Relief Well Spacing

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Introduction

Relief wells are commonly installed on the downstream side of an earth dam to control the seepage along the downstream face of the dam, as well as the pore-water pressures within the dam (i.e. levee). A key design requirement for problems of this type is the required well spacing.

The plan view option in SEEP/W can be used to explore the relative effect of well spacing on the seepage and pore-water pressures within the earth dam. The term 'relative' is used here because the plan view simulation is not a true three-dimensional analysis. The plan view analysis is ideally used to simulate the flow in confined aquifers; however, the relief well scenario in this example lends itself reasonably well to this type of analysis if a simplifying assumption is made that the levee acts as a confining unit and the foundation soils act as an 'aquifer'. Consequently, the plan view simulation can provide some useful information at considerably less 'cost' in comparison to a true 3D analysis. This example demonstrates how the SEEP/W plan view analysis can be used for this purpose.

Numerical Simulation

The analysis considers a levee that is 25 m wide installed on top of a foundation that is 10 m thick (Figure 1). The levee is installed along the left side of the foundation, with a reservoir that has a constant total head of 13 m, assuming that the datum is located at the bottom of the foundation layer. A 50 m section of the levee is simulated, with a line added to the domain to represent the toe of the foundation. The "far-field" boundary is considered to be controlled by a natural stream at a total head of 7 m, which acts as a seepage outlet. For the purpose of this example, it is assumed that pumping within the relief wells maintains the water level at 7 m at the location of the relief wells; the same elevation as the water in the outlet gulley.

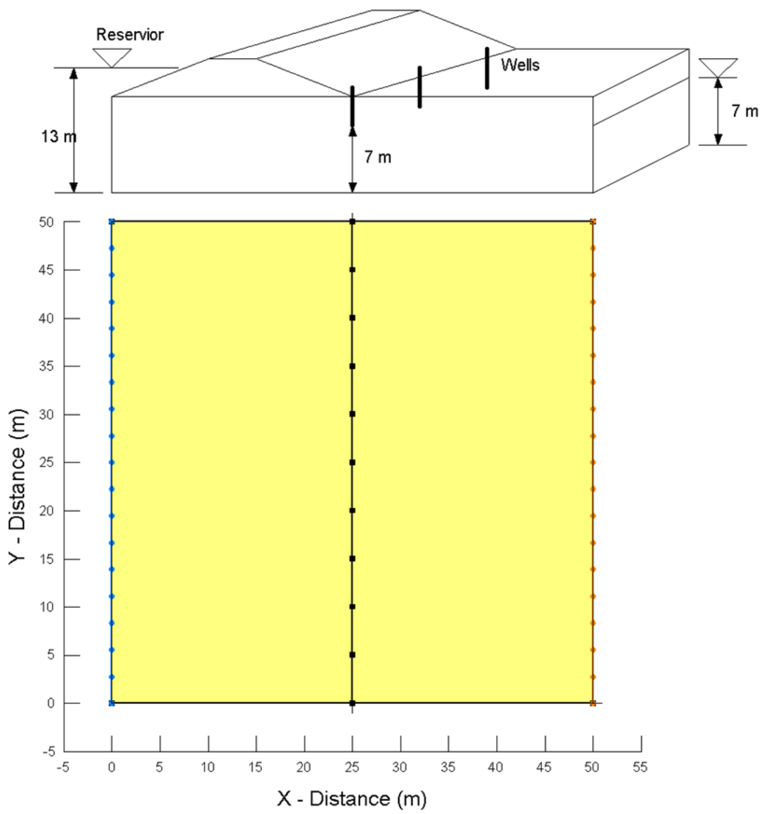

Figure 1. Problem schematic with SEEP/W plan view configuration.

Points have been added (using Draw Points) along the line to represent the location of relief wells along the toe of the levee. The mesh is generated along the line by ensuring the "Generate Mesh along Line" option is activated under the Draw Mesh Properties window with the line selected. A global element size of 1 m is defined for the mesh. As will be demonstrated, the points and the line segments are necessary for the specification of the boundary conditions.

To use the Plan view in SEEP/W, it is necessary to represent the original ground surface (i.e. before the levee was built) by specifying the x-y-z coordinates in a spatial function. The plan view option is selected using the Define Geometry Properties window. A Mesh Thickness Function must be created by going to Define > Spatial Functions > Mesh Thickness and defining the x-y-z coordinates (Figure 2). This spatial function must then be selected in the Define Geometry Properties window.

