Modeling of Historical Evolution of Salt Water Distribution in the Phreatic Aquifer in and around the silted up Zwin Estuary Mouth (Flanders, Belgium)

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ABSTRACT

The evolution of the salt-water distribution around the Zwin estuary mouth is modeled for a period of about five centuries. The modeled area is situated in the Flemisch coastal plain near the border of The Netherlands and Belgium. The Zwin estuary is the former waterway to the medieval seaports of Bruges and Damme. During the considered period this alluvial estuary silted up and the modeled area changes from an area around a tidal channel, over a mud flat to a rather complex polder dune area. The evolution is simulated by the 3D density depended groundwater flow model MOCDENS3D (Lebbe & Oude Essink, 1999). The row direction of the applied finite-difference grid is parallel to the present coast line. The simulation is based on old paintings and a large number of maps which allow a relatively detailed reconstruction of the evolution of the landscape. The results show the historical evolution of a large number of different inverse density problems in this area.

INTRODUCTION

To simulate this five hundred years period ten stress periods are considered. Before the 20th Century the stresses which influence the groundwater flow and the salt water distribution were principally determined by the evolution of the landscape. The simulation starts with the first sound representation of the area in a painting of Pourbus (1571). At that time the waterway to the seaport Damme ran from the upper right to the lower left corner of the modeled area (Fig. 1). This tidal channel was bounded at both sides by relatively flat banks which were temporally inundated by sea water depending on the tides. At both sides of the estuary mouth there were peninsulas principally existing of dune areas. Behind the western dunes there was a tidal flat area with a central gully. During the high waters at spring tides this tidal flat area was completely inundated by sea water whereas the sea retreated completely from it at low water. The southern boundary of the tidal flat area was bounded by a dyke protecting the polders behind it from inundations.

The subsequent stresses on the phreatic aquifer are due to the lateral changes of the landscape elements. In the dune area fresh water recharges with a constant rate (280 mm/year). In the tidal flat area, the banks of the tidal channel and the shores, the average fresh water head in the uppermost layer is derived from the tidal fluctuations and the elevation of the ground surface at the treated point. When there is a recharge of groundwater in all the fore mentioned areas the water quality corresponds with that of sea water (100% salt water). In the polder areas the top of the aquifer is drained at a prescribed level and there is a smaller recharge of water than in the dune area. The salt content (2%) of the water infiltrating in the polder area is slighter higher than those of the recharging water in the dune area (1%). During the 20th and the beginning of the 21th century the landscape elements do not change any longer and the considered stress periods depend principally from the changing withdrawal rates in the dune area.

During the presentation of the simulated results the evolution of the groundwater flow and distribution are treated at different levels in the aquifer and in different cross-section through it. Because of the limited space of this abstract only a small number of selected results can here be shown. First, the applied finite difference grid is located and the initial conditions of the

simulation are described. Hereafter, a small number of results are selected so that the different inverse density problems can be demonstrated.

