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GROUNDWATER FLOW MODEL OF THE GENERAL SEPARATIONS AREA USING PORFLOW (U)

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PREPARED BY:
Gregory P. Flach[a]

[a]Westinghouse Savannah River Company LLC

Westinghouse Savannah River Company LLC
Savannah River Site
Aiken, SC 29808

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ACRONYMS

ACRi	Analytic & Computational Research, Incorporated
BC	boundary condition
FACT	Subsurface Flow and Contaminant Transport code
GSA	General Separations Area
LAW	Low Activity Waste
LLC	Limited Liability Company
PA	Performance Assessment
QA	Quality Assurance
SRS	Savannah River Site
TCCZ	Tan Clay Confining Zone
UTR	Upper Three Runs
V&V	verification and validation

ABBREVIATIONS

d	day
ft	feet
in	inches
K	hydraulic conductivity
msl	mean sea level
yr	year

1.0 INTRODUCTION

The E Area PA (McDowell-Boyer et al. 2000) includes a steady-state simulation of groundwater flow in the General Separations Area as a prerequisite for saturated zone contaminant transport analyses. The groundwater flow simulations are based on the FACT code (Hamm and Aleman 2000). The FACT-based GSA model was selected during preparation of the original PA to take advantage of an existing model developed for environmental restoration applications at the SRS (Flach and Harris 1997, 1999; Flach 1999). The existing GSA/FACT model was then slightly modified for PA use, as described in the PA document. FACT is a finite-element code utilizing deformed brick elements. Material properties are defined at element centers, and state variables such as hydraulic head are located at element vertices. The PORFLOW code (Analytic & Computational Research, Inc. 2000) was selected for performing saturated zone transport simulations of source zone radionuclides and their progeny. PORFLOW utilizes control volume discretization and the nodal point integration method, with all properties and state variables being defined at the center of an interior grid cell.

The groundwater flow calculation includes translating the Darcy velocity field computed by FACT into a form compatible for input to PORFLOW. The FACT velocity field is defined at element vertices, whereas PORFLOW requires flux across cell faces. For the present PA, PORFLOW cell face flux is computed in a two-step process. An initial face flux is computed from FACT as an average of the normal components of Darcy velocity at the four corners. The derived flux field approximately conserves mass, but not rigorously. Thus, the flux field is subsequently perturbed to force rigorous mass conservation on a cell-by-cell basis. The undocumented process used is non-unique and can introduce significant artifacts into the final flux field.

Another issue with using both FACT and PORFLOW for saturated modeling is the different mesh numbering systems used by the two codes. Both codes share the identical mesh, but the (I,J,K) element/cell numbering indices differ by one. The different numbering scheme has lead to errors in defining source zones.

The GSA groundwater model will soon be updated to reflect characterization and monitoring data acquired since the original development to support the Saltstone PA revision. The decision was made to also migrate from FACT to PORFLOW for groundwater flow simulations. The motivation is to consolidate all flow and transport analyses to a single software product, and avoid technical issues related to code differences, such as those discussed above.

This report describes how the FACT-based GSA flow model described in the PA has been converted to PORFLOW 5.95.0 (03 MAR 2004), the latest version available to Westinghouse Savannah River Company LLC under license from ACRi. Verification and validation testing pertaining to the new GSA/PORFLOW groundwater flow model following the PORFLOW Software QA Plan (Collard 2002) is also described.

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2.0 MIGRATION FROM FACT TO PORFLOW

In migrating the existing GSA/FACT groundwater flow model to PORFLOW, the main objective was to effect only a change of simulation software. To this end, the original characterization and monitoring datasets, pre-processing algorithms, and model calibration strategies were retained largely intact. Nevertheless, differences between the two codes lead to notable exceptions which are described in the sections below. Flach and Harris (1999), Flach (1999) and the PA (McDowell-Boyer et al. 2000) provide additional information about the baseline GSA/FACT model.

2.1 Computational Mesh

The computational mesh used with FACT conforms to the ground surface as shown in Figure 2-1a. Note that model layers are not truncated by the ground surface, but rather become thin and follow the ground surface beyond outcrops. The resulting mesh contains significantly distorted grid cells. FACT is capable of accurately representing the velocity field, despite element distortion, when the Gaussian quadrature option is used (Hamm and Aleman 2000). However, distorted grid cells are undesirable for PORFLOW, and thin grid cells can lead to severe time step constraints due to high cell Courant numbers when simulating contaminant transport.

Therefore, the logic for constructing the computational mesh was modified for PORFLOW to truncate mesh layers at the ground surface. Also, the mesh layers above the tan clay confining zone are non-uniformly distributed between the TCCZ and an elevation of 325 ft msl, rather than uniformly distributed between the TCCZ and ground surface in GSA/FACT. A cross-section of the GSA/PORFLOW mesh, comparable to Figure 2-1a, is shown in Figure 2-1b. Note that the layering below the tan clay confining zone is essentially the same between the two models. In E Area, the water table occurs just above the tan clay confining zone. To approximately preserve the vertical mesh resolution of the GSA/FACT model in the saturated zone between the water table and tan clay, a non-uniform distribution of layers is used in the PORFLOW grid.

The meshes are identical in plan view, with a nominal spacing of 200 ft square (Figure 2-2). Figure 2-3 provides a perspective view of the entire PORFLOW mesh looking toward the northeast in the SRS coordinate system.

2.2 Boundary Conditions

Four types of boundary conditions are used in the GSA/FACT model as depicted in Figure 2-2: prescribed head, general head, combined recharge and drain, and no flow. From a physical perspective, the same boundary conditions are effectively applied in the GSA/PORFLOW model, with a few exceptions:

1. The maximum recharge rate has been increased from 18 in/yr in the GSA/FACT model to 19 in/yr in the GSA/PORFLOW model, for reasons discussed further in section 2.5 on model recalibration.
2. Recharge/drain BCs are applied over the entire top of the mesh in the GSA/FACT model, including areas also receiving general head BCs. Implementation of two BCs at the same location was an apparent oversight. For the GSA/PORFLOW model, only one BC is allowed at a cell face.
3. The independent variable in the recharge/drain BC is defined to be pressure head ($\psi = p/\rho g = h - z$) in FACT. For the GSA/PORFLOW model, the independent variable is chosen as the product of pressure head and a normalized vertical conductivity at the face,

$$\psi' = \psi \frac{K_v}{K_{ref}} \qquad \text{(Eq. 2-1)}$$

where K_{ref} is set to 1 ft/d. The functional form of the recharge/drain BC is shown in Figure 2-4 for reference. The modification was made to mitigate numerical convergence issues described in section 2.4, and has little effect on the hydraulic head computed at the boundary face from a physical perspective.

4. Low permeability caps are represented in the GSA/FACT model by setting the conductivity in the uppermost grid layer to a very low value. In the GSA/PORFLOW model, caps are ignored as being unimportant to regional groundwater flow. Thus, material properties just beneath the surface are unaltered and the recharge rate is the same as adjacent areas (Figure 2-4). This modification also alleviates numerical difficulties caused by the presence of a very low permeability surface elements.

5. The general head BC applied to an area described as the "H-area recharge polygon" in Flach and Harris (1999, Figure 18) has been omitted, for reasons discussed in section 2.5 on model recalibration.

Although the boundary conditions are physically very similar between the two models, implementation differs somewhat to accommodate mesh and code differences. In FACT boundary conditions are applied to element vertices, whereas in PORFLOW boundary conditions are applied to cell faces. FACT boundary conditions are translated into PORFLOW boundary conditions using the following logic:

1. Prescribed head boundary conditions defined at boundary cell vertices in the GSA/FACT model are first identified. Boundary faces having 3 or more prescribed head boundary conditions at corners in GSA/FACT receive a prescribed head BC in the GSA/PORFLOW model. The value prescribed on the face is the average of the head values prescribed at vertices. Boundary faces of any orientation (x-, x+, y-, y+, z-, z+) are eligible to receive a prescribed head BC.

2. General head boundary conditions are applied in a similar manner, except that only horizontal faces (z- or z+) are considered and any existing prescribed head BC takes precedence over a general head BC.

3. Recharge/drain boundary conditions are applied in a similar manner, except that only ground surface faces (z+ orientation) are eligible and the preceding 2 BCs take precedence. The PORFLOW code does not have an explicit recharge/drain BC option. However, the concept can be implemented using the prescribed flux BC, with flux being set to a certain function of pressure head at the boundary face. Further information is provided in section 2.4.

4. No flow boundary conditions are applied to all remaining boundary faces.

Figure 2-5 illustrates some of the boundary conditions resulting from the above logic.

The greatest difference in boundary condition implementation occurs at the top of each model. In the GSA/FACT model, the top of the mesh smoothly conforms to the ground surface (Figure 2-1a) and each element vertex receives a recharge/drain boundary condition. In the GSA/PORFLOW model, layers crop out at the ground surface producing a stair-step effect (Figure 2-1b). The horizontal z+ faces receive a recharge/drain or general head BC, and all vertical faces receive a no flow boundary condition (Figure 2-5).

2.3 Material Properties

The algorithm for defining the initial PORFLOW model hydraulic conductivity field is unaltered from that used previously for FACT. However, the three-dimensional K fields for the two models differ due to differences in the grids used (Figure 2-1), and how the respective numerical algorithms use cell properties. In the GSA/PORFLOW, geometric averaging of properties at cell faces was chosen. Differences in the initial K field occur primarily in the volume above the tan clay confining zone. The initial K field in both models was subsequently modified during model calibration to field data. These modifications differ somewhat between FACT and PORFLOW, as discussed in section 2.5, and introduce further differences in the final K fields. Figure 2-6 shows a typical cross-section through the final K field in both models. The fields are similar, but clearly not identical. Additional information about the calibrated GSA/PORFLOW K fields is provided in section 3.0 on model results.

Although the primary focus of the GSA/PORFLOW model is saturated flow beneath the water table, the vadose zone is included in the mesh. Therefore, soil characteristic curves are needed to simulate flow in unsaturated zones. A common practice in this circumstance is to specify "pseudo-soil" characteristic curves that exhibit less non-linearity than actual soil curves. The main function of the vadose zone becomes transfer of water from the ground surface to the water table under steady conditions. Saturations and pressure heads computed in the vadose zone should be largely ignored. The pseudo-soil functions adopted for the GSA/PORFLOW model are depicted in Figure 2-7, and differ somewhat from the GSA/FACT model. The primary modification was to reduce the thickness of the simulated capillary fringe to increase the downward component of vadose zone flows near the water table.

A single set of soil characteristic curves is used in GSA/PORFLOW irrespective of actual soil type. For consistency and to avoid significant lateral flows in unsaturated zones, the saturated hydraulic conductivity field was made uniform in unsaturated zones. Specifically, horizontal and vertical conductivities of cells with a computed saturation less than 90% are set to 0.1 ft/d. The latter value was somewhat arbitrarily chosen to represent average conditions. The homogeneous and isotropic nature of the K field ensures that moisture movement in the vadose zone is vertically downward for practical purposes. The action produces a similar effect to setting the "`pkrz`" parameter to 1.0 in the FACT code. Figure 2-8 shows simulated velocity at the same cross-section through the GSA/PORFLOW mesh as depicted in earlier figures. Note that above the computed water table, the vectors are predominantly downward, as desired.

Prior to setting K to 0.1 ft/d, significant lateral flows were observed above the water table. This was believed to be an artifact of anisotropy in the K field for saturated conditions, coupled with a homogeneous relative permeability. Anisotropy in the saturated K field was present at the mesh scale (cell horizontal K >> vertical K), and at larger scales due to a heterogeneous conductivity field that represented strata. The same degree of anisotropy was thus present in the unsaturated K field because the relative permeability curve was identical throughout the mesh. A slight horizontal head gradient produced large horizontal flows. In reality, relative permeability fields for coarse and fine-grained sediments tend to crossover at a certain water saturation. At a sufficiently low saturation, a coarse-grained material will have lower permeability than a fine-grained. This counteracts the anisotropy present under saturated conditions and leads to largely vertical flow in response to a largely vertical gradient.

2.4 Implementation of Recharge/Drain BC

In FACT, the recharge/drain concept is implemented as a kind of mixed (Cauchy) boundary condition, similar to the "general head" and "drain" BCs. Non-linear equations representing the recharge/drain BC at various nodes are included in the overall system of equations being solved at each numerical step. Thus, pressure heads at a recharge/drain BC nodes are solved implicitly with other unknown (e.g. interior) pressures.

PORFLOW includes a mixed boundary condition equivalent to the "general head" BC in FACT, but does not offer a recharge/drain BC option. An initial attempt to implement the recharge/drain concept using a prescribed flux BC, with flux defined to be the function of pressure head shown in Figure 2-4, proved numerically unstable. PORFLOW performs the boundary pressure head and flux calculations in between time steps in an explicit manner. Apparently the recharge/drain equation was not sufficiently coupled to the system of other equations being solved simultaneously.

