GeoStudio Example File
Tidal Water Exchange through Sand Embankment

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Introduction

Coastal wetland systems are studied in many areas of the world to understand the influence of tidal water fluctuations on groundwater regimes and nearby shallow waters, such as coastal wetlands, lagoons and creeks. The movement of solutes or seawater intrusions are also important aspects of understanding the tidal water exchange processes involved in coastal systems. The objective of this example is to illustrate the use of a Head vs Volume boundary condition to simulate the response of a wetland pond to tidal fluctuations across a sand embankment. The model domain has been designed based on a physical model developed by Ebrahimi et al. (2007).

Background

Ebrahimi et al. (2007) developed a physical model of a sand embankment with manual tidal fluctuations on one side and a scale model of a coastal wetland on the other side (Figure 1). A dye tracer was added along the sand embankment on the wetland side to understand the influence of the water exchange and solute transport through the sand embankment during tidal cycles. The sand material used by Ebrahimi et al. (2007) was reported to have an average hydraulic conductivity of approximately 1 x 10^{-3} m/sec and a specific yield of 29%.

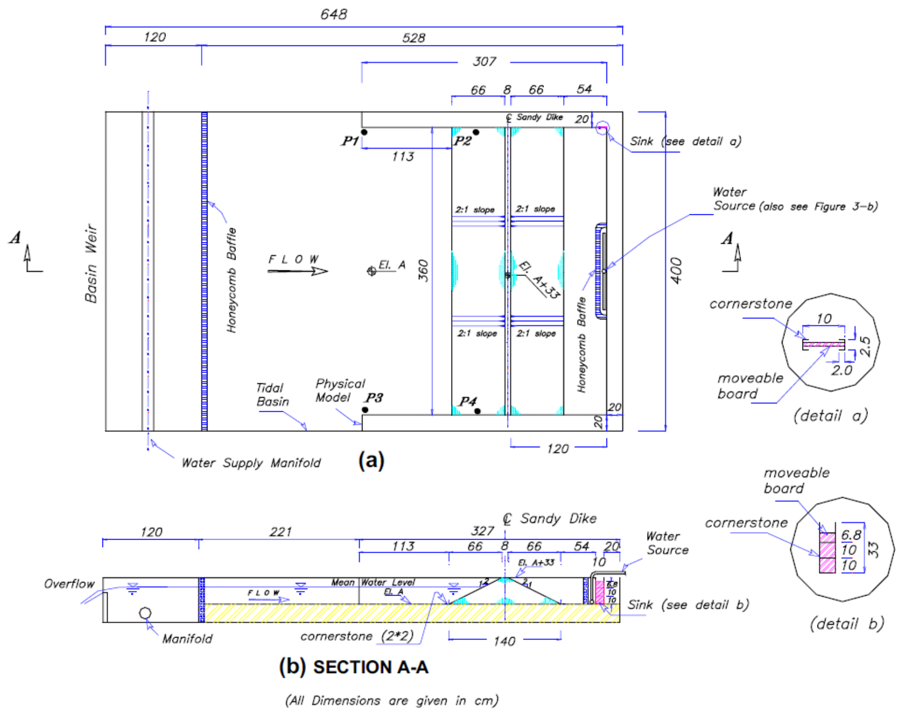

Figure 1. Physical model dimensions given by Ebrahimi et al. (2007).

Numerical Simulation

The cross-section from Ebrahimi et al. (2007) was used to develop the model domain of the sand embankment between the coast and wetland (Figure 2). The sand embankment is 0.33 m high with 2:1 side slopes and a total width of 1.4 m. The floor of the physical model was an impermeable material, but was modeled in the domain to simulate the required volume of water on either side of the embankment.