FINITE DIFFERENCE GRID, INITIAL CONDITIONS AND SOME RESULTS

The modeled area is 4.4 km on 3.5 km. The finite difference grid consists of 88 columns, 70 rows and 12 layers. All finite difference cells have the same size. These cells have a thickness of 2 m and a squared base plane with a side of 50 m. The evolution of the salt water distribution is calculated with the method of the characteristics. At the initial time one assumes that the phreatic aquifer was completely filled with salt water. So, eight particles per finite difference cell are places with a salt water percentage of 100%. The stresses on the aquifer during the first stress period depend of the different landscape elements derived from the painting of Pourbus (1571) as described in the introduction. The duration of this stress period was chosen so that a dynamic equilibrium is nearly reached in the salt water distribution (see Figure 1).
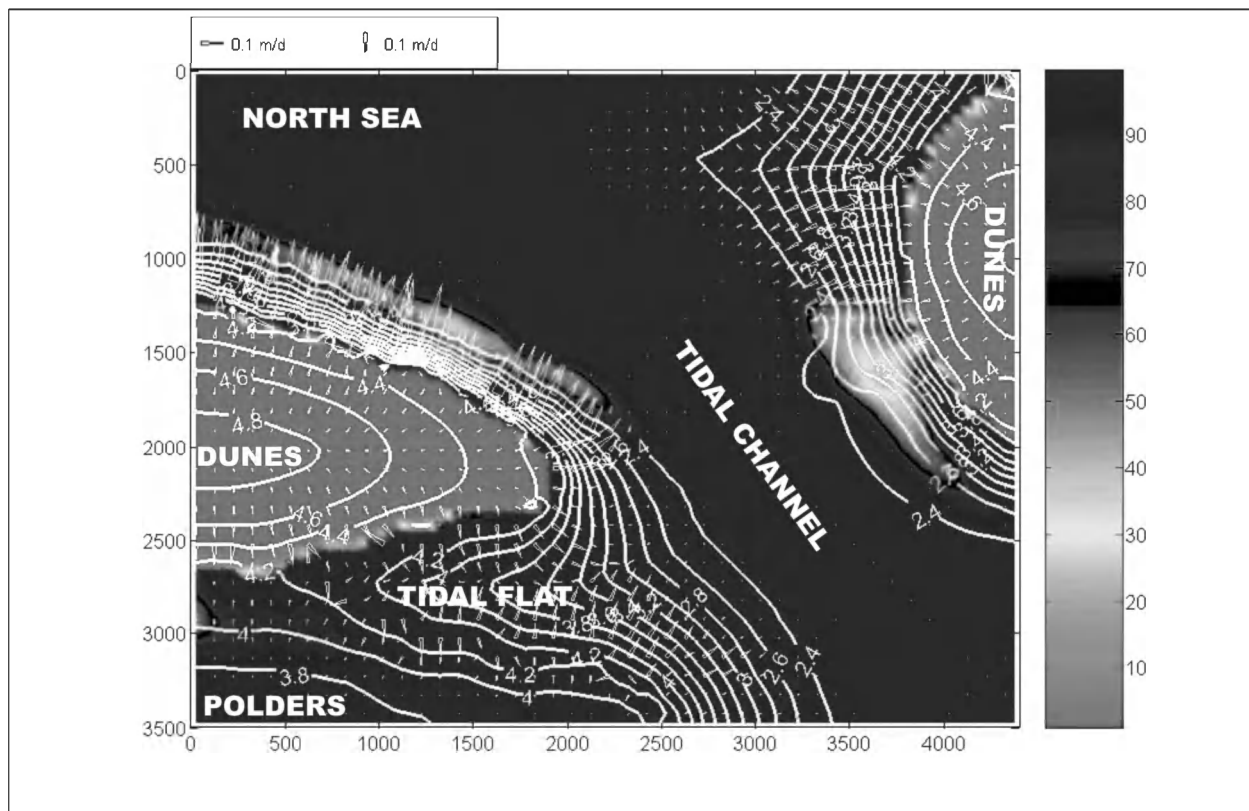

Figure 1. The modeled area with the principal landscape elements according to the painting of Pourbus (1571) along with the simulated fresh water head contour lines (in white), the groundwater flow (vectors) and the saltwater percentage (gray scale) of layer 2 (x and y coordinates in m)