To mitigate numerical instability, an under-relaxation scheme was implemented. The basic idea of under-relaxation is to dampen the perturbations in boundary pressure that would otherwise occur. Although the calculation is still explicit, under-relaxation produces adequate numerical stability. The precise calculation sequence used in the GSA/PORFLOW model is

1. At the beginning of step n, set the boundary flux at a recharge/drain BC based on the pressure head from the previous step (cf. Figure 2-4)

$$q_n = q(\psi'_{n-1}) \quad \text{(Eq. 2-2)}$$

2. Solve the non-linear system of equations for pressure head at the center of the grid cell with a recharge/drain BC, ψ_n^I.

3. Compute a preliminary new boundary pressure head, $\tilde{\psi}_n$, using Darcy's law

$$q_n = -K_v \frac{\tilde{\psi}_n - \psi_n^I}{z - z^I} \quad \text{(Eq. 2-3)}$$

4. Set the final boundary pressure using under-relaxation, where $0 < \omega < 1$

$$\psi_n = \psi_{n-1} + \omega\left(\tilde{\psi}_n - \psi_{n-1}\right) \quad \text{(Eq. 2-4)}$$

5. Compute the pressure head and conductivity product

$$\psi'_n = \psi_n \frac{K_v}{K_{ref}} \quad \text{(Eq. 2-5)}$$

The under-relaxation parameter should be set to roughly 0.5 when the flow field is undergoing a transient, and then be reduced as steady-state conditions are approached. Under the latter conditions, values in the range $0.01 < \omega < 0.1$ are effective at dampening numerical instabilities.

2.5 Model Recalibration

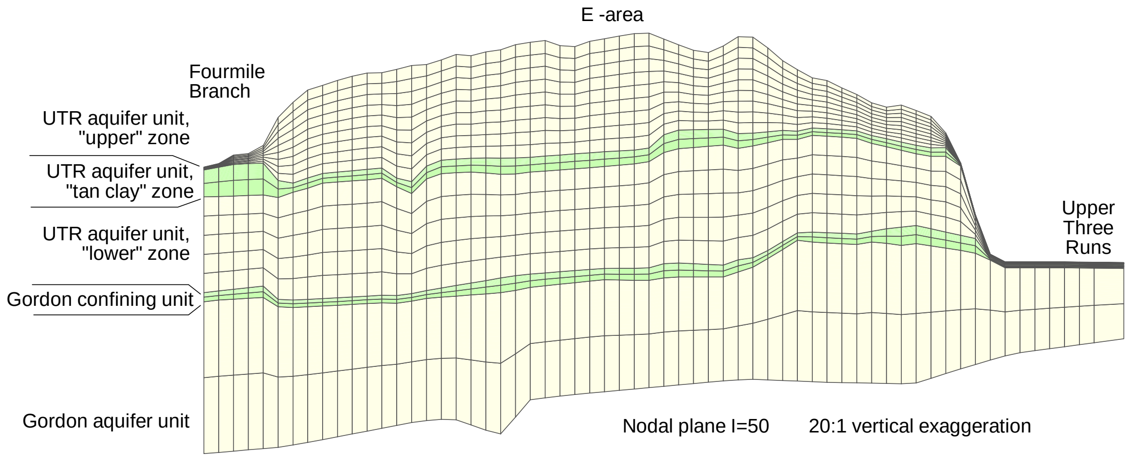
During calibration of the original GSA/FACT model, recharge was increased over H-area to produce simulated heads observed in the field (Flach and Harris, 1999, p. 21). Increased recharge was based on speculation that process water leaks produced an artificial source of recharge in H-area. Presently, high well water levels are believed to be the result of a low permeability confining zone beneath part of H-area, and perhaps lower horizontal conductivity. Therefore, supplemental recharge in H-area was omitted in the GSA/PORFLOW model. Instead, conductivities around H-area were adjusted downward during recalibration to match measured well levels.

After preliminary adjustments to the GSA/PORFLOW conductivity fields to match hydraulic head targets, particle tracking simulations were performed for both models in order to compare groundwater travel times. GSA/PORFLOW travel times were generally longer than those for GSA/FACT. To better match travel times and subsequent transport simulations, the maximum recharge rate in the recharge/drain BC was increased from 18 in/yr in GSA/FACT to 19 in/yr in GSA/PORFLOW. As an additional although minor step, capped areas were ignored.

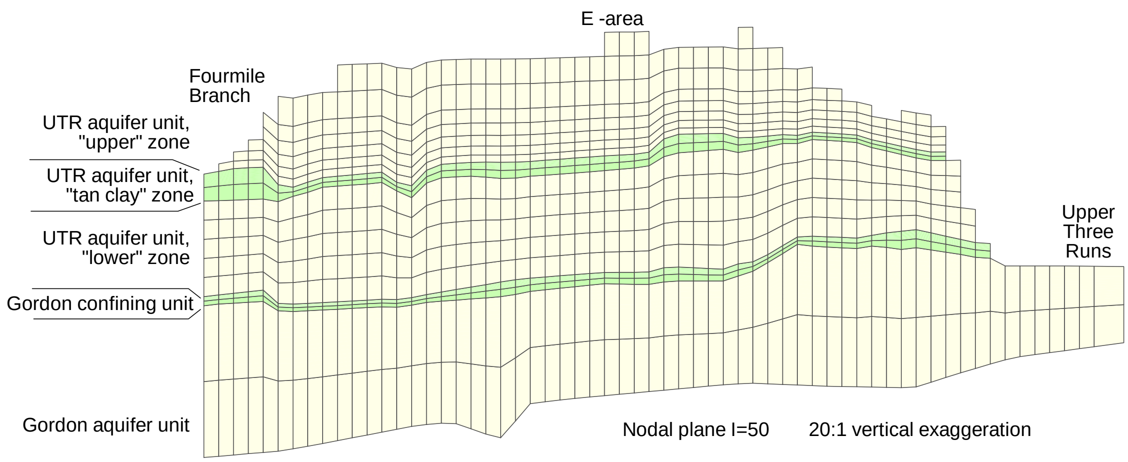
Relative to the GSA/FACT model, the modifications needed to GSA/PORFLOW achieve similar calibration results included

1. Increasing horizontal K in the upper aquifer zone by 25%
2. Decreasing vertical K in the tan clay confining zone by 50%
3. Increasing horizontal K in the lower aquifer zone by about 35%.

A few more minor changes were also made (see the "`./MatProp/Cal.dat`" files for each model for a precise comparison). Changes to the K field were larger than anticipated and probably reflect geometric averaging at cell faces in PORFLOW versus the corresponding logic used in FACT.



(a)



(b)

Figure 2-1. Cross-sectional view of computational mesh for (a) FACT, and (b) PORFLOW.

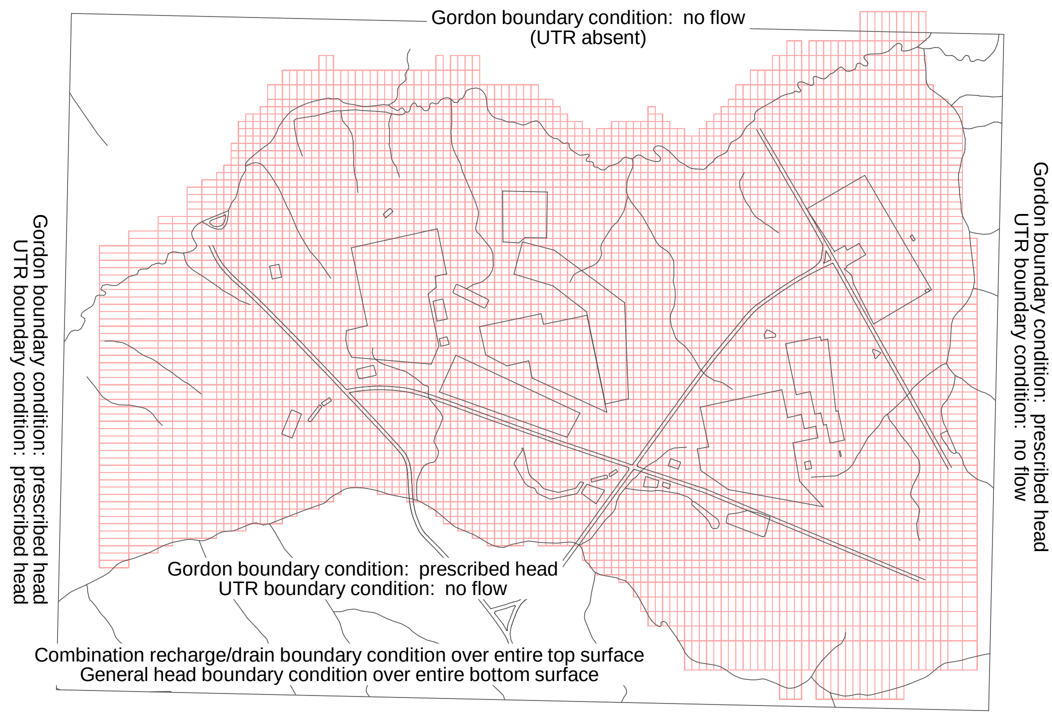


Figure 2-2. Plan view of GSA/FACT and GSA/PORFLOW computational meshes.

Figure 2-3. Perspective view of GSA/PORFLOW computational mesh.

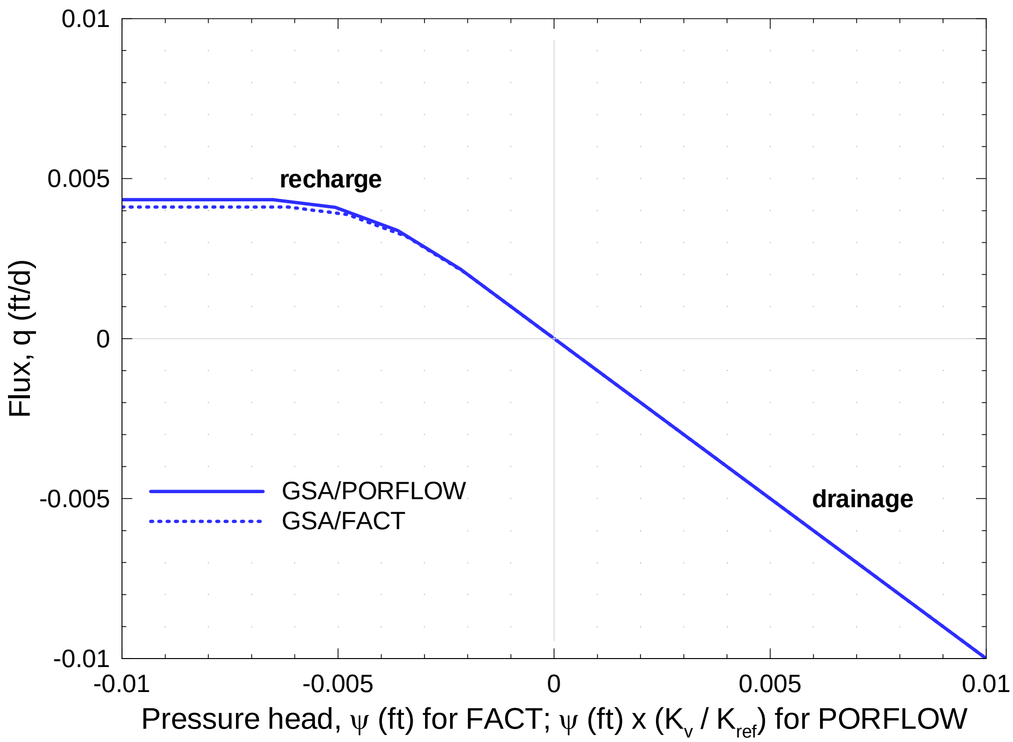
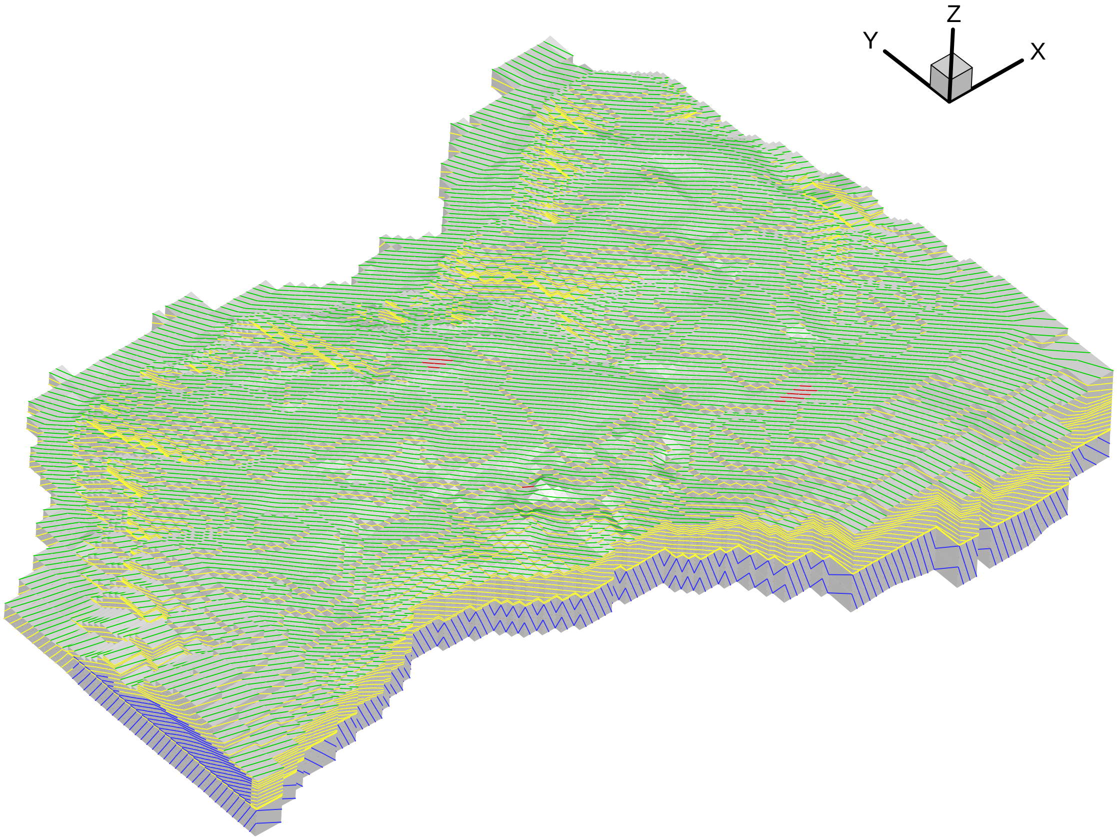
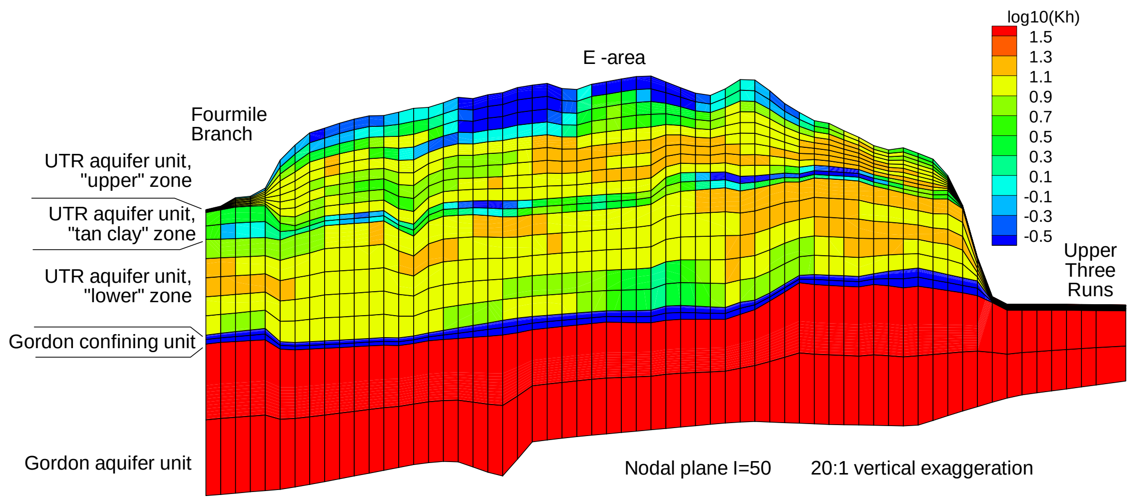