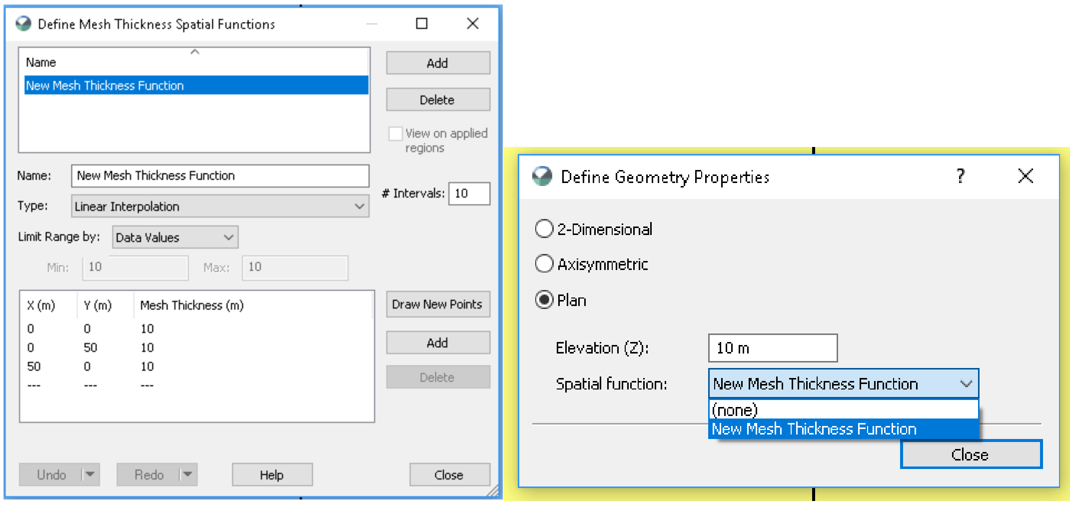

Figure 2. Plan view dialog box for mesh thickness generation.

Points #1 and #2 define the left side of the plan view mesh and correspond to the position on the upstream toe of the levee. Point #3 defines the lower-right corner of the plan view mesh and corresponds to the position along the stream. The z-coordinate is considered to be the elevation of the ground surface; that is, the top of the foundation layer. Clicking on the Generate button generates the appropriate thickness for all the elements in the mesh.

The reservoir is represented with a total head (H) boundary condition on the left boundary equal to 13 m. The water level in the outlet gulley is represented with a total head boundary condition of 7 m. There are 6 steady-state analyses in the Project (Figure 3). These analyses represent different scenarios to be investigated, including:

1. No wells, where the pore-water pressure conditions are simulated without the presence of relief wells along the toe of the levee;
2. Variably spaced relief wells, where the effect of the relief well spacing is explored, with well spacing of 50 m, 25 m, 10 m, and 5 m along the downstream toe; and
3. A drainage trench is considered, where the entire line along the downstream toe of the levee is assumed to remain at a total head of 7 m.

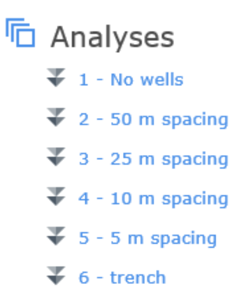

Figure 3. Analysis Tree for the Project.

It is important to recognize that, in a Plan view analysis, only the specified saturated conductivity is used. The foundation is assumed to remain fully saturated during a Plan View analysis. Therefore, the Saturated Only material model is used. For illustrative purposes, a saturated hydraulic conductivity of 1 m/d is used for the foundation in all analyses. A total head boundary condition of 7 m is used on the line or points being simulated as a trench or relief wells, based on the relief well spacing specified for the analysis, as described above.

Results and Discussion

The resulting steady-state total head contours for the analysis with no relief wells or trench included are shown in Figure 4. The total quantity of seepage through the foundation is 60 m^3/day, which can be viewed by creating a graph of the water rate using subdomains. A subdomain was created on both the left and right side of the line representing the toe of the levee (Figure 5). Given this initial analysis has no relief well or trench present, the total seepage is the same on both sides of the line.

