelling of groundwater flow, French-Belgian border.

Abstrakt. Zachodniobelgijska równina przybrzeżna, występująca wzdłuż granicy francusko-belgijskiej, składa się z wybrzeża, wydm i polderów. Na terenie wydm znajduje się ujęcie wód, tworzące cenny rezerwat przyrody. W ostatnich latach problemem na tym obszarze stały się wlewające się z polderu wody słone. W niniejszym artykule przedstawiono wpływ zachodzących zmian na wody tego ujęcia. Szczególną uwagę poświęcono rozwojowi przepływu słonych wód z polderu i morza na obszar wydm przy granicy francusko-belgijskiej. W celu zbadania tego procesu, przy pomocy programu MOCDENS3D opracowano przestrzenny model przepływu wód podziemnych o różnej gęstości na obszarze wybrzeża, wydm i części polderu. W modelu na podstawie licznych profili wiertniczych i pomiarów geofizycznych odtworzono heterogeniczny zbiornik wód podziemnych. Symulacje były skalibrowane z wykorzystaniem obserwacji głowic hydraulicznych oraz jakości wody. Za pomocą modelu wykazano, że intruzje słonych wód są ograniczone do bezpośredniego otoczenia ujęcia wodnego, nie wkraczają na jego obszar i nie zagrażają rezerwatowi przyrodniczemu.

Słowa kluczowe: intruzje słonych wód, ujęcie wodne, wydmy, modelowanie przepływu wód podziemnych, granica francusko-belgijska.

INTRODUCTION

Fragmented dunes are found along the Belgian coast. They are part of the northwestern European coastal dunes, which form a long, narrow strip from Calais (France) to the north of Denmark. The most important, still unfragmented part is found in the Belgian western coastal plain along the French-Belgian border. This is a highly valuable area from an ecological point of view due to its richness in fauna and f1ora. One of the largest Flemish nature reserves, the Westhoek nature reserve, is located in the dunes along the French-Belgian border.

The dunes are also very important for the production of drinking water because they are the only source of fresh water in the coastal plain. This is due to a fresh water lens present in the dunes. In the adjacent low lying area (so-called polder)

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mainly salt and brackish water are found. Under the shore, a particular density distribution of a salt water lens is present above a fresh water tongue. There are two water catchments in the dunes. One of them is located close to the French-Belgian border, in centre of the study area (Fig. 1). Since the 1990s, this water catchment has had problems with intrusions of brackish water in its production wells (Fig. 2).

The aim of this study is to model the influence zone of this water catchment. Special attention goes to the intrusion of salt water from the polder or from the sea into the dunes along the French-Belgian border and into the nature reserve. Therefore, a 3D growater flow model was made of the dunes, shore and a part of the polder along the French-Belgian border.