Figure 2-4. Combined recharge and drain boundary condition used in GSA/FACT and GSA/PORFLOW models.



Cross-hatching key
blue = prescribed head
red = general head
green = recharge/drain
yellow = no flow

Figure 2-5. Boundary conditions applied to GSA/PORFLOW computational mesh.



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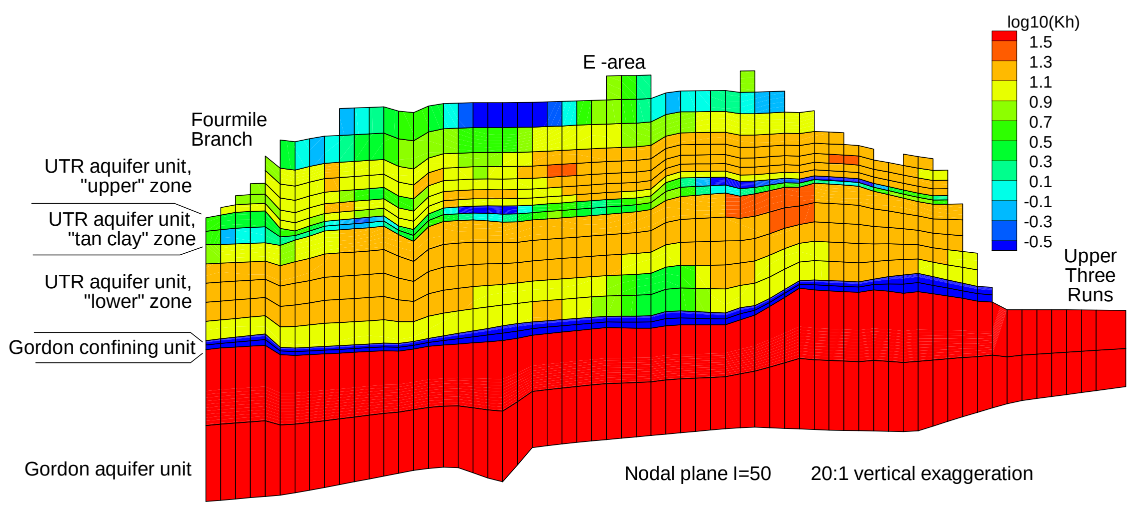


(b)

Figure 2-6. Cross-sectional view of horizontal hydraulic conductivity field for (a) FACT, and (b) PORFLOW.

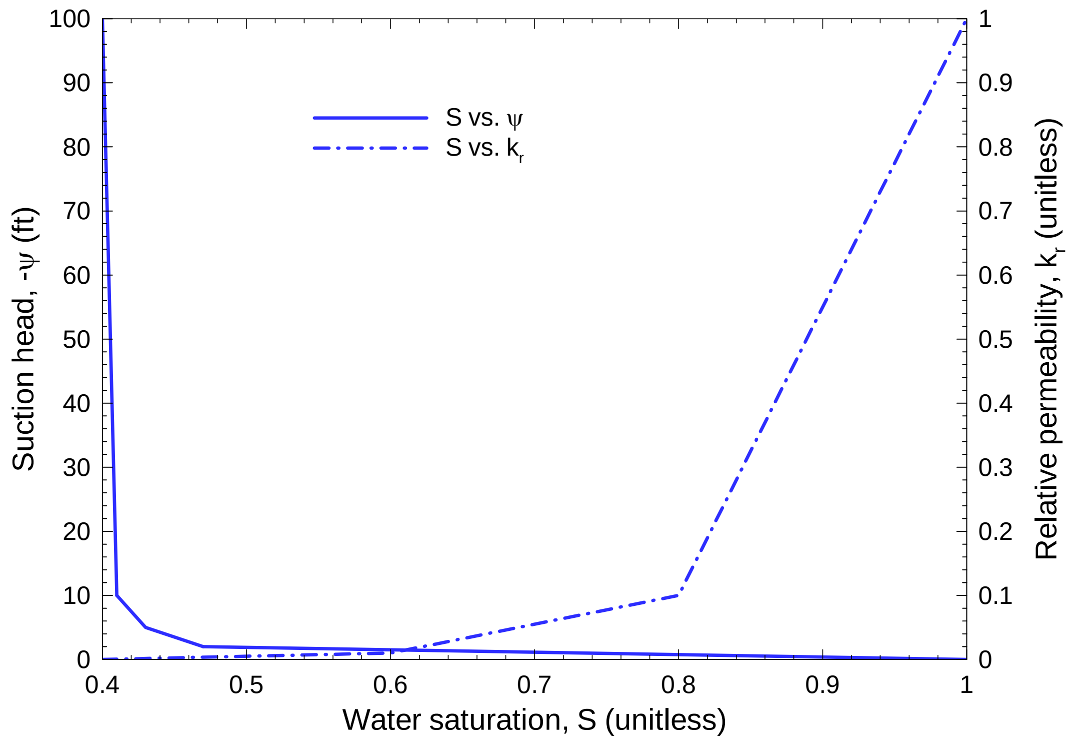


Figure 2-7. Pseudo soil characteristic curves.

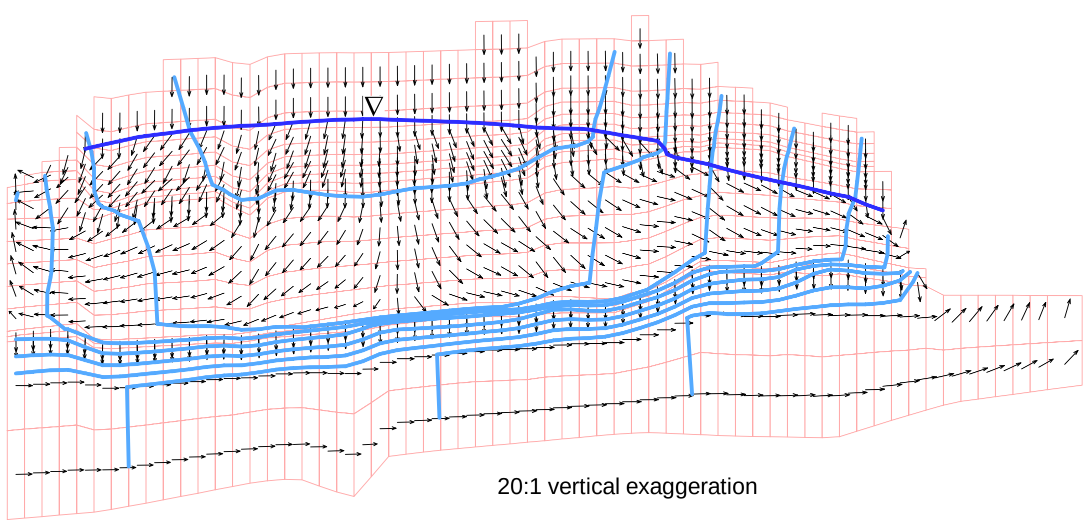


Figure 2-8. Example velocity field showing predominantly downward flow in the vadose zone; vectors are fixed length showing flow direction only.

3.0 STEADY-STATE GROUNDWATER FLOW SIMULATION

Steady-state results from the final calibrated GSA/PORFLOW model are presented in this section. Summary measures of model calibration are also included. Discussion of results and additional model verification and validation testing are provided in section 4.0.

3.1 Hydraulic Head

Portions of the three-dimensional hydraulic head field are shown in Figures 3-1 and 3-2, which show the top surface of the mesh and a cross-sectional slice, respectively. Two-dimensional plots of vertically-averaged head in each aquifer zone are shown in Figures 3-3a through 3-5a. Residuals at well locations, defined as computed minus measured heads, are shown in the Figures 3-3b through 3-5b. Statistics of the head residuals are summarized in Table 3-1.

Table 3-1. Summary statistics for hydraulic head residuals in GSA/PORFLOW.

Aquifer zone	Number	Median residual (ft)	Average residual (ft)	Root-mean-square residual (ft)	Minimum residual (ft)	Maximum residual (ft)
Gordon	79	-0.0	-0.5	1.7	-4.7	2.5
lower UTR	173	+0.8	+0.6	4.6	-9.4	27.0
upper UTR	386	-0.1	-0.5	3.4	-15.2	10.0

3.2 Groundwater Flows

Figure 3-6 defines seepage faces simulated by the GSA/PORFLOW model. The seepline predicted by the model is the border between recharge (red) and discharge (blue) areas. A survey of the seepline in the early 1990's is shown in the figure for comparison. The flux of water entering the model at the ground surface is shown in Figure 3-7. Groundwater discharge areas correspond to positive flux values. Figures 3-6 and 3-7 are similar with the former indicating only the direction of water flow and the latter showing magnitude as well. The average recharge rate for the model, defined as top surface inflow divided by total area including seepage faces, is 14.7 in/yr. Table 3-2 compares simulated and measured values of recharge and stream baseflow.

Table 3-2. Comparison of measured and simulated stream baseflow in GSA/PORFLOW.