In Figure 1 the simulated results are represented in a horizontal plane at level -2 m below mean sea level (bmsl) according to the landscape of 1571. Under the dunes the upper part of the phreatic aquifer was filled with fresh water. Before the western dunes there was an outflow of fresh and brackish water at the low water line of spring tides. The flow of fresh water from the eastern dune area to the eastern bank of the tidal channel was concentrated to the southern part of the bank which had a more permeable subsurface and a slightly steeper slow than its northern part.
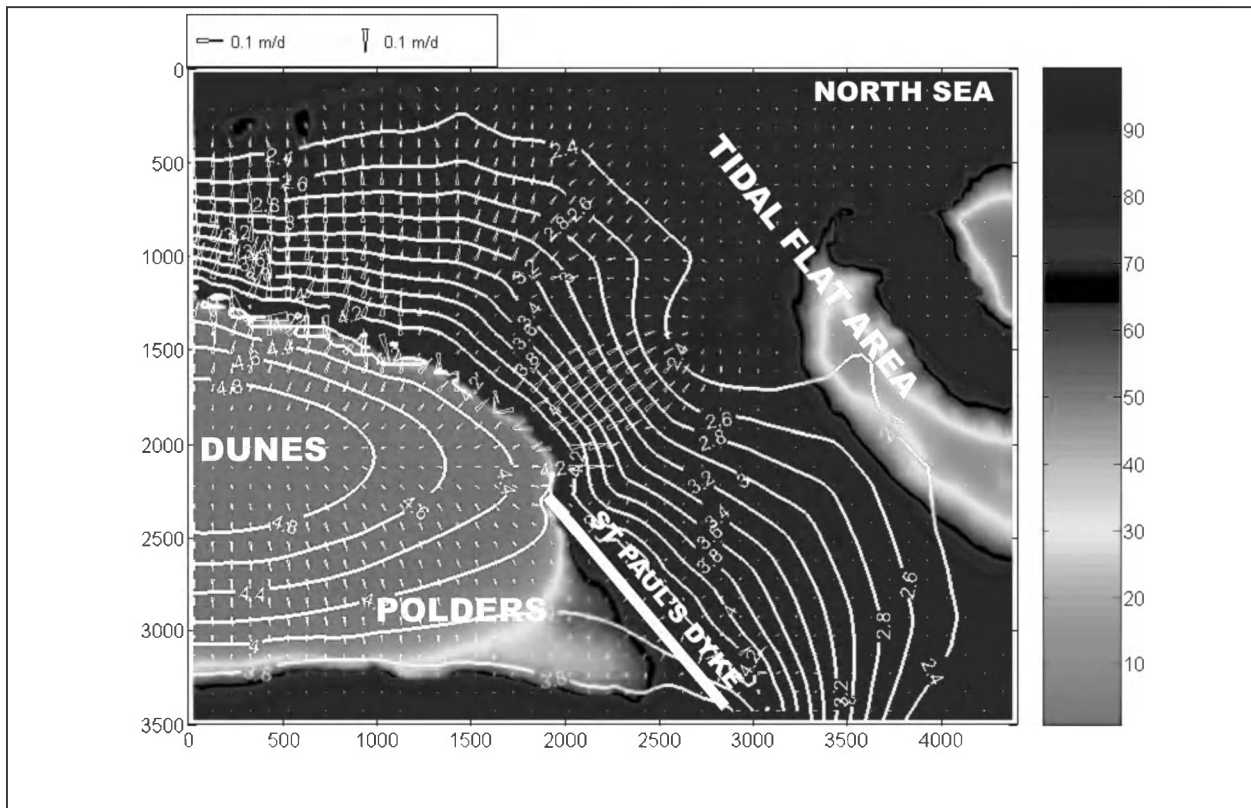
Figure 2. Principal landscape elements according to the map of Wilschut (1740) along with the simulated groundwater flow and the saltwater distribution in layer 2

During the 17th Century the tidal channel silted up. First, the eastern dunes grew towards the west resulting in a larger fresh water lens under these dunes. The deepest part of the channel moved towards the west and the channel became shallower. Due to this the slope of the western bank of the tidal channel decreased while the slope of the eastern bank increased. On the southern part of the eastern bank there was an important fresh water flow from the eastern dunes toward the low water line. Above this fresh water flow there was a large salt water lens. This density inversion developed in a similar way as the density inversion described by Vandebohede & Lebbe (2006). In the second half of the 17th Century there was an erosion of the feet of the eastern dunes and the high water line moved toward the east. Finally, this resulted in a tidal flat area in the upper right part of the modeled area (Fig.2) whereas the low water line of the North Sea retreated to the upper right corner of the modeled area. In this tidal flat area there were still remains of the fresh water lens of the former eastern dunes and also of the density inversion under the former eastern bank of the tidal channel. Because the hydraulic gradients under the tidal flat area are very limited, there was only a density dependent very slow flow due to the inversed distribution of salt and fresh water (Fig.3). In the beginning of the 18th Century the polders in the lower left part of the modeled area were enlarged by the construction of the Saint Paul's dyke. Due this reclaim of the former tidal flat a very slow freshening process started in the top of the phreatic aquifer.