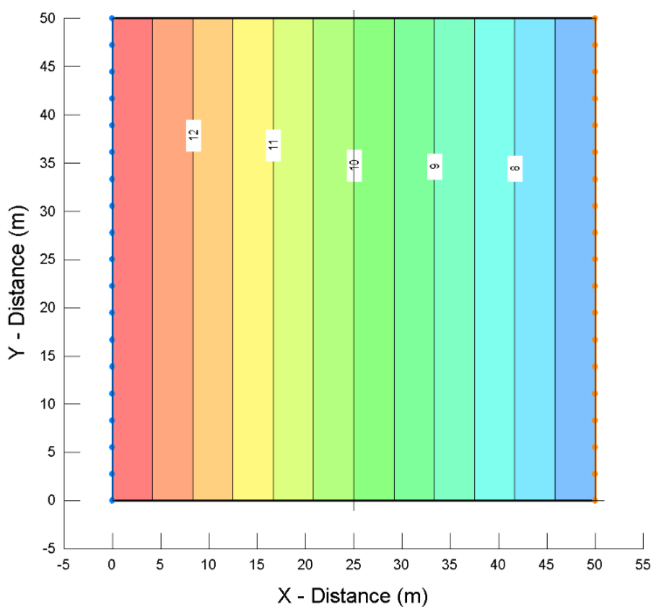

Figure 4. Flow situation with no wells.

The flux quantity (Q) can be verified by a simple calculation because the gradient and cross-sectional area of the foundation are constant:

$$Q = k\left(\frac{dH}{dl}\right)A = (1)\left(\frac{13-7}{50}\right)(50)(10) = 0.12(500) = 60\ m^3/day$$

Equation 1

The equal spacing of the contours in Figure 4 is reflective of the constant gradient.

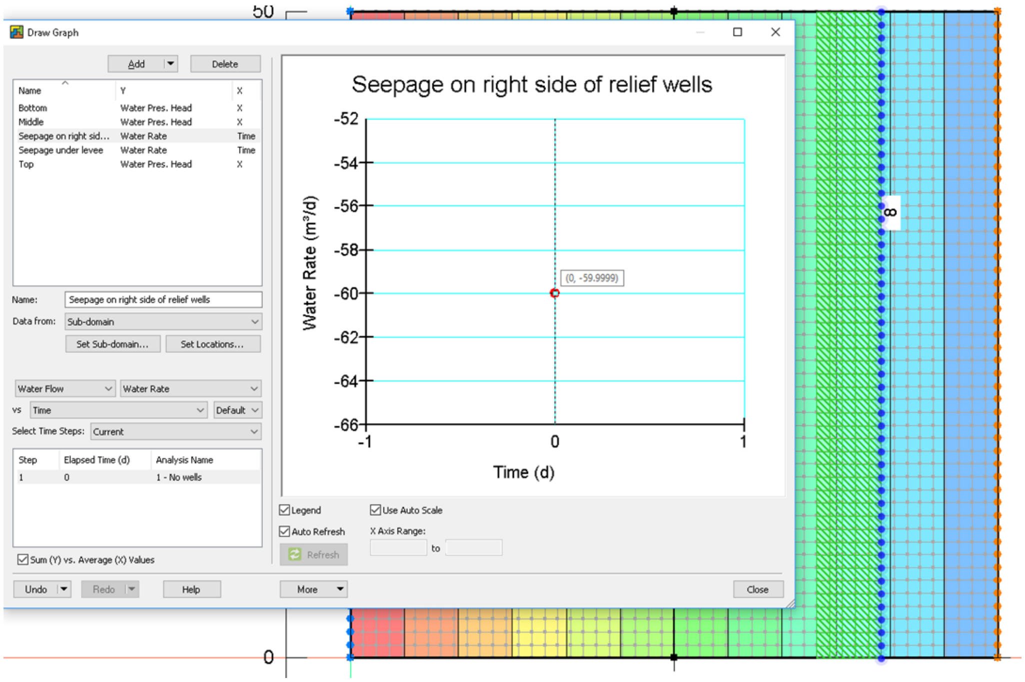

Figure 5. Total seepage graph with subdomain and node locations defined on right side of levee toe line.

The resulting total head contours for the varying relief well spacing of 50 m, 25 m, 10 m, and 5 m are shown in Figure 6, Figure 7, Figure 8, and Figure 9, respectively. The total seepage passing each of the subdomains under the levee and along the right side of the model domain are shown in Table 1 for each of the cases depicting varying relief well spacing.

