Fresh-salt water distribution in the Zwin estuary before and after a future expansion

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ABSTRACT

Plans are made to enlarge the tidal flat area around the Zwin estuary which is silting up and situated around the Dutch-Belgian border. First, the evolution of the fresh-salt water flow and fresh-salt water distribution is simulated in this area and the surrounding polder area for a period of 50 years taking into account the forecasted sea-level rise. The initial fresh-salt water distribution is based on an existing map of the depth of the fresh-salt water interface with additional electromagnetic borehole loggings. MOCDENS3D is used to simulate the 3D groundwater flow. After this first simulation the evolution of the fresh-salt water distribution and flow is simulated for a period of 50 years taking into account the expansion of the estuary and its surrounding tidal flats with a surface of 120 hectare. This action results in an increase of the salt water seepage area in the adjacent polder area. The model shows that this increase can be mitigated by the application of deep drainage instead of the traditional shallow drainage. In the long run this mitigating measure allows even to reduce the present salt water seepage area.

INTRODUCTION

The Zwin estuary and its surrounding tidal flats act like a sediment trap, resulting in the silting up of the inlet. To mitigate this sedimentation process an expansion of the area with 120 hectares was put forward. Within the framework of an environmental impact assessment study the consequences of this expansion on the fresh-salt water distribution and flow in the adjacent polder area were studied using a numerical model. To assess this impact two density-dependent groundwater flow simulation were run over a period of 50 years. In the first simulation the traditional shallow drainage in the polder area is continued while the impact of the forecasted sea-level rise in the present day estuary and the surrounding tidal flat is taken into account. In the second simulation the forecasted sea level rise is taken into account in the estuary channel with the expanded tidal flat area while the shallow drainage system of the surrounding polder area is unmodified. The third simulation shows that the increased salt water seepage area can be mitigated by the change from the traditional shallow drainage system to a deep drainage system.

METHODS

Six deep and 6 shallow observation wells were placed around the planned expansion area. In every deep observation well electromagnetic induction measurements were executed with the Geonics EM-39 probe. These measurements provide a detailed view of changes in conductivity with depth which makes it an excellent tool for studying salt-fresh water distribution in

sediments around observation wells. The initial fresh-salt water distribution is based on a map of the depth of the fresh-salt water interface (De Breuck *et al.* 1974). The 3D density dependant groundwater flow model MOCDENS3D (Oude Essink 1998) is used. Visual MOCDENS3D is used as a postprocessor (Vandenbohede 2007). The simulated area is discretised in 72 columns and 99 rows each with a width of 50 m. In vertical direction the aquifer system is subdivided in 14 layers each with a thickness of 1.5 m. The hydrogeological data base of the Flemish Environmental Agency is used for the schematisation of the groundwater reservoir and the spatial change in its horizontal and vertical conductivity (Lebbe *et al.* 2008). The model takes climate change into account by including a sea level rise of 6 mm/y (IPCC 2007).