Stream	Estimated baseflow contribution from GSA (ft^3/s)	Simulated baseflow contribution from GSA (ft^3/s)
Upper Three Runs and tributaries excluding McQueen Branch	18.2	11.4
Fourmile Branch and tributaries	2.6	3.8
McQueen Branch	1.5	2.4
Crouch Branch	1.8	1.7

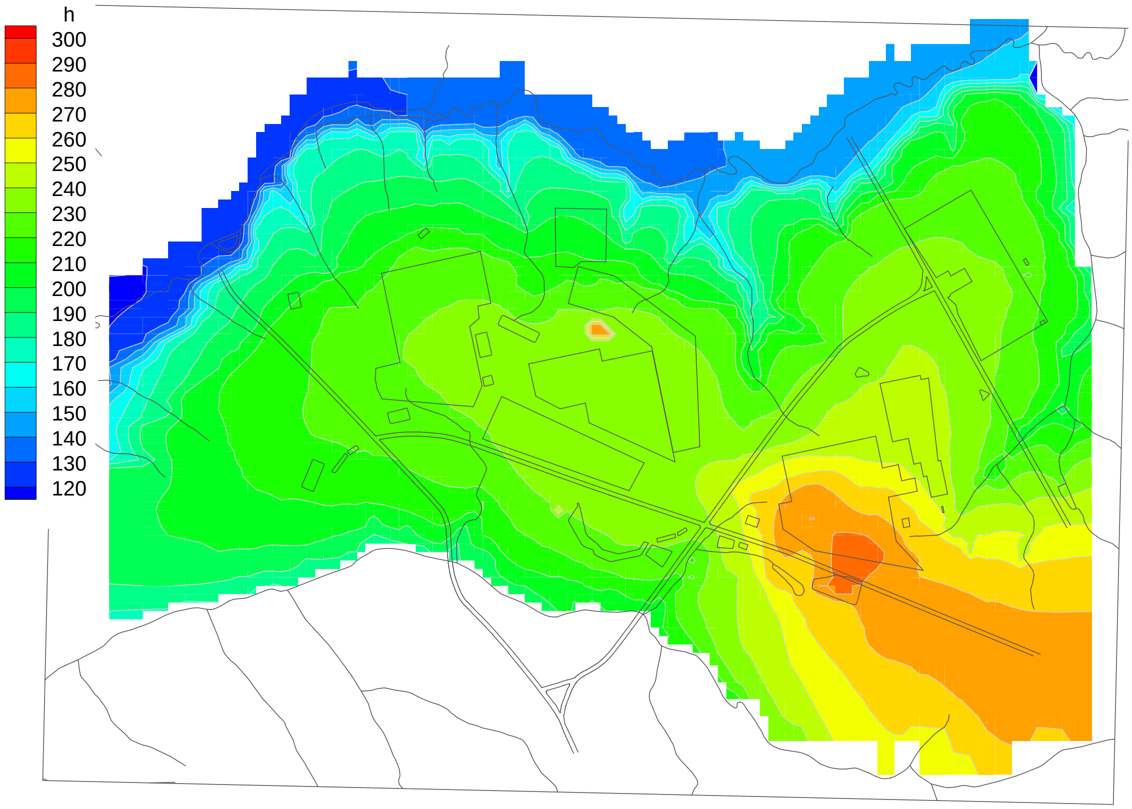


Figure 3-1. Simulated hydraulic head over the top surface of the GSA/PORFLOW mesh.

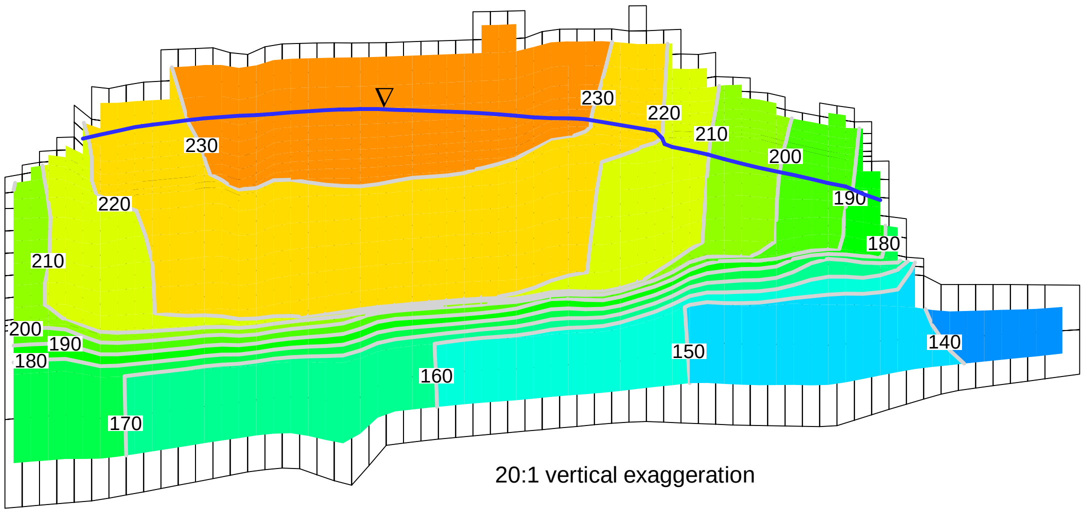
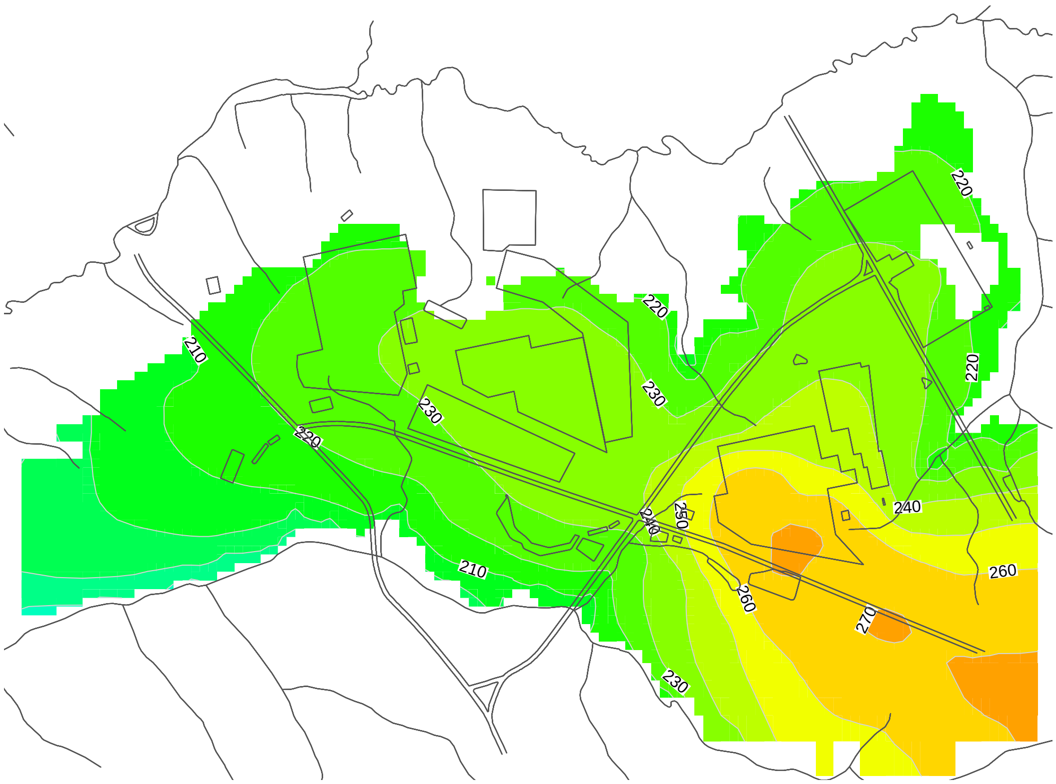


Figure 3-2. Simulated hydraulic head in GSA/PORFLOW model at cross-section through E Area (I=50).



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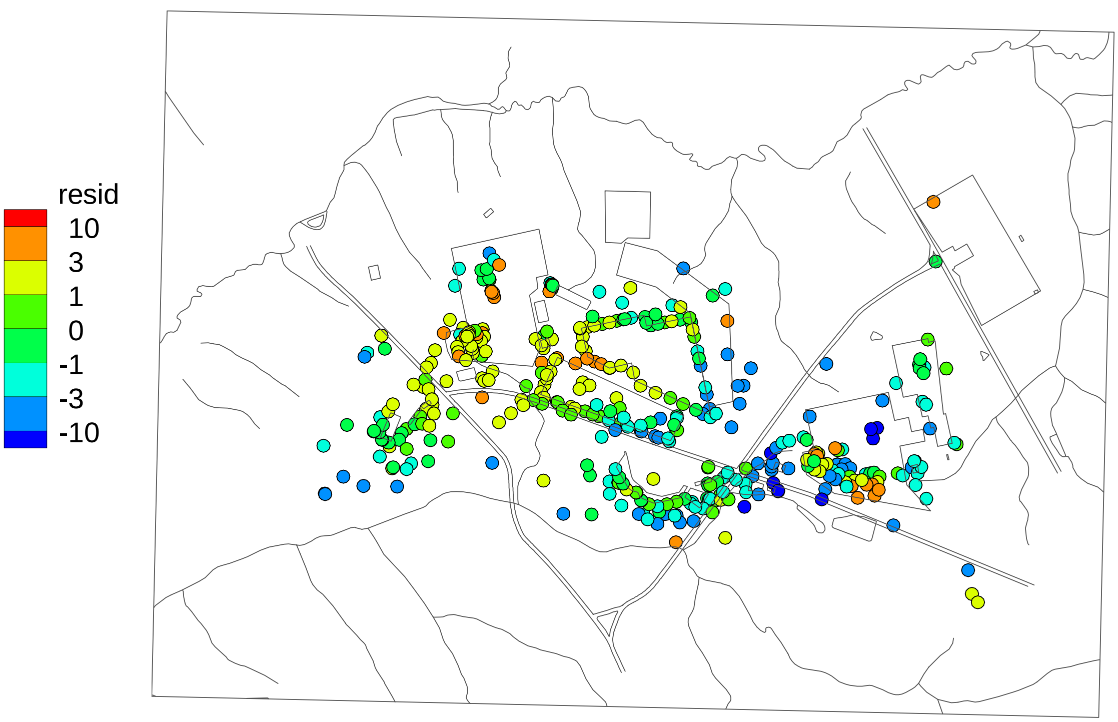
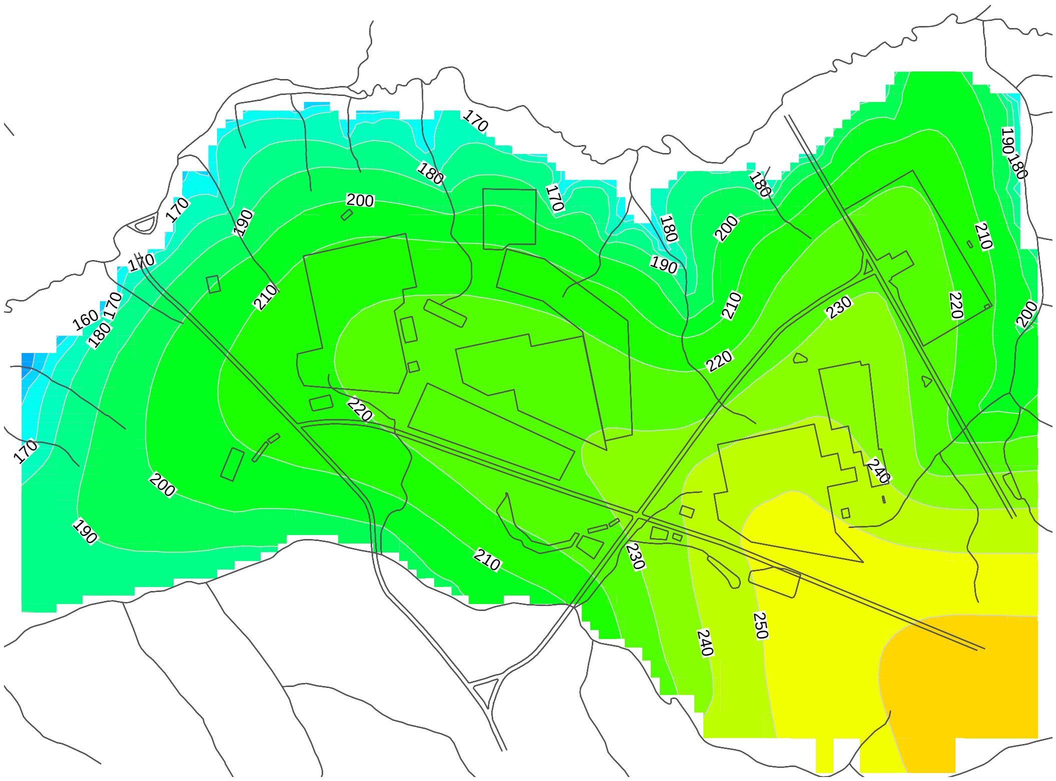


(b)

Figure 3-3. GSA/PORFLOW results for the UTR upper aquifer zone: (a) vertically-averaged head, and (b) residuals between computed and measured heads.