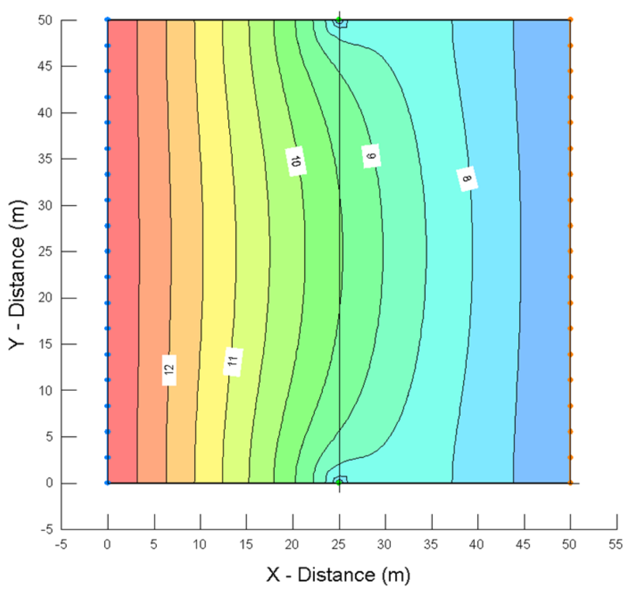

Figure 6. Flow with 50 m well spacing.

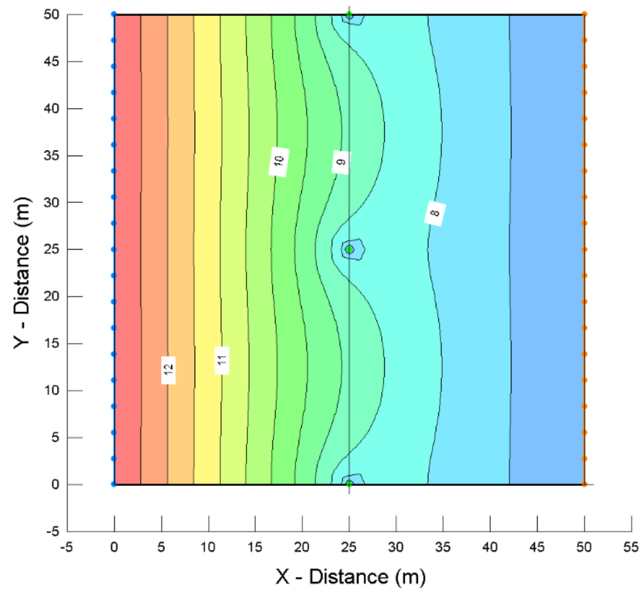

Figure 7. Flow with 25 m well spacing.

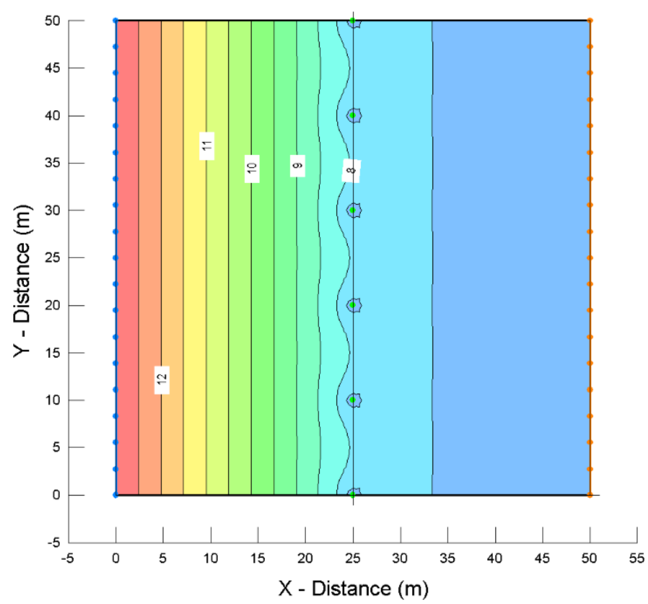

Figure 8. Flow with 10 m well spacing.