DISCUSSION AND CONCLUSIONS

The historical evolution of the salt-water distribution around the Zwin estuary mouth results in a large number of different inverse density problems. The evolution of one of these inverse density problems is shown above. A detailed study of these inverse density problems along with present

day observation in area which show similar evolution as around the Zwin estuary mouth will be a future challenge in the salt water intrusion research.
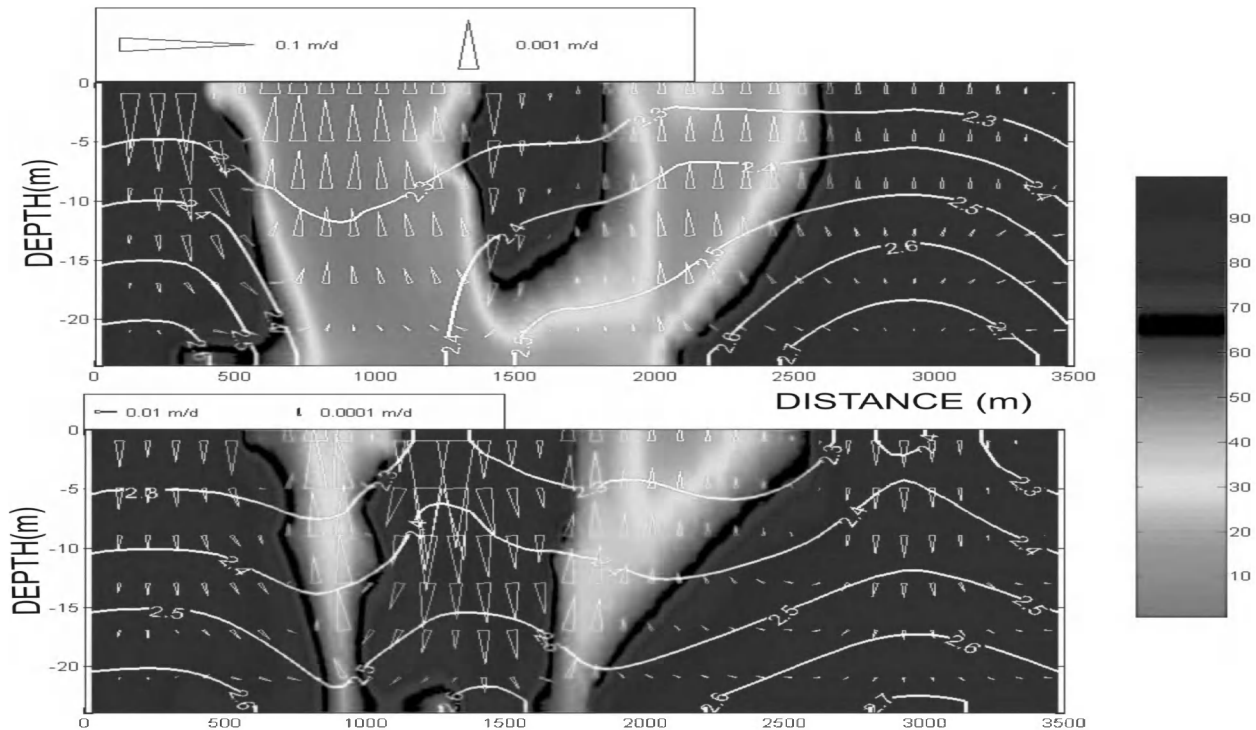

Figure 3. Simulated evolution of the remains of a fresh water lens of the eastern dunes and of the density inversion under the eastern bank of the tidal channel after the change of the area to a tidal flat area in the beginning (above) and at the end (below) of the 18th Century in a cross section along the row (x=4225 m)

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