Head versus Volume and Time

GEO-SLOPE International Ltd. | www.geo-slope.com

1200, 700 - 6th Ave SW, Calgary, AB, Canada T2P 0T8
Main: +1 403 269 2002 | Fax: +1 888 463 2239

Introduction

The objective of this example is to illustrate how SEEP/W can be used to simulate the filling and draining of a pond. The pond is near a hypothetical river that is undergoing seasonal changes in river water level height. The water from the rising river is allowed to pass through the soil and into the pond, causing the water level to rise, or vice versa. As the head in the pond is not known, and depends on the volume of water seeping out of or into the soil, a special type of boundary condition, called the Water Total Head vs. Volume boundary condition, is used. Two methods of using this boundary condition are introduced, with emphasis on the new automatic boundary condition functionality.

Numerical Simulation

The geometry of this example if over-simplified so that the key points are clearly illustrated. The model domain consists of a 20 m wide area that comprises a square river channel and a geometrically well-defined collection area, referred to as the pond (Figure 1). The pond can both collect water while the river is rising and supply water back to the river as the water level in the river declines.

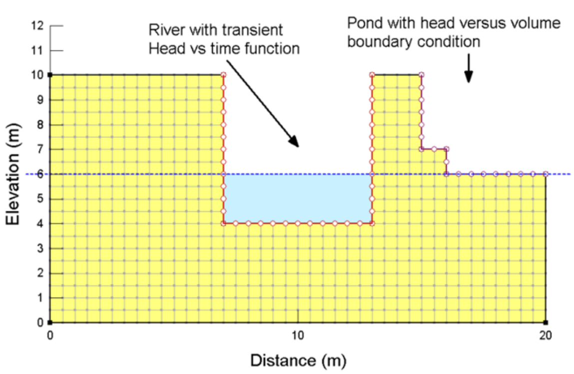

Figure 1. Problem configuration.

There are a total of four analyses in the file separated into two sets of two analyses, with each set having one analysis representing the river level rising and one with the river level declining. Each of the analyses has a simulation time of 150 days, for a total simulation of 300 days for each set. The time steps for all analyses increases exponentially with an initial time step of 6 hours (21,600 seconds) and a total of 30 time steps. The global element size was set to approximately 0.5 m for the entire region.

Only one material model was defined using the saturated/unsaturated model type. The volumetric water content function was defined using a saturated water content of 0.3 (Figure 2). The hydraulic conductivity function was defined with a saturated hydraulic conductivity of $1x10^{-6}$ m/sec (Figure 3). The initial water content for the filling analyses, also set as the Parent analyses, was defined as 6 m (blue dashed line in Figure 1). The initial pore-water pressure profile for the draining analyses was taken from the last time step of the filling analysis.

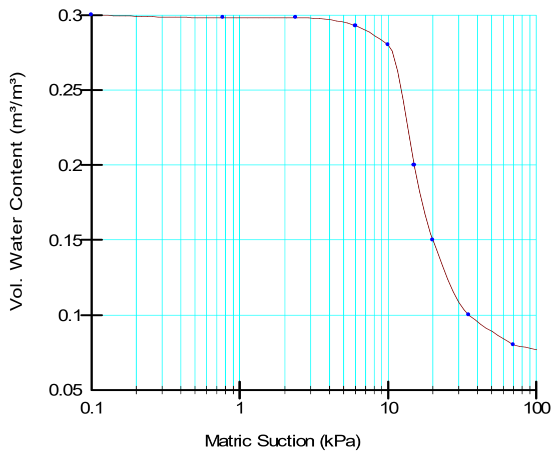

Figure 2. Volumetric water content function.

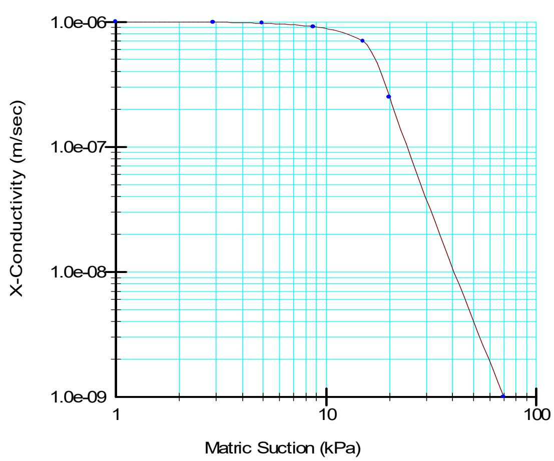

Figure 3. Hydraulic conductivity function.