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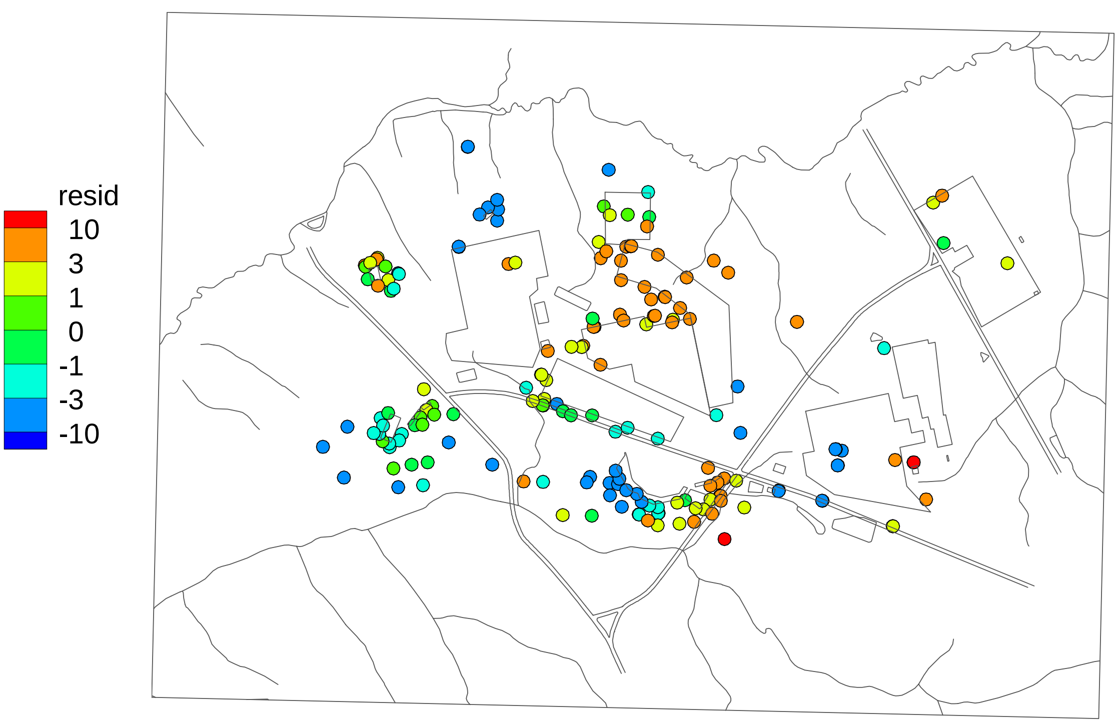
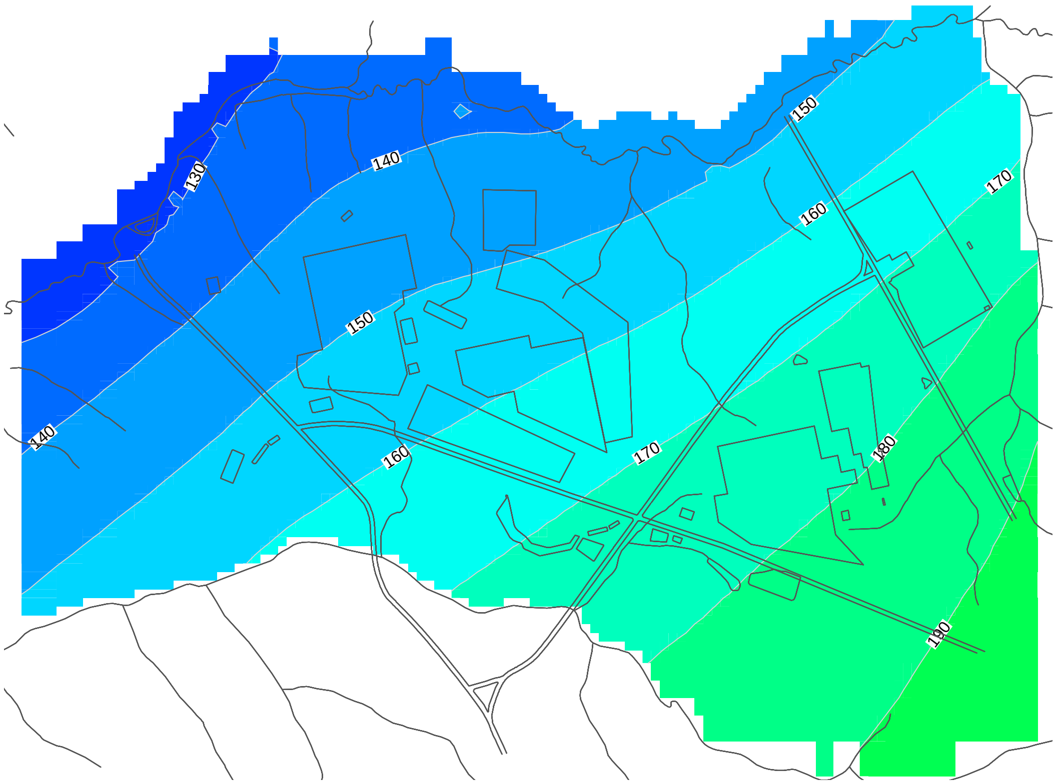


(b)

Figure 3-4. GSA/PORFLOW results for the UTR lower aquifer zone: (a) vertically-averaged head, and (b) residuals between computed and measured heads.



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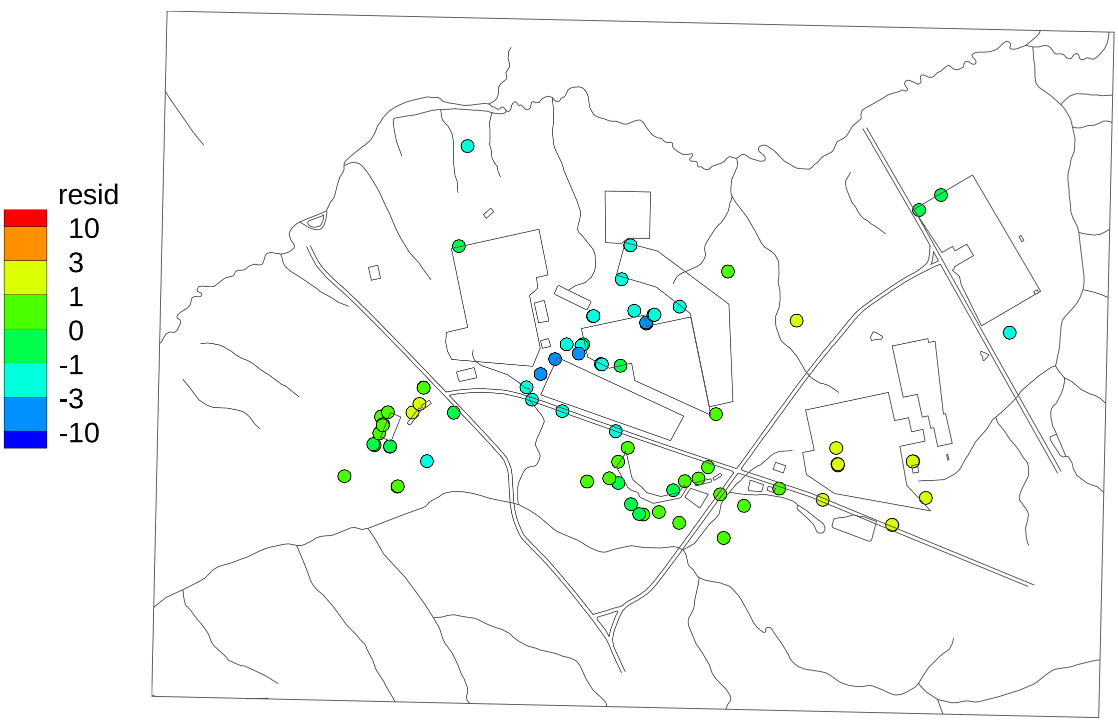


(b)

Figure 3-5. GSA/PORFLOW results for the Gordon aquifer unit: (a) vertically-averaged head, and (b) residuals between computed and measured heads.

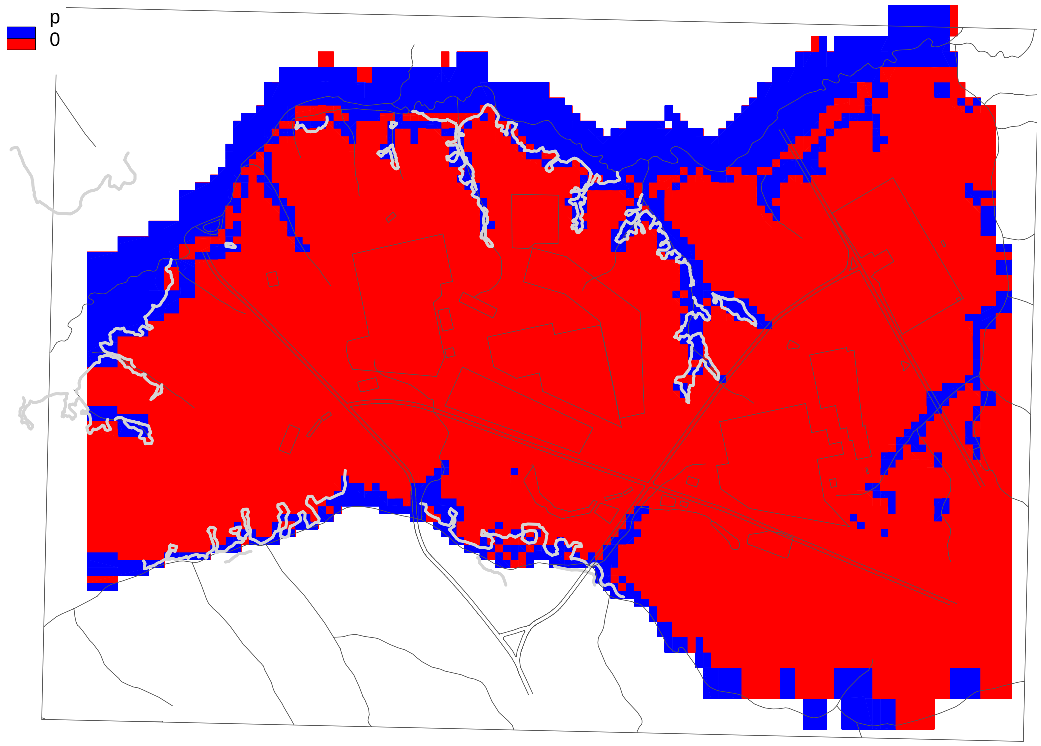


Figure 3-6. Simulated seepage areas in GSA/PORFLOW model compared to available seepline survey data.

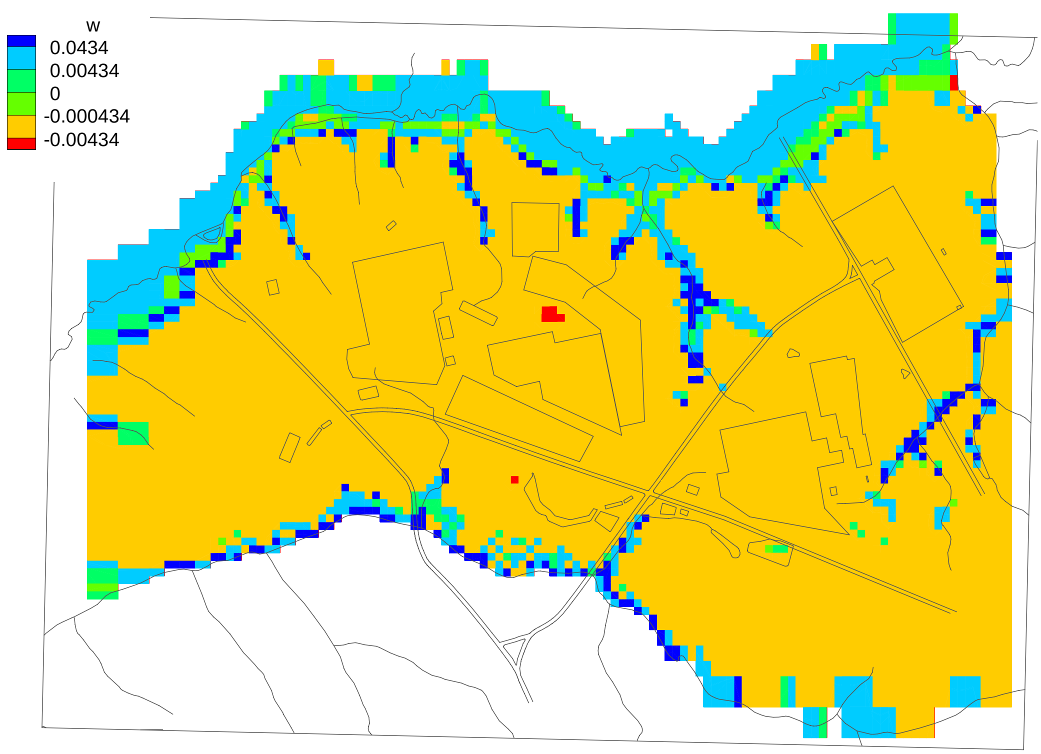


Figure 3-7. Simulated surface flux in GSA/PORFLOW model with positive values indicating groundwater discharge (ft^3/d).