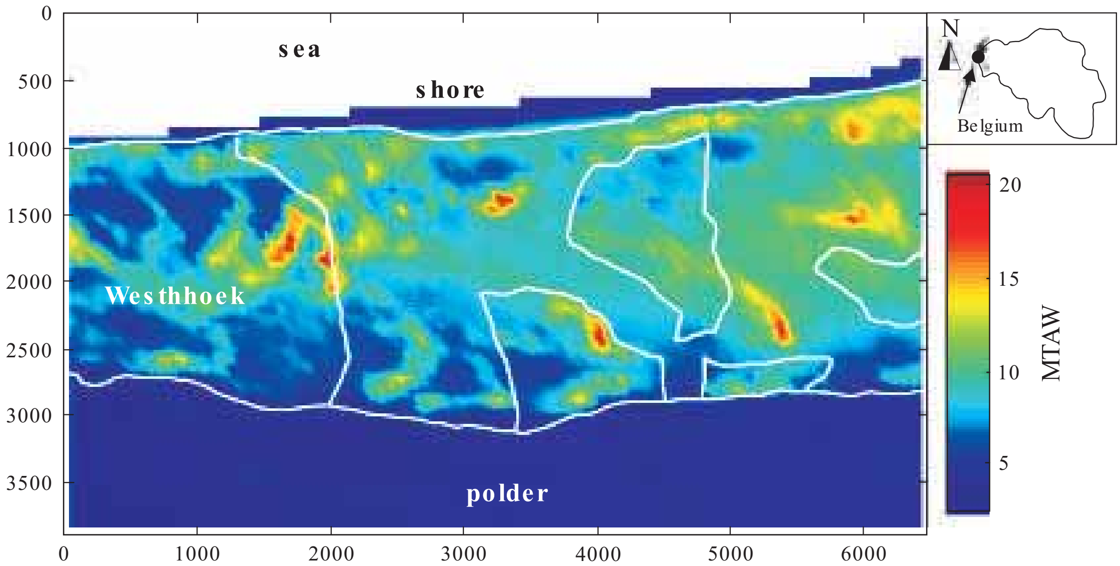

Fig. 1. Location of the model area

The relief map shows the dunes and the low lying polder (MTAW is the Belgian ordnance datum referring to the mean low low water level, about 2.3 m below mean sea level); the conserved dune areas and the Westhoek nature reserve are encircled in white; W.C. marks the position of the water catchment

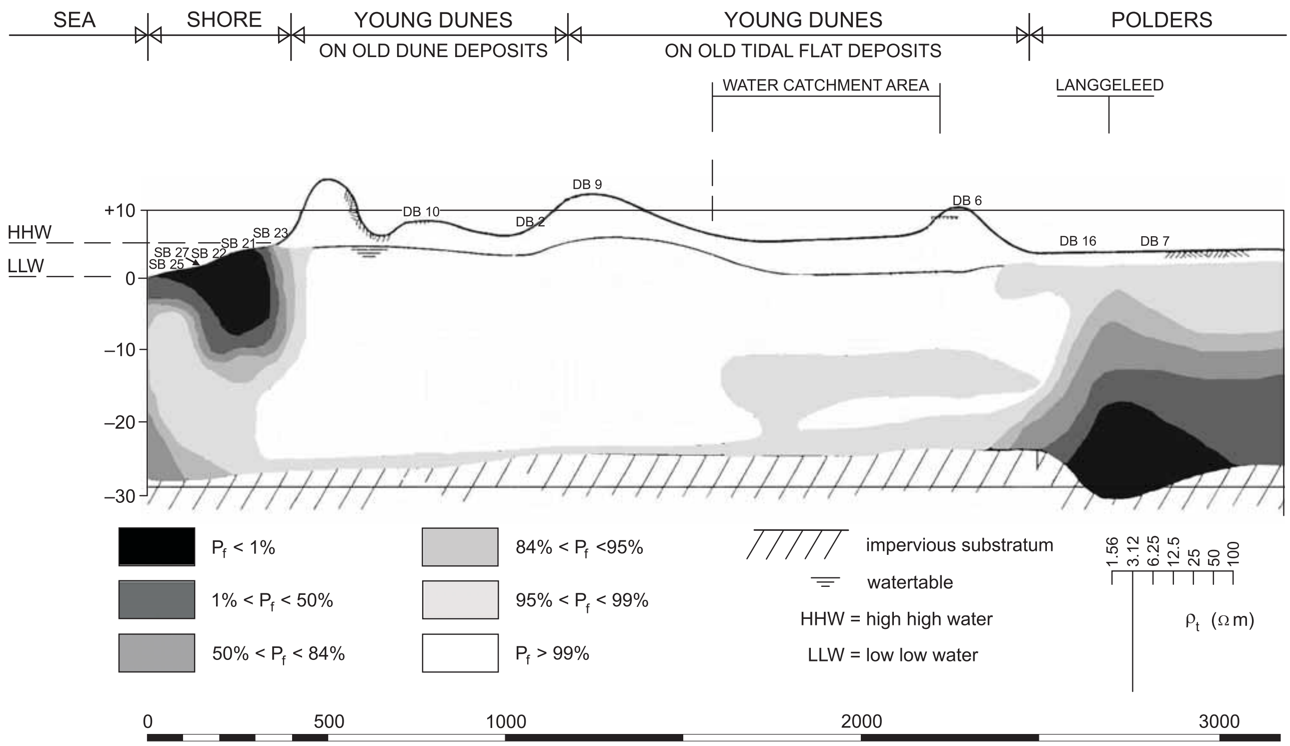

Fig. 2. Cross-section through the shore, dunes with the water catchment and polder

Water quality is indicated based on geophysical borehole observations (log normal resistivity logs)

MOCDENS3D MODEL

The density dependent groundwater flow model MOCDENS3D was applied (Oude Essink, 1998, 2001). It is based on a three-dimensional solute transport computer code MOC3D (Konikow *et al*., 1996), adapted for density differences. A phreatic groundwater reservoir is build of heterogeneous sediments of quaternary age. A study of the literature was, therefore, made to collect available drilling descriptions, geophysical borehole measurements, etc. These data were used to construct a conceptual model of the sediments spatial distribution aiming at implementation of the state of the art knowledge on the groundwater reservoir geology.