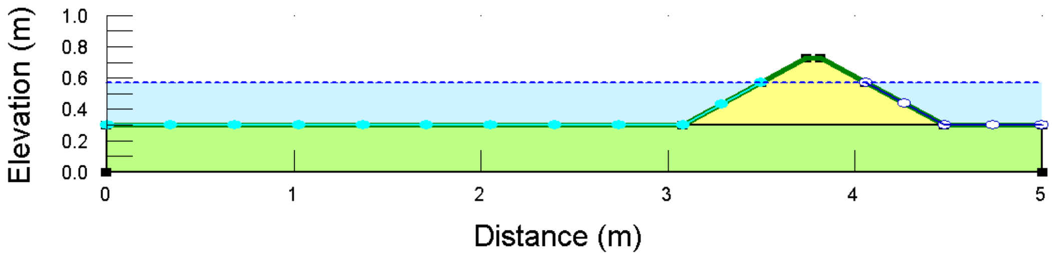

Figure 2. Problem configuration.

The impermeable floor of the physical model was defined using a Saturated Only material with a saturated hydraulic conductivity of 1 x 10^{-12} m/sec. The sand embankment material was defined using the saturated-unsaturated material model with a saturated water content of 0.3 and a coefficient of volume compressibility (m_v) of 1 x 10^{-5} /kPa (Figure 3). The saturated hydraulic conductivity was varied until a similar response as the physical model could be obtained. The final saturated hydraulic conductivity of the embankment was defined as 8 x 10^{-3} m/sec (Figure 4).

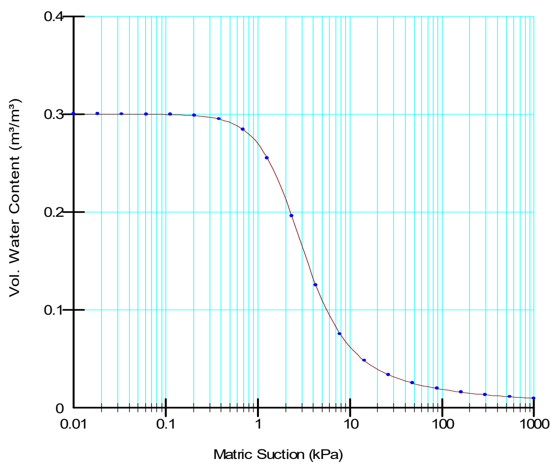

Figure 3. Volumetric water content function.

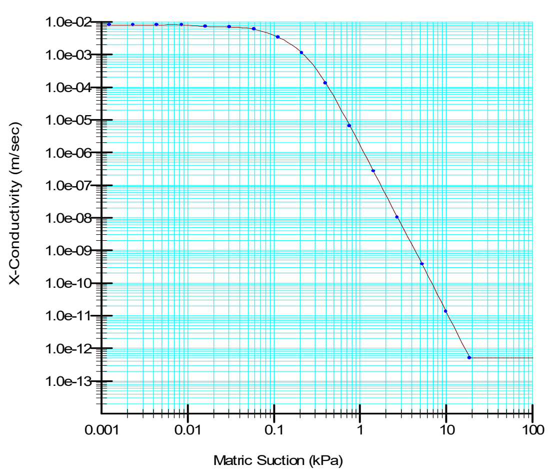

Figure 4. Hydraulic conductivity function.

The coastal waters were simulated using a head function with the tidal fluctuations reported as changes in total head with time (Figure 5). This boundary condition was applied to the coastal "floor" and the coastal side of the embankment up to a point representing the highest tidal water elevation. Although the tidal fluctuations were set to be $\pm$0.060 m from the mean water level (MWL) of 0.214 m with each cycle lasting 355 seconds, Ebrahimi et al. (2007) reported that the actual water fluctuations experienced on the coastal side of the embankment were +0.060 m and -0.056 m. The head function in SEEP/W was modified to incorporate this minor adjustment during low tide.

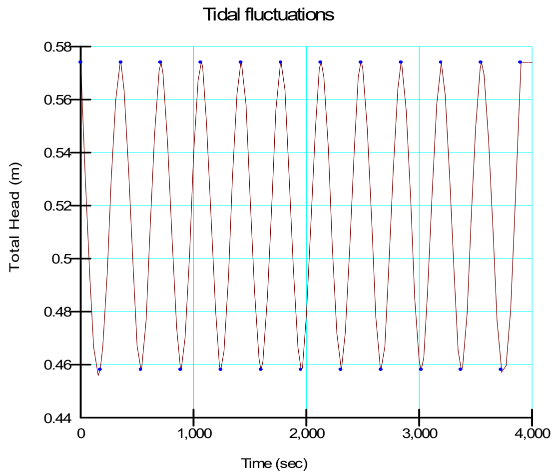

Figure 5. Total head verses time for the tidal boundary condition.