4.0 VERIFICATION AND VALIDATION

As used in this report, the term "verification" refers to confirmation that conceptual and/or mathematical models have been correctly implemented in software comprised of execution and input files. The GSA/PORFLOW model consists of a generic PORFLOW version 5.95.0 binary executable file and several ASCII input files to PORFLOW that define specific attributes of the GSA hydrologic system. "Validation" refers to confirmation that the software model is a valid representation of the physical system. Thus assuming a model has successfully undergone verification testing, validation emphasizes the broader question of whether the underlying conceptual and/or mathematical models adequately represent the actual hydrologic system. This section describes a sequence of V&V tests of the GSA/PORFLOW model. These include code-to-code comparisons between GSA/FACT and GSA/PORFLOW.

The PORFLOW Software Quality Assurance Plan is defined by Collard (2002). The document also contains acceptance testing results specific to PORFLOW version 4.00.7. The GSA/PORFLOW model results described in Section 3.0 were generated with PORFLOW version 5.95.0, thus acceptance testing for the newer PORFLOW code is required (Collard 2002, Sections 1.5.4 and 1.9.1 and p. 32). Under current plans, use of version 5.95.0 will be limited to generation of the steady-state GSA groundwater flow field described herein. Therefore, PORFLOW acceptance testing was limited to only those tests required to validate the steady-state flow field from the present application. Specifically, PORFLOW was tested to confirm that the code conserves mass and satisfies Darcy's Law, the governing equations embedded in PORFLOW. These two software V&V tests are described in the current report, a form of documentation permitted by the software QA plan (Collard 2002, p. 14). Additional V&V tests pertaining to the overall GSA/PORFLOW model follow.

4.1 Conservation of Mass

Under steady-state and constant fluid density conditions and no internal sources or sinks present, the net volumetric flow entering the model grid should be zero. A global mass balance is provided in Table 4-1. The discrepancy between incoming and outgoing flows (ft^3/d) is negligible at -0.04%. Under the same conditions, the net volumetric flow should also be effectively zero on a cell-by-cell basis. The results of mass balance computations for individual grid cells are summarized in Table 4-2. Discrepancies are few, small and presumably the result of incomplete model convergence.

Table 4-1. Global mass balance for GSA/PORFLOW model.

BOUNDARY:	IN	OUT	NET FLOW	IN	OUT	NET FLUX
RECH01:	1.220E+01	1.521E+01	-3.006E+00	1.467E+01	1.828E+01	-3.614E+00
RECH02:	1.125E-01	0.000E+00	1.125E-01	1.901E+01	0.000E+00	1.901E+01
GENH01:	5.940E-01	1.080E-03	5.929E-01	7.151E-01	1.300E-03	7.138E-01
GENH02:	4.619E-03	0.000E+00	4.619E-03	5.462E+00	0.000E+00	5.462E+00
GENH05:	1.030E-02	0.000E+00	1.030E-02	9.744E+01	0.000E+00	9.744E+01
GENH10:	1.590E-02	0.000E+00	1.590E-02	3.009E+01	0.000E+00	3.009E+01
HEAD01:	5.249E-02	4.039E-01	-3.514E-01	5.710E+01	4.394E+02	-3.823E+02
HEAD02:	3.819E+00	1.205E+00	2.613E+00	1.684E+02	5.314E+01	1.152E+02
TOTALS:	1.681E+01	1.682E+01	-7.365E-03	-0.04%		

Table 4-2. Summary of cell-by-cell mass balance for GSA/PORFLOW model.

Description	Number	Percentage of total
Grid cells	102295	100%
Cells with a flow imbalance exceeding 0.1% of largest magnitude flow among the 6 adjoining cell faces	89	0.09%
Cells with a flow imbalance exceeding 0.1% of largest magnitude flow among all cell faces in the grid	0	0%

4.2 Darcy's Law

For a saturated porous medium and coordinate directions aligned with the principal axis of the conductivity tensor, Darcy's law for a particular coordinate axis can be expressed in terms of flowrate as

$$Q = qA = -KA\frac{dh}{dx} \qquad \text{(Eq. 4-1)}$$

where

Q = volumetric flow (L^3/T)

q = volumetric flux (L/T)

A = area normal to flow (L^2)

K = hydraulic conductivity (L/T)

h = hydraulic head (L)

x = distance in flow direction (L)

The precise numerical implementation of Eq. 4-1 is not defined in PORFLOW user documentation. Therefore, rigorous verification that Darcy's law as represented in PORFLOW is satisfied in GSA/PORFLOW is not readily attainable. Nevertheless, an independent calculation should be close to that embedded in PORFLOW and can serve as a validation test at a minimum.

Table 4-3 summarizes the results of such a calculation for cell faces in the saturated zone. The flowrate across each cell face was computed using a finite-difference version of Eq. 4-1 and geometric averaging to define conductivity at the face. This flowrate was compared to that reported by PORFLOW. The flowrates reported by PORFLOW and computed using Darcy's law are in general agreement. Discrepancies occur mostly at the Z- and Z+ faces of cells. At these locations the conductivity contrasts are often large (e.g. between aquifer and confining zones) and vertical mesh distortion creates ambiguities in the distance x. Thus the discrepancies are understandable. The comparison confirms that Darcy's law is satisfied.

Table 4-3. Summary of testing to confirm Darcy's law is satisfied at saturated internal cell faces.

Description	Number	Percentage of total
Interior (non-boundary) cell faces in saturated zone	239,562	100%
Faces with a flow imbalance exceeding 5% of largest magnitude flow among the 6 adjoining cell faces	34,088	14%
Cells with a flow imbalance exceeding 1% of largest magnitude flow among all cell faces in the grid	2382	1.0%

4.3 Stratigraphy

Hydrostratigraphic surfaces, as represented in the GSA/PORFLOW model, are shown by flooded contours in Figures 4-1 through 4-5. The locations of individual picks used to create the surfaces are shown as scattered data, along with control data outside the model domain. The elevation of each pick is indicated by the color fill inside the outline of the symbol. Triangulation was used to interpolate the scattered picks onto layers of finite-element vertices (Flach 1999). Therefore, the interpolation is exact and color fill for the model surface and scattered data are observed to be identical. The GSA/PORFLOW stratigraphic surfaces are identical to those in the GSA/FACT model, which have previously been validated (Flach 1999, Figures 5.1.1 through 5.1.5 and Section 5.1). Figures 4-1 through 4-5 can also be validated through visual comparison to Figures 3 through 7 in Flach and Harris (1999), which are same surfaces developed in EarthVision using an alternative interpolation algorithm. The two sets of surfaces are observed to be similar.

4.4 Hydraulic Conductivity

The initial hydraulic conductivity field in the original GSA/FACT model was qualitatively validated against characterization data as described in Flach (1999, Section 5.5). The same comparison to field data is repeated in Appendix A for the calibrated GSA/PORFLOW model. The GSA/PORFLOW model conductivity field follows the trend indicated by slug and pump test data in 44% of the comparisons. That is, the model K field exhibits a higher (lower) than average value when the data exhibit a higher (lower) than average value. The model is counter to the data trend 17% of the time. Indeterminate or neutral comparisons comprise 39%. The former are cases in which the slug and pumping test data indicate opposing trends. Appendix A suggests that the calibrated GSA/PORFLOW conductivity field is valid in that it agrees or is neutral with respect to the data 83% of the time. These percentages are similar to those for the GSA/FACT model.

4.5 Hydraulic Head

Hydraulic head results from the GSA/PORFLOW model exhibit adequate agreement with well data considering uncertainties in the long-term average well water levels, limited characterization of field-scale conductivity, and the model resolution. Head residuals for GSA/PORFLOW are somewhat larger than those for GSA/FACT (Table 4-4) for various reasons. The artificial recharge zone in the GSA/FACT model was more effective in reducing head residuals near H Area, but is currently viewed as less realistic than the GSA/PORFLOW model. The coarser vertical resolution of the GSA/PORFLOW mesh may also be a contributing factor. More extensive calibration efforts would likely improve the GSA/PORFLOW model.

Table 4-4. Summary statistics for hydraulic head residuals in GSA/FACT.

Aquifer zone	**Number**	**Median residual** (ft)	**Average residual** (ft)	**Root-mean-square residual** (ft)	**Minimum residual** (ft)	**Maximum residual** (ft)
Gordon	79	-1.2	-1.8	2.5	-6.2	-
lower UTR	172	-0.4	-0.1	4.8	-	16.0
upper UTR	407	0.0	-0.3	2.6	-9.8	-

4.6 Recharge and Stream Baseflows

The average recharge rate in the GSA/PORFLOW model, 14.7 in/yr, is about the same as the best-estimate based on field data, 15 in/yr. For comparison, the GSA/FACT model has an average rate of 14.5 in/yr. Stream baseflows are similar for the two models, with the largest differences occurring for Upper Three Runs and McQueen Branch (Table 4-5). The GSA/PORFLOW model prediction for McQueen Branch (2.4 ft^3/s) is significantly closer to the prior estimate (1.5 ft^3/s) than the GSA/FACT model (3.6 ft^3/s). Conversely, the GSA/PORFLOW model prediction for Upper Three Runs (11.4 ft^3/s) is deviates further from the prior estimate (18.2 ft^3/s) than the GSA/FACT model (14.5 ft^3/s).

The GSA/PORFLOW model prediction of seepage faces is approximately the same as past survey data (Figure 3-6). The resolution of seepage faces and seeplines is poorer for GSA/PORFLOW compared to the GSA/FACT model. The top surface of the latter conforms to the actual ground surface more accurately.

Table 4-5. Comparison of measured and simulated stream baseflow in GSA/FACT.

Stream	**Estimated baseflow contribution from GSA (ft^3/s)**	**Simulated baseflow contribution from GSA (ft^3/s)**
Upper Three Runs and tributaries excluding McQueen Branch	18.2	14.5
Fourmile Branch and tributaries	2.6	3.6
McQueen Branch	1.5	4.7
Crouch Branch	1.8	1.6

4.7 Particle Tracking and Solute Transport

Figure 4-6 compares particle tracking simulations based on the velocity fields from GSA/FACT and GSA/PORFLOW, as a V&V test of GSA/PORFLOW through code-to-code comparison. Overall, particle trajectories and timing are close between the two models. Locally, differences can be more significant.

Flach and Millings (2003) recently performed tritium transport simulations for several pairs of LAW vault footprints in E Area using the GSA/FACT flow field. Table 4-6 summarizes the peak groundwater concentration results from those computer runs, and analogous simulations performed using the GSA/PORFLOW flow field. The transport simulations for both flow fields were performed with PORFLOW using the identical contaminant source and transport parameters. On average the peak concentration results are about the same. However, individual runs tend to vary on the order of ±25%.

The particle tracking and solute transport comparison indicates the velocity field is similar between the two models.

Table 4-6. Tritium transport simulations for various LAW vault footprints following Flach and Millings (2003).

H-3

Peak conc. at 100 meter well (any location) — **GSA/FACT** — Tecplot Tecplot Tecplot ~PORFLOW — **GSA/PORFLOW**

Case	Peak conc. node I	J	K	Peak time (yrs)	Peak conc (pCi/L)	Peak conc. node N	i	j	k	Keqv	Peak time (yrs)	Peak conc (pCi/L)	Conc. vs. FACT	
PA	36	24	9	9	1.59E+03									
Case01	36	24	11	9	2785	65772	55	51	11	12	9	3153	**1.13**	
Case02	37	23	12	10	3145	71174	56	50	12	13	9	3027	**0.96**	
Case03	41	21	11	10	2411	59907	60	48	10	11	10	1816	**0.75**	
Case04	43	19	12	10	2369	59717	62	46	10	11	11	1574	**0.66**	
Case05	43	15	13	12	2195	75584	63	40	13	14	11	1946	**0.89**	
Case06	44	12	14	12	1788	80508	64	37	14	15	11	1891	**1.06**	
Case07	44	10	14	12	2183	80408	64	36	14	15	12	1915	**0.88**	
Case08	42	17	13	11	2848	70603	61	44	12	13	11	2454	**0.86**	
Case09	42	16	13	11	2923	70502	61	43	12	13	11	2206	**0.75**	0.88 avg
Case10	44	13	14	11	5812	75584	63	40	13	14	12	5330	**0.92**	

Peak conc. within aquifer zone only — **GSA/FACT** — Tecplot Tecplot Tecplot ~PORFLOW — **GSA/PORFLOW**

Case	Peak conc. node I	J	K	Peak time (yrs)	Peak conc (pCi/L)	Peak conc. node N	i	j	k	Keqv	Peak time (yrs)	Peak conc (pCi/L)	Conc. vs. FACT	
PA	36	24	9	9	1.59E+03									
Case01	36	24	**10**	**10**	**2248**	**54516**	55	51	9	**10**	**10**	**2095**	**0.93**	
Case02	37	23	**10**	**12**	**1595**	71174	56	50	12	13	9	3027	**1.90**	
Case03	41	21	**10**	**12**	**1783**	**54227**	60	48	9	**10**	**11**	**1522**	**0.85**	
Case04	43	19	**10**	**12**	**1171**	**54031**	62	46	9	**10**	**12**	**1177**	**1.01**	
Case05	43	15	13	12	2195	75584	63	40	13	14	11	1946	**0.89**	
Case06	44	12	14	12	1788	80508	64	37	14	15	11	1891	**1.06**	
Case07	44	10	14	12	2183	80408	64	36	14	15	12	1915	**0.88**	
Case08	42	17	13	11	2848	70603	61	44	12	13	11	2454	**0.86**	
Case09	42	16	13	11	2923	70502	61	43	12	13	11	2206	**0.75**	1.01 avg
Case10	44	13	14	11	5812	75584	63	40	13	14	12	5330	**0.92**	

4.8 Summary Assessment

The GSA/PORFLOW model conserves mass, satisfies Darcy's law, and produces simulated hydraulic heads and groundwater flows that substantially agree with extensive field data. GSA/PORFLOW particle tracking and solute transport results are similar to those produced by GSA/FACT. Thus the new PORFLOW model appears to produce valid simulations of groundwater flow in the GSA.