The groundwater reservoir is subdivided in 12 layers, 86 columns and 52 rows (height 2.5 m width and length 75 m) resulting in 53,664 finite difference cells. It is very important that the extensions of permeable and semi-permeable layers are included in the model as accurately as possible. They dictate groundwater flow and have their influence on the distribution of fresh and salt water. The heterogeneity of the groundwater reservoir was therefore introduced in the model by means of three hydrogeological type section maps, of the lower, middle and upper parts of the groundwater reservoir, respectively. On these maps are distinguished typical successions of permeable and semi-permeable layers, which occur over a wide area. The hydraulic parameters of the different layers are based on interpretations of a number of pumping tests performed in the dunes and in the polders. By applying this approach with type sections, all available hydrogeological and lithological knowledge is integrated in the best possible way.

History of the water catchment's discharge rate is developed along with the drainage system in the polder, and recharge rates. The water catchment started in 1967. For the simulation stress periods of 3 years were used. The extraction rates over these periods were averaged. Observations of hydraulic heads, water quality analyses and geophysical measurements were used to calibrate the model.

RESULTS AND DISCUSSION

Figure 3 shows two cross-sections through the model. The first is located along the column 10, situated in the Westhoek nature reserve, close to the French-Belgian border. An interesting water quality distribution can be seen there. A fresh water lens is present in the dunes. A part of the fresh recharge water flows towards the shore. The other part flows towards the polder. The heterogeneity of the groundwater reservoir influences this flow. For instance, a shallow clay layer which can be found in most parts of the dunes is of a great importance. The water table above this clay layer is significantly higher than the hydraulic head blow it.

Under the shore, a particular water quality distribution is found. A salt water lens is present in dynamical equilibrium above a fresh water tongue. This was observed using geophysical borehole measurements (Lebbe, 1981) and modelled in detail by Lebbe (1981, 1983, 1999) and Vandenbohede (2003). This distribution is due to a combination of actors: the shore width (about 400 m), tides with a large tidal amplitude (mean amplitude of 2 meters), and a permeable groundwater reservoir. Salt water infiltrates the back shore during high tide and flows out on the foreshore mainly during low tide. In this way, a small flow cycle of salt water comes into existence under the shore. The fresh water flowing from the dunes towards the sea is pushed deeper in the vicinity of high water line and forms a fresh water tongue beneath the salt water lens. This fresh water flows out more seaward. In the polders, adjacent to the dunes, there is a seepage of fresh water. The lower part of the groundwater reservoir is filled over the whole polder area with brackish to salt water. Around major drainage canals an upcoming of salt and brackish water is possible.

The second cross-section on Figure 3 is situated along the column 35 — through the water catchment. The influence of the water catchment can be clearly distinguished. The flow pattern has changed considerably. A naturally occurring flow from the dunes towards the sea and the polders is reduced. Because the flow towards the sea is almost completely lost, the typical fresh water tongue has disappeared completely and the groundwater reservoir under the shores is filled with salt water. A major threat of salt water encroachment into the water catchment comes, however, from inland. The flow of fresh dune water towards the polders is reversed and salt water is flowing now from the polders into the dunes, and ultimately towards the water catchment. This is in accordance with the available water quality observations and the extraction of brackish water in a number of production wells. Worth noticed is also a relic of old salt water trapped in a semi permeable lens situated under the water catchment. This salt water has not been washed out completely by the recharge of fresh dune water.