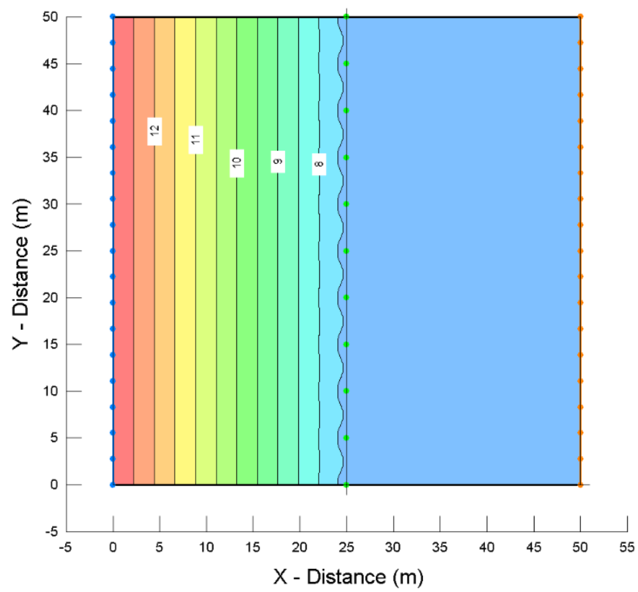

Figure 9. Flow with 5 m well spacing.

Table 1. Percentage of flow passing the relief wells at various well spacing.

Analysis	Spacing (m)	Seepage under Levee (m³/day)	Seepage on right side of Levee toe (m³/day)	Percent passing wells
2	50	76	44	37
3	25	88	32	27
4	10	105	15	13
5	5	113	7	6

The sum of the two seepage rates in each of the cases is 120 m^3/day. The difference between the two is the amount captured by the wells (Table 1). This can be verified by using the View Result Information command and clicking on the Point at the well. Figure 10 shows the View Result Information for Analysis 2, where 2 points are used to represent relief wells that are spaced 50 m apart. The water rate leaving at each of these wells is approximately 16 m^3/day to meet the defined total head of 7 m (the negative indicates water leaving the domain). The difference in seepage on the left and right side of the levee toe is 76 m – 44 m = 32 m, with each of the relief wells removing half of the seepage.

It is interesting to note that even a wide spacing between the relief wells has a significant impact on the amount of flow through the foundation. However, the pore-water pressure profile between the drains (along the top of the model) is hardly affected. Figure 11 shows the pore-water pressure for a profile through the drain at the top of the model and at the middle between two drains when the spacing is 50 m. Conversely, the pore-water pressure profiles along the drain and in between the drains are nearly identical when the spacing is 5 m, as shown in Figure 12 – the only difference is right at the well.

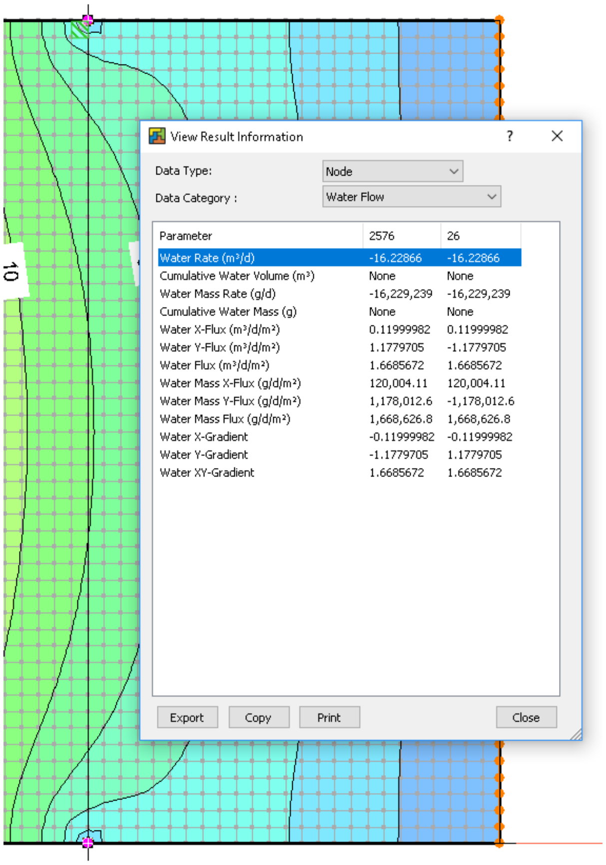

Figure 10. View Result Information for the points representing the relief wells in Analysis 2.

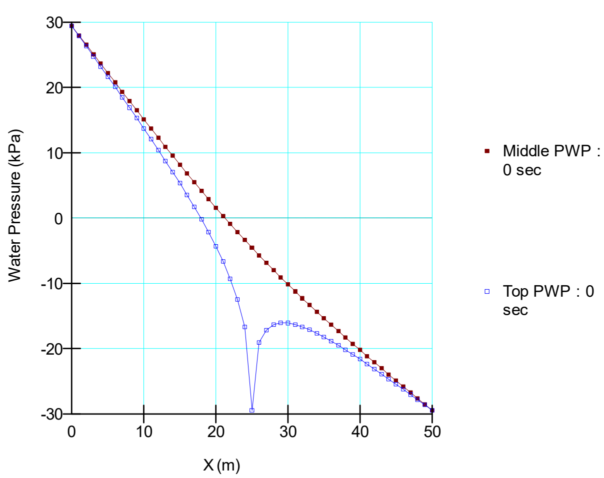

Figure 11. Pore-water pressure profiles with a 50 m spacing.