The wetland side of the embankment was simulated using the Head vs. Volume boundary condition, where the total head of the pond is calculated based on an internally generated head versus volume relationship (Figure 6). The water elevation of the pond is calculated based on the volume of water recharging or discharging along the boundary.

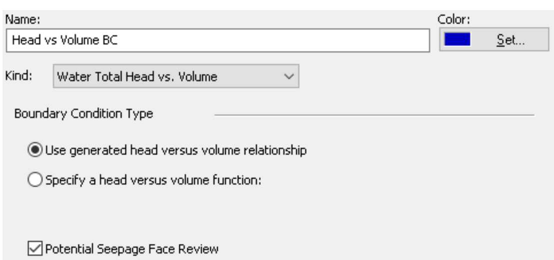

Figure 6. Automatic head vs. volume boundary condition option.

The initial water level is set to a total head of 0.574 m using a water table, which represents the mean water level (Figure 2). The total duration of the analysis is 3,550 seconds, or 59.2 minutes, with 60 time steps. The global element size is set to 0.1 m, with mesh refinement within the sand embankment set to a ratio of 50% of the global element size or 0.05 m (Figure 7).

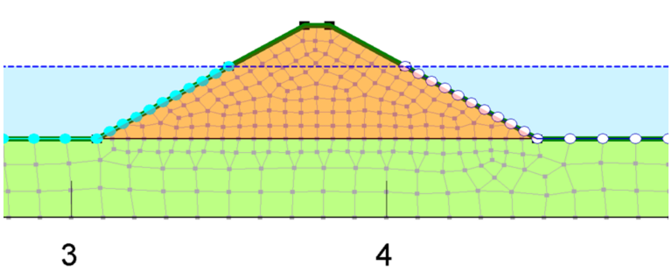

Figure 7. Mesh refinement within the sand embankment.

Results and Discussion

During each cycle of high or low tide, the wetland pond cycles between filling and draining cycles. Figure 8 shows a draining cycle that is experienced around 38.5 minutes, where the tide has reached the lowest level of approximately 0.46 m. The flux vectors show that water is being removed from the wetland side of the embankment, passing through the sand embankment and into the coastal water (right to left). When the tide rises back up to about 0.58 m, the flux vectors are reversed, indicating that water is flowing through the sand embankment and filling the wetland pond (Figure 9).

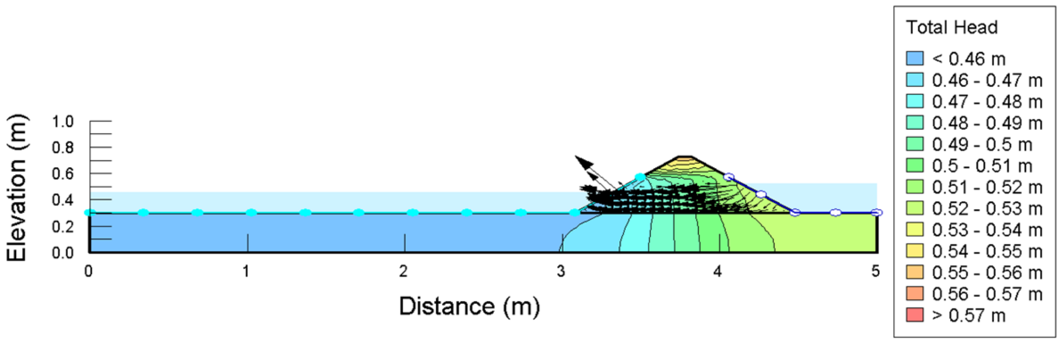

Figure 8. Total head contours and velocity vectors for low tide “draining” pond (38.5 minutes).