Figure 4 gives four horizontal cross-section through the model in order to show the lateral extent of the salt water intrusion. They are as follows: 1967 (gust for the start of the water catchment), 1990 (maximum extraction rate — 2,000,000 m^3/year), 2004 (current situation with an extraction rate of 1,000,000 m^3/year) and 2025 (extraction rate of 500,000 m^3/year). The cross-sections were constructed along the layer 8; two thirds of the groundwater reservoir are situated above this layer and one third below it. In 1990 there was already an important salt water encroachment towards the water catchment. That was a situation which did not change much during the 1990s. To remedy this and save the water catchment from salinisation of all the production wells, the extraction rate will be reduced by 100,000 m^3/year from 2005 onward. From 2010, the extraction rate will remain at 500,000 m^3/year. Due to the smaller extraction rate, the salt water intrusion is pushed back because the fresh water flow from the dunes towards the polders is partially restored. This effect will be visible already in 2025 (Fig. 4).

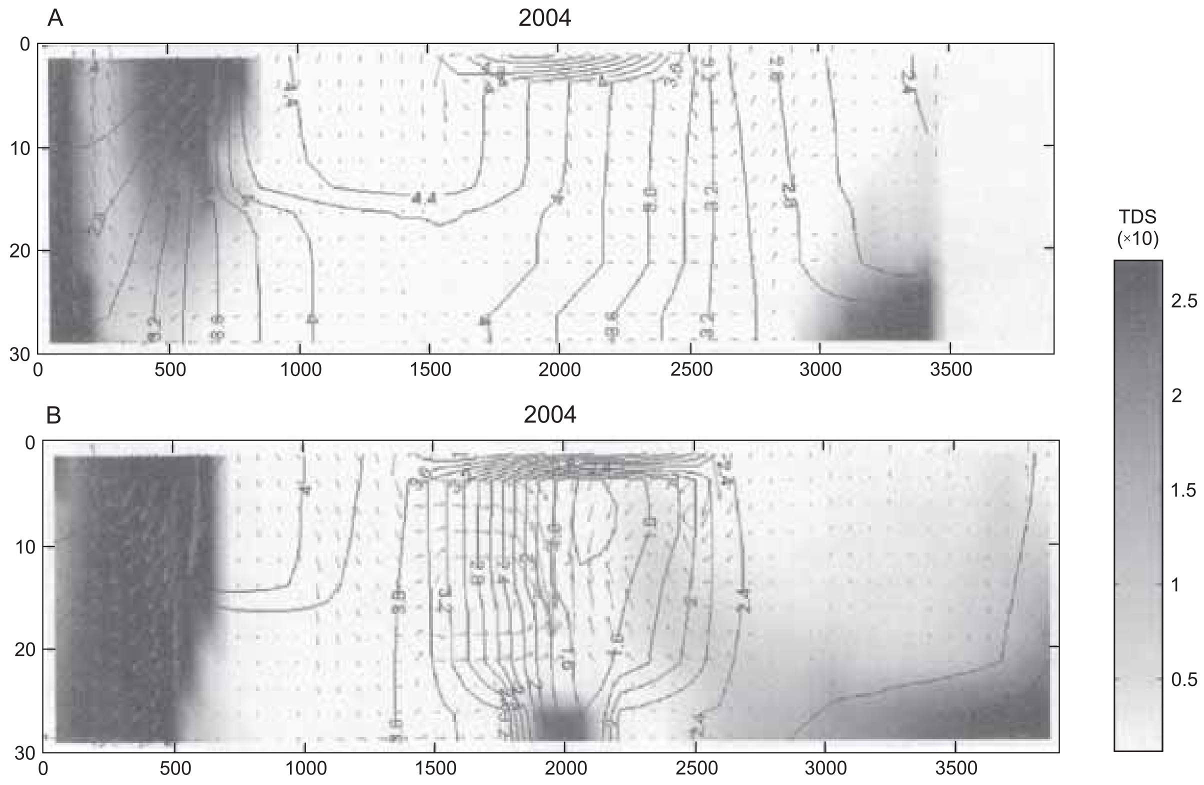

Fig. 3. Vertical cross-sections along column 10 (A) and column 35 (B) with indication of water quality distribution, hydraulic heads and groundwater flow for the current situation

TDS — total dissolved solids (mg/l)