RESULTS

Case 1: Present situation and situation after 50 years

Figure 1 shows the present and future (after 50 years) fresh-salt water distribution in the tidal flat and surrounding areas. The white contour lines represent the freshwater heads. The lower freshwater heads in the tidal flat correspond with channels in the Zwin. The Zwin inlet is enclosed by a dike.
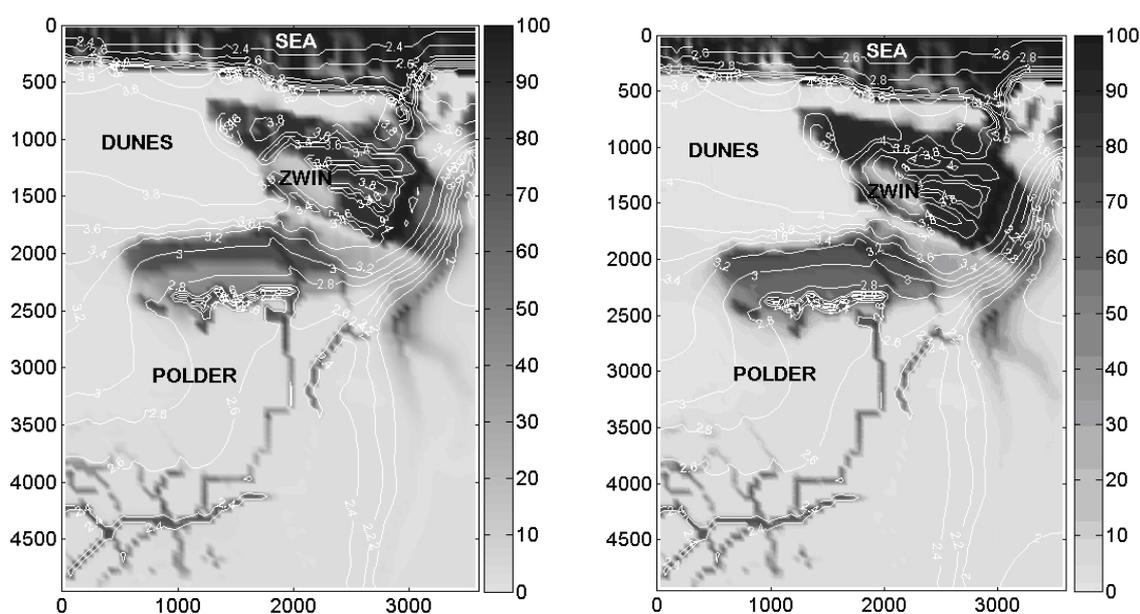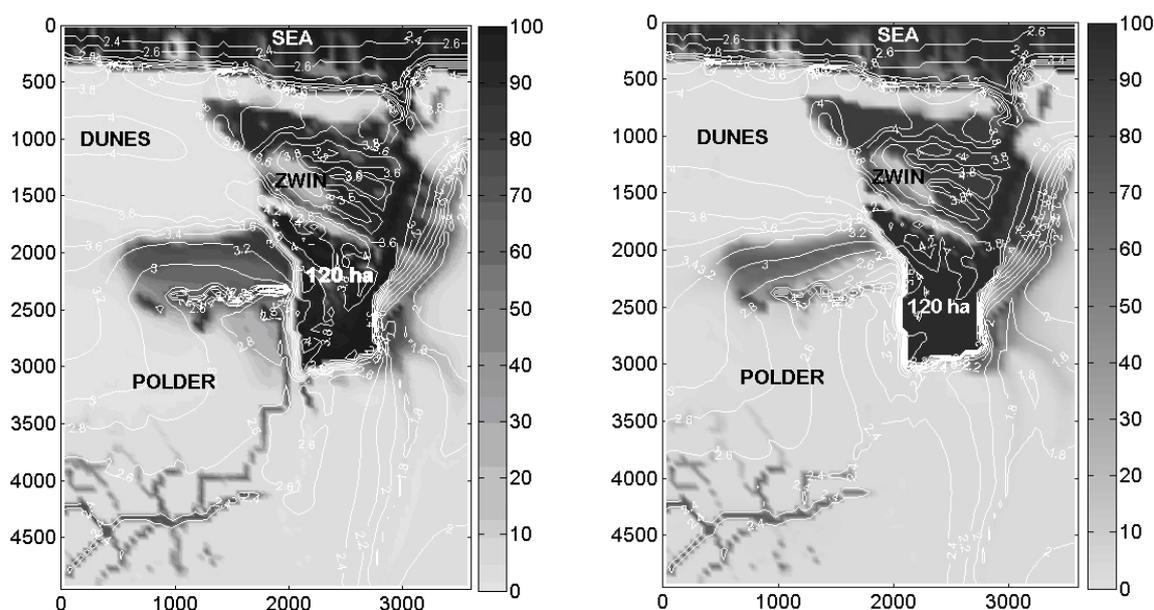

Figure 1. A) Fresh-salt water distribution just below the water table in present situation (white – 100% fresh, black- 100% salt). B) Fresh-salt water distribution just below the water table after 50 years.White contour lines are the freshwater heads in mTAW (=Belgian reference level, 0 mTAW equals 2.36 m below mean sea level).