The rising and falling of the river water level were simulated using the total head versus time functions, as shown in Figure 4 and Figure 5, respectively. The river is set to rise 4 m, to a total head of 10 m, over the initial 10 days and then remains at 10 m for the remaining duration of the initial analysis. Then, at the beginning of the draining analysis, the river level declines by 4 m to return to the initial 6 m total head for the remainder of the second analysis.

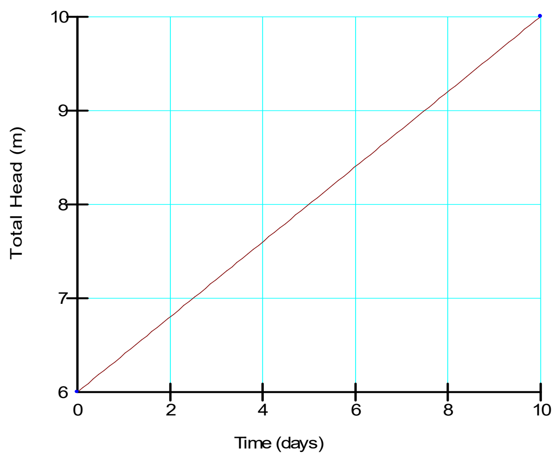

Figure 4. Total head versus time function used to define the rising river water level.

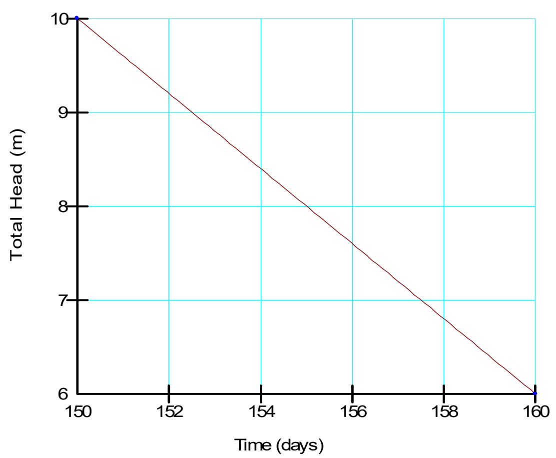

Figure 5. Total head versus time function used to define the declining river water level.

In previous versions of SEEP/W, the boundary condition representing the pond was defined using a head versus volume function (Figure 6). Here, the filling of the pond is represented by a relationship between the required volume of water leaving the soil at the specified pond boundaries to determine the total head level of the pond. The negative volume value is required, as the water must be leaving the domain for this head level to be reached. When the pond is draining, however, the relationship must use positive volumes, as the water is being returned to the domain from the pond. For example, when the pond is filling, the total head is 7 m when 4 m^3 of water has collected in the bottom portion of the pond (4 m x 1 m x 1 m) and 19 m³ when the total head has reached the full 10 m.

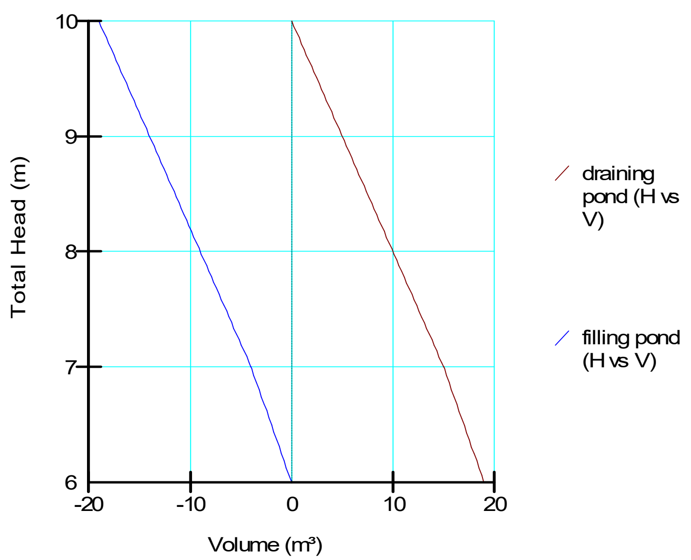

Figure 6. Head versus volume functions used in previous SEEP/W versions.