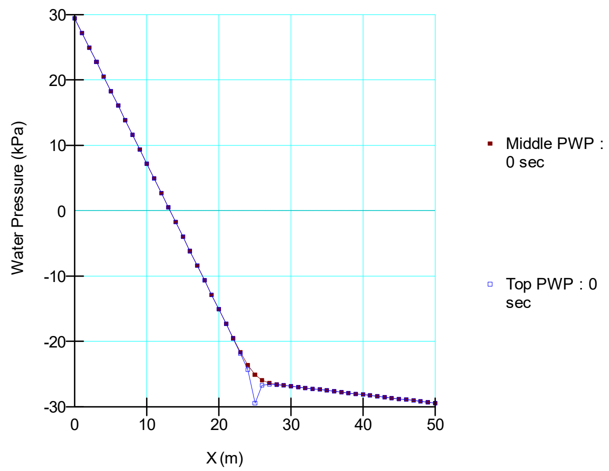

Figure 12. Pore-water pressure profiles with a 5 m spacing.

The installation of a free draining collection trench (analysis 6) would permit the water level to be maintained at an elevation of about 7 m. Essentially, the same flow system would develop if the wells were spaced closely. This analysis and Analysis 1 could both be simulated using a two-dimensional, cross-section analysis.

Figure 13 shows the resulting total head contours for the trench analysis. There is no flow beyond the trench, as indicated by the lack of head contours, for two reasons: 1) all of the seepage from the reservoir is collected by the trench; and 2) the water elevation in the trench is the same as the outlet gulley (i.e. there is no flow from the outlet gulley towards the trench).

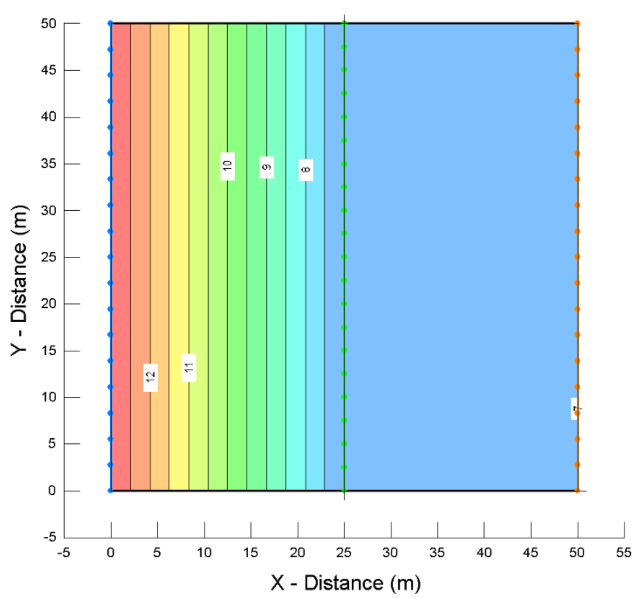

Figure 13. Flow with an open collection trench.

The total flow quantity is now twice the value reported previously because the gradient has doubled: (13- 7) / 25 = 0.24. It is interesting to note that by decreasing the well spacing or installing the trench, the total seepage under the levee increases.

Perhaps the most significant observation is that with a 5 m well spacing, the results are very close to the trench case. The implication is that a conventional 2D cross-section analysis would be a realistic representation of the actual conditions in the field for the 5 m well spacing or the trench scenario. Such a conventional 2D analysis could of course capture more of the complexity of a cross-section, such as flow through the levee itself. The results of the plan view analysis are best viewed as relative values for various spacing. Actual seepage quantities would be better represented by a conventional 2D analysis.

Summary and Conclusion

The plan view analysis in SEEP/W can be used to gain an understanding of conducting simple scenarios involving confined aquifers. This example illustrates one scenario in which the plan view option can be useful in understanding the influence of relief well spacing on the seepage under a levee or earth dam, as well as the influence on pore-water pressure profiles. It is important to note that the plan view option is not a true three-dimensional analysis, but relative results can be viewed.