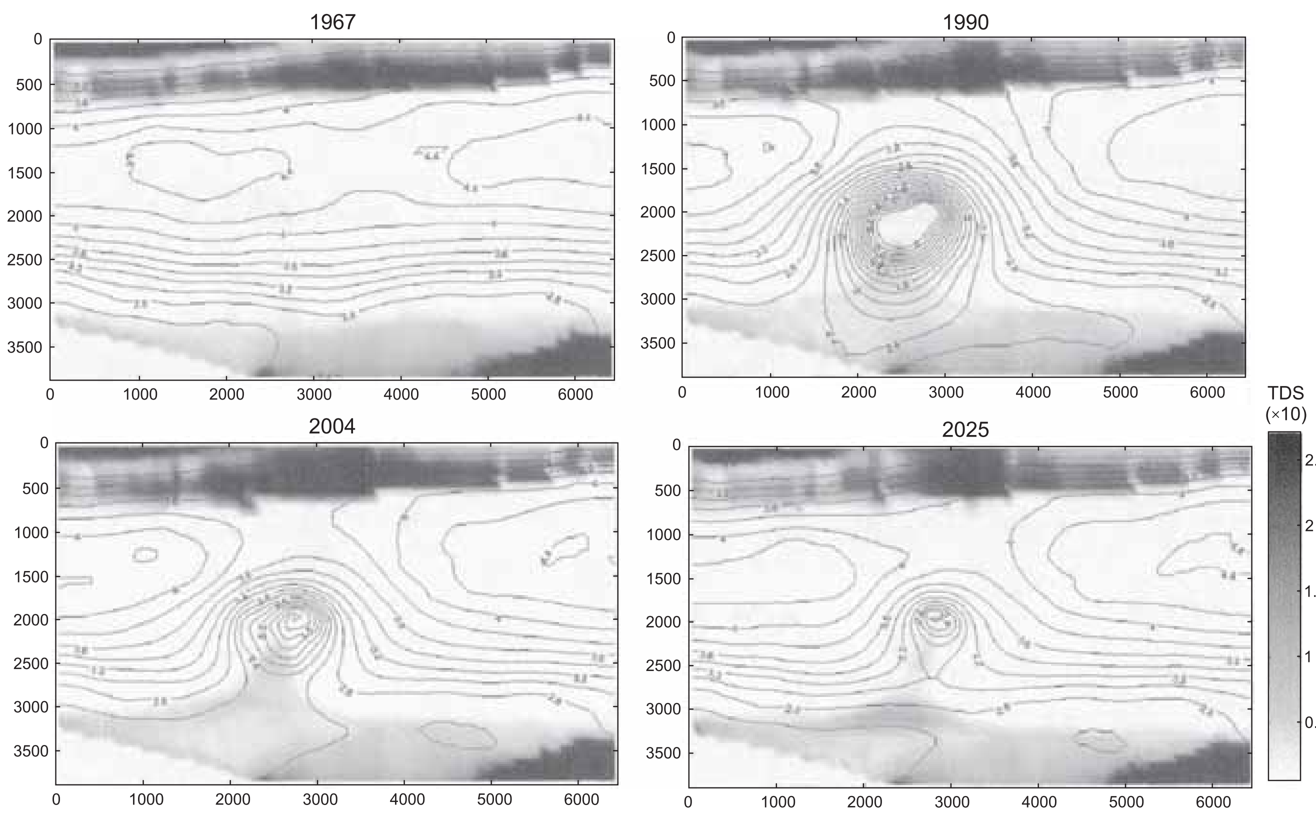

Fig. 4. Horizontal cross-section along layer 8 for years 1967, 1990, 2004 and 2025 with indication of water quality distribution, hydraulic heads and groundwater flow

TDS — total dissolved solids (mg/l)

CONCLUSIONS

This paper illustrates the usefulness of groundwater f1ow models to simulate solute transport problems with a case study in the Belgian coastal plain. The available hydrogeological and geologic information on the area was schematised in the model. The model was calibrated with hydraulic heads and water quality observations. Cross-sections showed that the salt water intrusion has always been located in the vicinity of the water catchment (Figs. 3, 4). The main threat comes from the polder and not from the sea. The water quality distribution close to the French-Belgian border is only slightly influenced. There has been no salt water intrusion from the sea or from the polder that could have threatened the delicate ecological balance of the nature reserve. It is important also to notice that the hydraulic heads in this area are only a few decimetres lower than in the case of the natura1 flow. Due to the lower extraction rates this situation will remain such for the next decades. Also the present salt water intrusion from the polders will be reversed.

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