As a new feature, SEEP/W now has the option to use the Water Total Head vs. Volume boundary condition that uses a generated total head versus volume relationship that is calculated internally (Figure 7). By simply choosing this option as the boundary condition for both the filling and draining pond scenarios, the internal solver will determine the total head based on the total volume of water leaving or entering the domain along the pond boundaries.

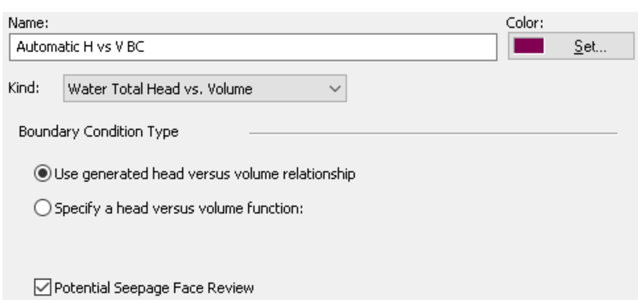

Figure 7. Automatic head vs. volume boundary condition option.

Results and Discussion

Given that the results of each set of analyses are identical, only the automatic head versus volume boundary condition results will be discussed. As the river water level rises, the water level within the pond begins to rise and water flows from the river, through the soil, and into the pond, until the pond water level matches that of the final river head (Figure 8). Then, as the river water level declines, the water from the pond begins to also drain, flowing through the soil and back into the river, until the lowered river head is extended across the soil profile (Figure 9).

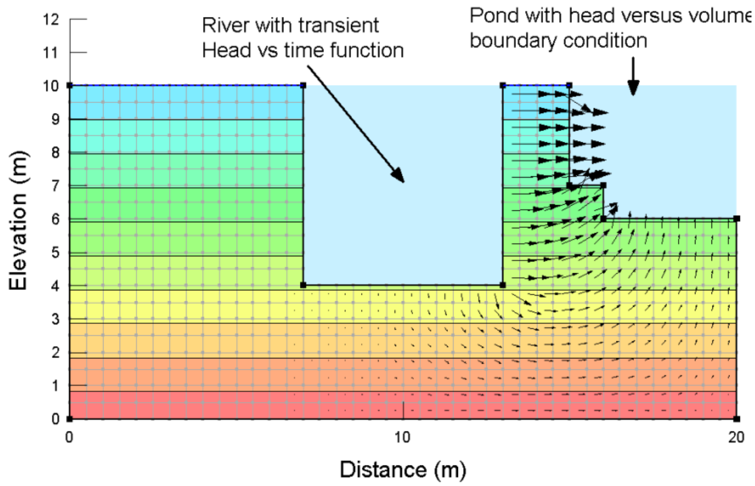

Figure 8. Resulting pore-water pressure contours and velocity vectors following the river filling.

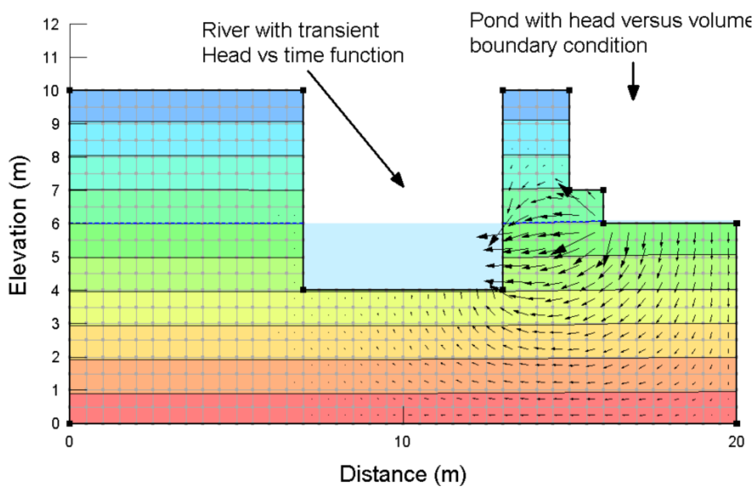

Figure 9. Resulting pore-water pressure contours and velocity vectors following the river draining.