Under the shore and the 'Zwin' salt water is present at surface level due to floods caused by the tide. The flow rate and the saltwater percentage of the water in the tidal flat area are strongly dependant on the surface level. With sea level rise the freshwater head will rise and the areas that are prone to flooding will increase. Within 50 years the tidal flat will become more saline. In the present situation the area southwest of the tidal flat is saline due to the salt water that recharges the Zwin inlet. In 50 years time this lateral expansion area will increase and the salt water percentage will increase. The drainage channels are saline and will become more saline in 50 years time.

Case 2: Expansion of the tidal flat area with 120 hectare and mitigation measure.

The main focus lies on the consequences of the expansion of the tidal flat area on the fresh-salt water distribution. The expansion can be executed in different ways. In this paper only one possibility is simulated. This simulated implementation plan for the expansion will not necessarily correspond with the execution plan which will be chosen in the future. In this simulation the tidal flat area is extended with 120 hectares by a 250m breach in the dike south of the Zwin and placing a threshold at 3.5 mTAW. Once this threshold is crossed by seawater there will be a continuous presence of saltwater in this expanded area and the water level will fluctuate between 3.5 mTAW and maximum sea level. The width and the level of this threshold have a crucial role in the further development of the expanded area. It will be the decisive factor whether there will be a small or large inflow of salt water flowing from the existing channel of the Zwin. Figure 2A shows the fresh-salt water distribution in the tidal flat and surrounding areas after 10 years expansion with 120 hectare. After 10 years salt water is present in the extended area and the area southwest of the Zwin influenced by salt water has enlarged due to the expansion. After 50 years water in de expansion area is more saline and the lateral zone of saline influence in the southwest has extended.

Figure 2. A) Fresh-salt water distribution just below the water table after 10 years expansion (white – 100% fresh, black- 100% salt). B) Fresh-salt water distribution just below the water table after 10 years mitigation of the expansion area. White contour lines are the freshwater heads in mTAW (mTAW=Belgian reference level, 0 mTAW equals 2.36 m below mean sea level).

The lateral expansion of the infiltrating salt water flowing from the 120 hectares to the surrounding areas can be mitigated by changing from shallow drainage to deep drainage as shown in figure 2B. In case of shallow drainage most fresh water will be taken away by a network of drainage pipes or channels from the upper part of the phreatic aquifer. In case of deep drainage the water is taken from the bottom part of the phreatic aquifer. This part of the aquifer is mainly filled with salt water thus the groundwater taken away is mainly salt water. The water can be extracted by means of a series of wells linked with a siphon to a suction well that has the requisite pumping capacity. These wells and siphon are situated at the foot of the surrounding dike of the expansion area. The extracted salt water can flow through a pipe of

limited length directly to a deeper lying part of the expansion area which has to be permanently flooded with salt water to ensure good water quality. In the long run this mitigating measure allows even the reduction of the present salt water seepage area.

DISCUSSION AND CONCLUSIONS

Today salinisation is already a fact to the west of the tidal flat due to lateral expansion of the salt water in the Zwin inlet. In the future, taking into account a sea level rise of 6 mm/y this salinized area will expand more laterally without any mitigation measures. In case of expansion of the tidal flat area with 120 hectare not only will this expansion area become more saline but also parts to the southwest of the Zwin. The main factor that regulates this area of 120 hectares affected by salinisation is the width and the level of the threshold that is constructed on the place where the dike is breached. The model illustrates that changing from superficial drainage to deep drainage is very effective to mitigate the salinisation of surrounding areas. This deep drainage will be a tool to reduce the lateral expansion of infiltrating salt water coming from the Zwin expansion area in the phreatic layer.

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