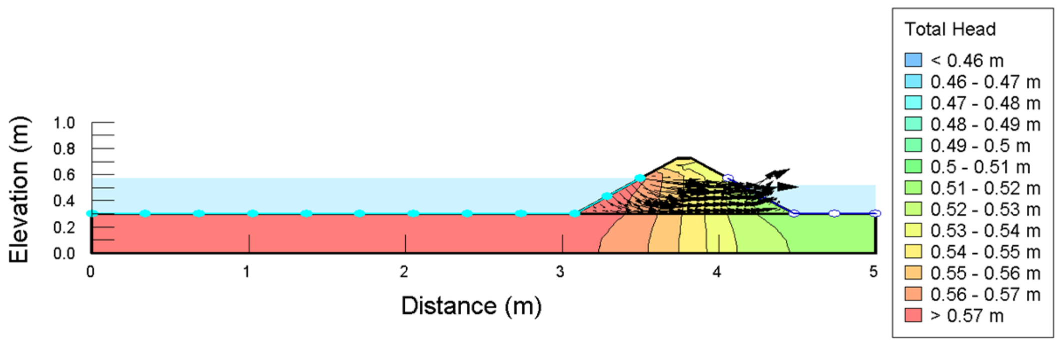

Figure 9. Total head contours and velocity vectors for high tide “filling” pond (59.2 minutes).

To further understand the response of the wetland, the coastal water fluctuations are compared to the modeled wetland total head relative to the MWL (Figure 10). The measured values taken from the physical model by Ebrahimi et al. (2007) are also added for comparison. The water level experienced in the wetland is naturally dependent on the total water volume passing through the sand embankment and filling or draining the pond. The Head vs. Volume boundary condition calculates the water level of the pond based on the water volume that is moving in or out of the soil domain along the pond boundaries. The delay in the high and low water levels experienced in the wetland pond is a direct result of the water volume moving through the sand prior to entering the wetland system. This is experienced both in the physical model by Ebrahimi et al. (2007) and the SEEP/W simulated water levels.

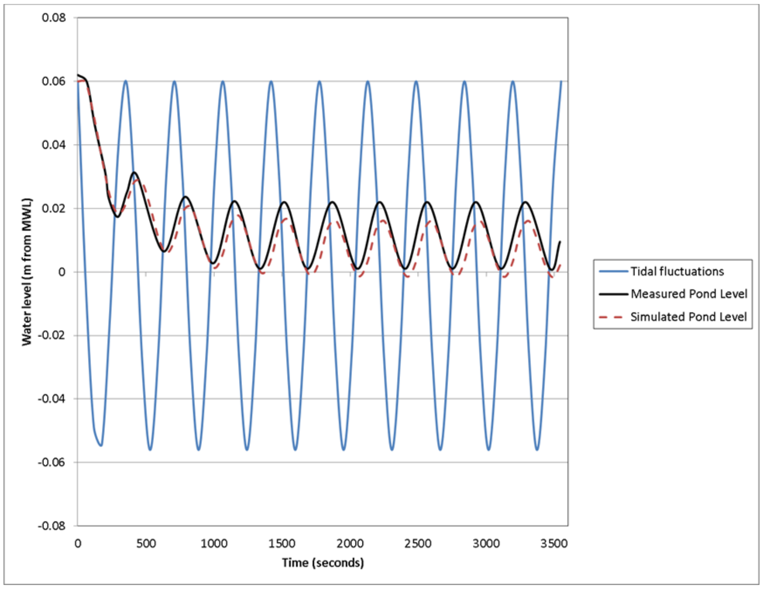

Figure 10. Simulated and measured pond water levels compared to tidal fluctuations around the MWL.

The Ebrahimi et al. (2007) results are only shown here to compare the overall response of the wetland water level. Exact material data on the sand embankment are not well defined, so the purpose of this example is not to match the physical model results exactly, but to show the response can be recreated in a water transfer analysis in GeoStudio using the Head vs. Volume boundary condition.

The rate of water entering and leaving the wetland and tidal side can be viewed using the Draw Graph option (Figure 11). The negative and positive values indicate discharge and recharge, respectively. At any point in time, a difference between the recharge and discharge rate implies a change in storage within the sand embankment.