To further understand what is happening in the analyses, the pond and river head profiles versus time can be graphed (Figure 10). The river head profile matches the filling and draining total head functions that were used as the boundary conditions. The pond head, however, is dependent on the volume of water that is seeping out of or into the soil volume. The Head vs. Volume boundary condition can set the head based on the volume of water flowing into or out of the soil to generate the appropriate pond water level. Naturally, there is a delay in the filling of the pond when compared to the river, as the pond does not reach the full water level of 10 m until day 150. By the end of the second analysis, the pond has still not reached the full draining water level that exists in the river.

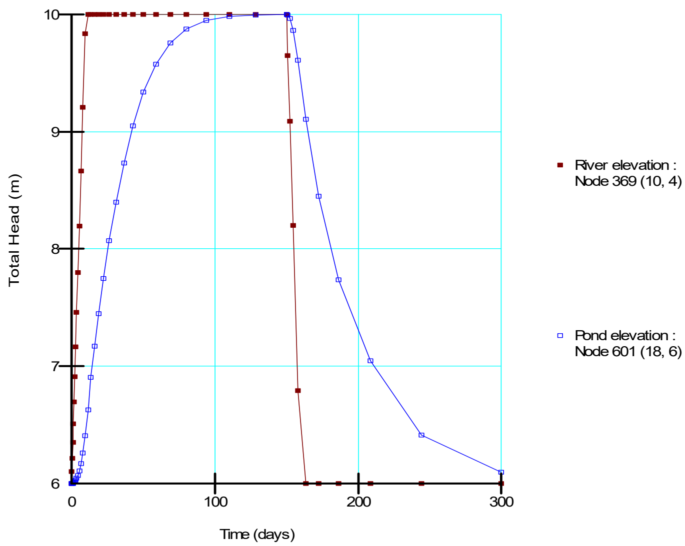

Figure 10. Total head versus time at the base of the river and pond.

Figure 11 shows the cumulative water volumes that flowed out of the soil domain and into the pond during the filling analysis, as well as cumulative volumes that flowed into the soil domain and out of the pond during the draining analysis. This graph was generated using all of the lines that represent the boundaries of the pond and using the "sum Y versus average X" graphing option; that is, sum the cumulative volume for all nodes and plot this value versus time at each saved time step. The cumulative volume out of the domain and into the pond reaches approximately -18.9 m^3 when the pond is full at 150 days. The second analysis excludes the results from the first analysis, forcing the graph to reset to 0 at the initiation of the second analysis. The cumulative volume then increases to approximately 18.7 m^3 after another 150 days, as the water flows back into the soil from the pond, and finally back into the river. The head of the pond declines accordingly with this gradual return of water into the domain (Figure 10).

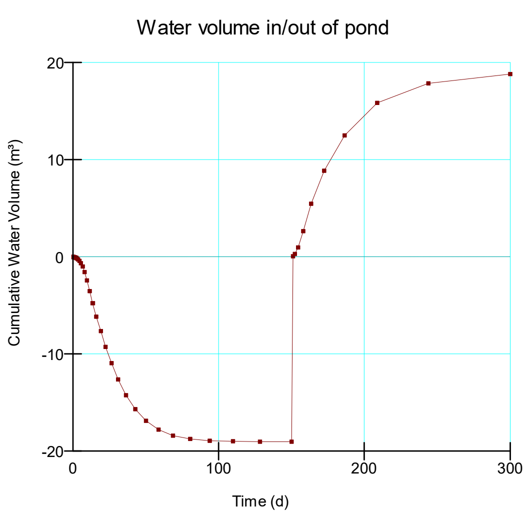

Figure 11. Cumulative water volume entering the pond versus time.

Summary and Conclusions

The objective of this example was to illustrate the ability of the Water Total Head vs. Volume boundary condition to accurately predict the changing total head of a pond based on the water volume passing through a soil as a nearby river undergoes seasonal changes in water level. The use of this boundary condition allows the user to see the cumulative water volume moving in and out of the soil domain to fill or drain the pond accordingly. The rising and falling head of the pond was delayed when compared to the rapid rise and fall of the river. This realistic behavior is based on the movement of the water through the soil, as well as the total area of the pond being simulated.