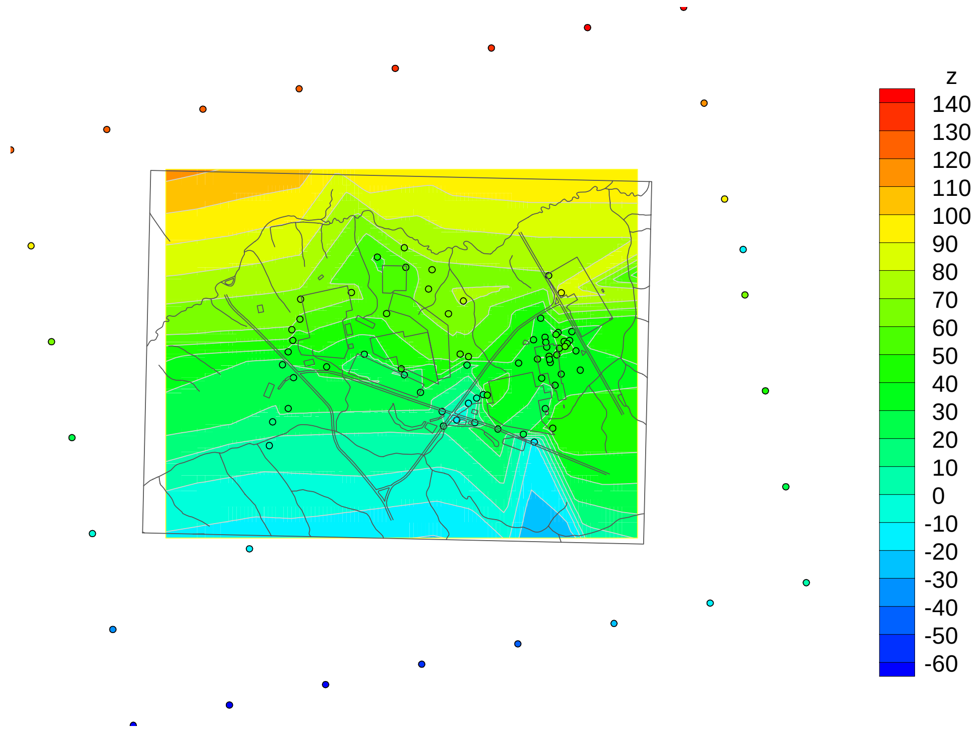


Figure 4-1. GSA/PORFLOW representation of the top of the Meyers Branch confining system (Crouch Branch confining unit).

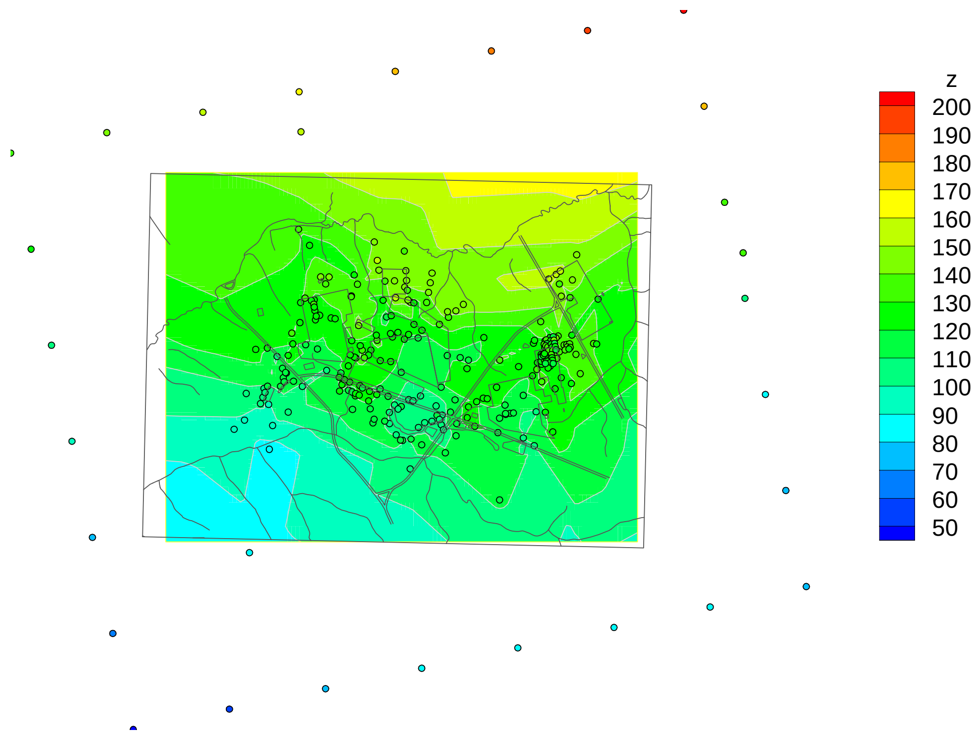


Figure 4-2. GSA/PORFLOW representation of the top of the Gordon aquifer unit.

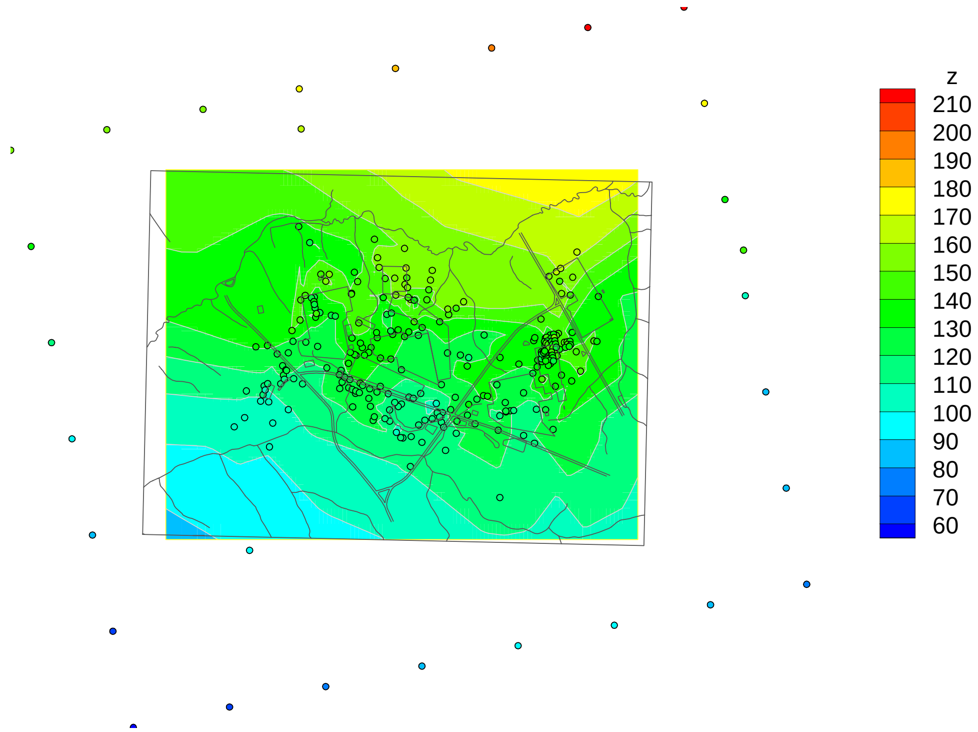


Figure 4-3. GSA/PORFLOW representation of the top of the Gordon confining unit.

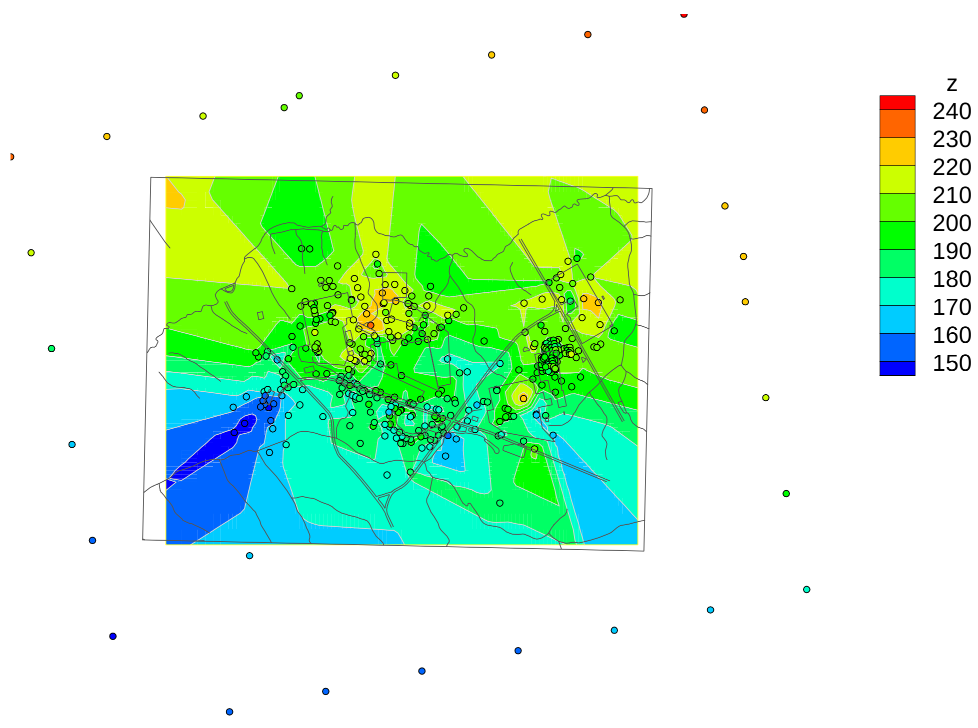


Figure 4-4. GSA/PORFLOW representation of the top of the UTR lower aquifer zone.