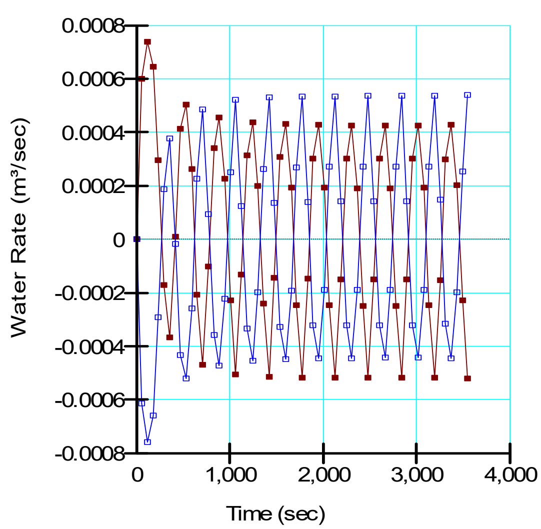

Figure 11. Water rate along the wetland and tidal boundaries during tidal cycles.

The cumulative water volume passing through the sand embankment across the wetland boundary is shown in Figure 12. The total head experienced in the wetland is also included to help explain what the cumulative water volume plot is illustrating. As the coastal tide is decreasing, water moves from the wetland to the tidal side, thus the cumulative water volume increases. When the tidal waters start to increase towards the end of the first cycle, water flows from the tidal side toward the wetland causing the cumulative volume to decrease. It can be seen that wetland response is delayed as storage in the embankment is filled.

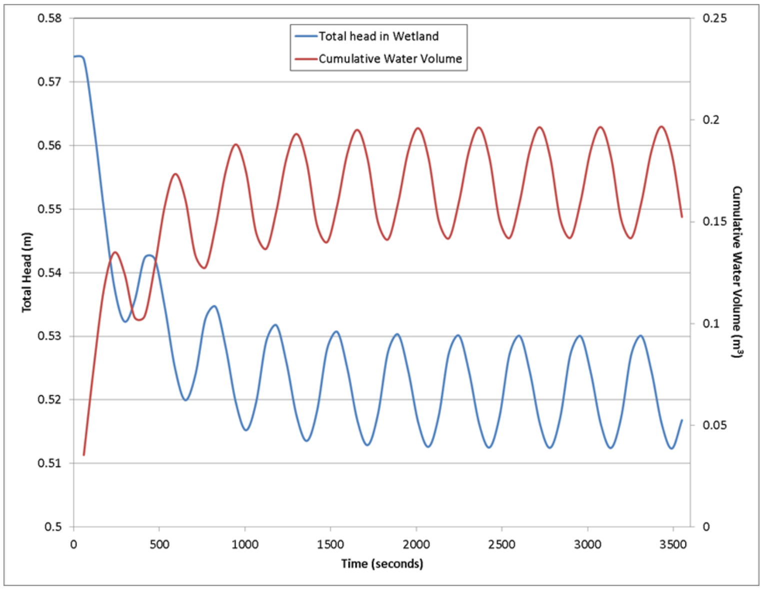

Figure 12. Cumulative water volume and total head along the wetland boundary.

Summary and Conclusions

The objective of this example was to illustrate the ability of the Head vs. Volume boundary condition to accurately simulate the response of a wetland pond to tidal fluctuations across a sand embankment. The results of the water transfer analysis are compared to actual measurements from a physical model developed by Ebrahimi et al. (2007). The use of the Head vs. Volume boundary condition allowed water to be moved to and from the wetland pond across the sand embankment in response to the rise and fall of the coastal tides. The delay in this rise and fall of the wetland pond is very similar to what is experienced in the physical model, as well as what would be expected in field conditions. This behavior occurs due to changes in water storage within the sand embankment in response to the changing water levels on either side.

References

Ebrahimi, K., Falconer, R.A. and Lin, B. 2007. Flow and solute fluxes in integrated wetland and coastal systems. Environmental Modelling & Software 22: 1337-1348.