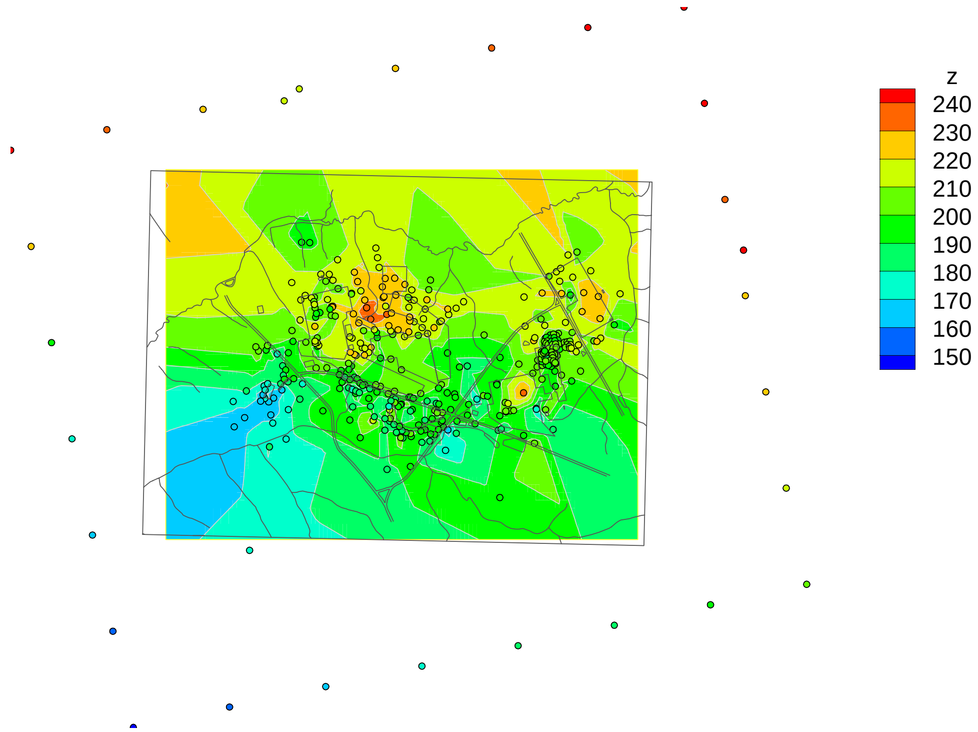
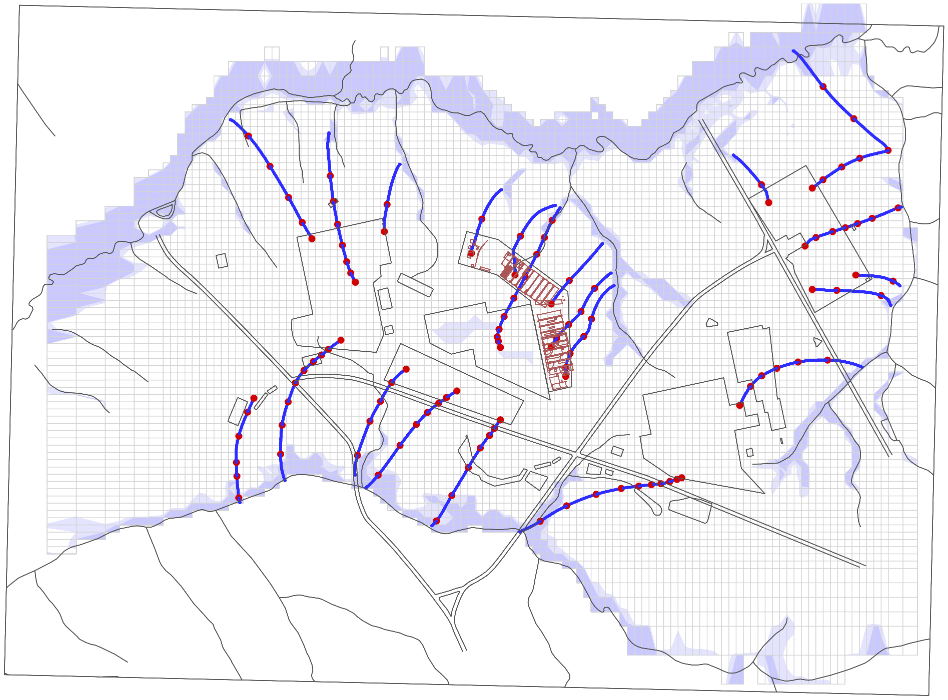
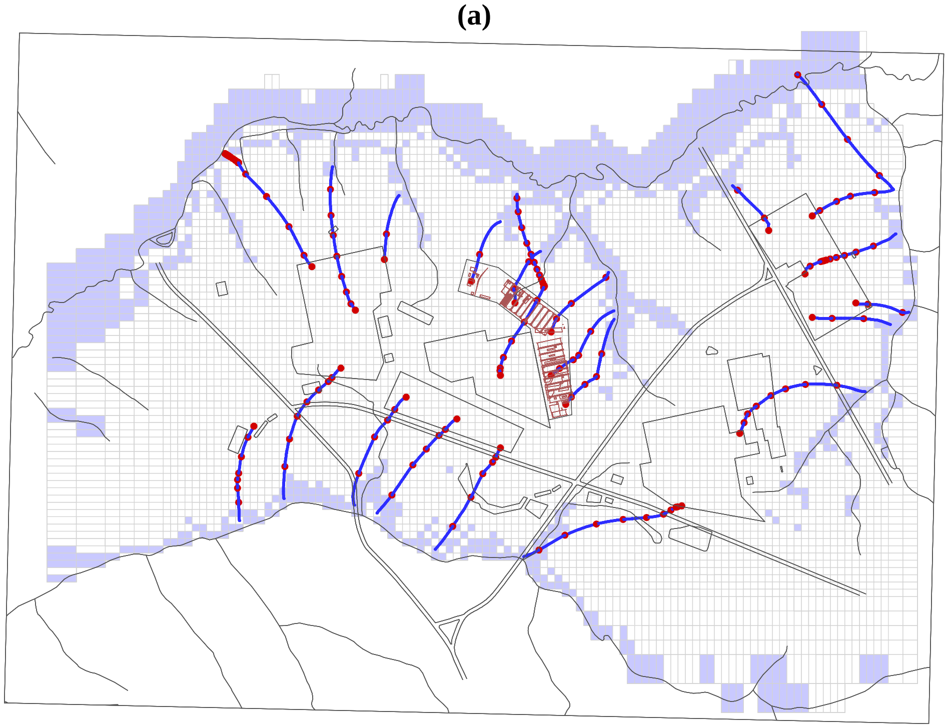


Figure 4-5. GSA/PORFLOW representation of the top of the UTR tan clay confining zone.



(a)



(b)

Figure 4-6. Particle tracking simulation with 5 year markers for (a) GSA/FACT and (b) GSA/PORFLOW.

5.0 CONCLUSIONS AND RECOMMENDATIONS

A numerical model of groundwater flow beneath the GSA using PORFLOW version 5.95.0 has been developed based on the former GSA/FACT model. The original GSA/FACT characterization and monitoring datasets, pre-processing algorithms, and model calibration strategies were largely preserved. Differences in flow results between the two models, due to mesh and code differences, were minimized to the extent practical. The GSA/PORFLOW model is an equally valid representation of groundwater flow compared to GSA/FACT, and suitable as the new baseline for future Performance Assessment work.

Software acceptance testing of PORFLOW version 5.95.0 used to generate GSA/PORFLOW results was very limited in scope: Tests for mass conversation and satisfaction of Darcy's law were performed. These tests, combined with visual confirmation that boundary conditions have been adequately specified, are sufficient to validate the steady-state flow field results. Additional software testing would be required for other applications of PORFLOW version 5.95.0.

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APPENDIX A - QUALITATIVE COMPARISON OF GSA/PORFLOW HORIZONTAL CONDUCTIVITY FIELD TO CHARACTERIZATION DATA.

Table A-1. Comparison of characterization data trends for horizontal conductivity to GSA/PORFLOW variations from average.

(1) Well ID	(2) z bot (ft)	(3) z top (ft)	(4) %sand	(5) slug Kh (ft/d)	(6) pump Kh (ft/d)	(7) modl Kh (ft/d)	(8) sand trend	(9) slug trend	(10) pump trend	(11) model trend	(12) Agree/ Dis-agree
BGC001A	108	112	-1	0.46	-1	0.32	-	L	-	L	A
BGC002A	117.6	121.6	-1	0.02	-1	3.37	-	L	-	L	A
BGC003A	131.6	135.6	-1	15.9	-1	11.39	-	H	-	H	A
BGO001D	225	245	0.83	0.31	-1	10.56	H	L	-	H	-
BGO002D	218.9	238.9	-1	0.62	-1	6.46	-	L	-	L	A
BGO003A	103.7	113.7	0.82	4.22	-1	16.58	H	H	-	H	A
BGO003C	178.7	188.7	0.83	0.01	-1	1.44	H	L	-	L	-
BGO003D	227.6	247.6	0.71	0.14	-1	6.21	L	L	-	L	A
BGO004D	220.6	240.6	-1	0.69	-1	9.65	-	L	-	L	A
BGO005C	183.2	193.2	0.79	0.13	-1	7.66	H	L	-	L	-
BGO005D	219.3	239.3	0.84	0.73	-1	8.41	H	L	-	L	-
BGO006A	107.5	117.5	0.9	0.77	-1	4.37	H	L	-	L	-
BGO006C	158	168	0.71	1.51	-1	10.71	L	L	-	H	D
BGO006D	217.2	237.2	0.89	0.38	-1	10.99	H	L	-	H	-
BGO007D	220.2	240.2	-1	15.1	-1	12.97	-	H	-	H	A
BGO008A	105.3	115.3	0.76	0.21	-1	9.72	L	L	-	L	A
BGO008AR	94.6	104.6	0.91	0.9	-1	9.72	H	L	-	L	-
BGO008C	174.3	184.3	0.9	1.39	0.41	8.53	H	L	L	L	A
BGO008D	220.6	240.6	0.89	1.87	1.25	13.31	H	L	L	H	D
BGO009D	209.2	229.2	0.7	0.1	-1	7.02	L	L	-	L	A
BGO010A	111.1	121.1	0.88	0.16	-1	8.38	H	L	-	L	-
BGO010AA	80.8	90.8	0.63	0.43	-1	7.92	L	L	-	L	A
BGO010AR	96.5	106.5	0.9	0.85	-1	8.38	H	L	-	L	-
BGO010B	139	149	0.61	0.31	-1	1.85	L	L	-	L	A
BGO010C	157.3	167.3	0.69	0.07	-1	5.51	L	L	-	L	A
BGO010D	230.5	250.5	0.83	0.33	-1	9.03	H	L	-	L	-
BGO010DR	218.3	238.3	0.8	1.16	-1	10.01	H	L	-	L	-
BGO011D	216.3	236.3	-1	2.54	1.89	8.84	-	L	L	L	A
BGO012A	106.4	116.4	0.89	0	-1	4.99	H	L	-	L	-
BGO012AR	99.3	109.3	0.89	0.98	-1	4.99	H	L	-	L	-

(1) Well ID	(2) z bot (ft)	(3) z top (ft)	(4) %sand	(5) slug Kh (ft/d)	(6) pump Kh (ft/d)	(7) modl Kh (ft/d)	(8) sand trend	(9) slug trend	(10) pump trend	(11) model trend	(12) Agree/ Dis-agree
BGO012C	153.6	163.6	0.93	0.57	-1	7.77	H	L	-	L	-
BGO012CR	144	154	0.92	0.16	-1	7.33	H	L	-	L	-
BGO012D	217.8	237.8	0.87	0.12	-1	9.22	H	L	-	L	-
BGO013D	228.5	248.5	-1	0.14	-1	6.91	-	L	-	L	A
BGO013DR	210.3	220.3	-1	0.28	-1	9.95	-	L	-	L	A
BGO014A	109.6	119.6	0.87	0.04	-1	5.65	H	L	-	L	-
BGO014AR	96.8	106.8	0.88	1.65	-1	6.58	H	L	-	L	-
BGO014C	192.1	202.1	0.84	0.98	0.89	7.76	H	L	L	L	A
BGO014CR	190.1	200.1	0.82	0.4	-1	7.86	H	L	-	L	-
BGO014D	229.6	249.6	0.77	0.56	-1	6.12	L	L	-	L	A
BGO014DR	218.1	238.1	0.74	2.15	-1	11.05	L	L	-	H	D
BGO015D	218.7	238.7	-1	1.11	-1	6.12	-	L	-	L	A
BGO016A	102.5	112.5	0.94	0.15	-1	8.25	H	L	-	L	-
BGO016D	217.3	237.3	0.67	0.07	-1	4.99	L	L	-	L	A
BGO017D	204	224	-1	1.28	-1	9.75	-	L	-	L	A
BGO018A	99.5	109.5	0.91	12	-1	16.69	H	H	-	H	A
BGO018D	219.6	239.6	0.78	12.6	-1	14.24	L	H	-	H	-
BGO019D	196.8	216.8	-1	0.45	-1	7.68	-	L	-	L	A
BGO020B	131	141	0.83	0.38	-1	8.09	H	L	-	L	-
BGO020C	174	184	0.83	0.94	-1	10.23	H	L	-	H	-
BGO021D	217.7	237.7	0.73	0.79	-1	5.49	L	L	-	L	A
BGO023D	222	242	0.79	1.11	-1	8.03	H	L	-	L	-
BGO024D	221	241	-1	0.36	-1	7.83	-	L	-	L	A
BGO025A	104.1	114.1	0.89	0.5	-1	7.22	H	L	-	L	-
BGO029C	176.8	186.8	0.69	0.29	-1	8.34	L	L	-	L	A
BGO029D	208.5	228.5	0.89	1.58	-1	11.06	H	L	-	H	-
BGO041A	103.3	113.3	0.9	0.13	-1	9.09	H	L	-	L	-
BGO042C	185.9	195.9	0.91	0.45	-1	10.3	H	L	-	H	-
BGO043AA	62.2	72.2	0.86	0.86	-1	10.31	H	L	-	H	-
BGO044A	98	108	0.93	4.03	-1	10.06	H	L	-	H	-
BGO044AA	61.2	71.3	0.86	4.37	-1	13.07	H	H	-	H	A
BGO044B	148.1	158.1	0.73	0.06	-1	4.43	L	L	-	L	A
BGO044C	190.6	200.6	0.82	0.08	-1	7.39	H	L	-	L	-
BGO044D	223.4	233.4	0.83	13	-1	11.32	H	H	-	H	A
BGO045A	116.9	126.9	0.91	2.45	-1	4.48	H	L	-	L	-

(1) Well ID	(2) z bot (ft)	(3) z top (ft)	(4) %sand	(5) slug Kh (ft/d)	(6) pump Kh (ft/d)	(7) modl Kh (ft/d)	(8) sand trend	(9) slug trend	(10) pump trend	(11) model trend	(12) Agree/ Dis-agree
BGO045B	137	147	0.9	0.12	-1	7.94	H	L	-	L	-
BGO045C	190.5	200.5	0.7	1.22	-1	0.01	L	L	-	L	A
BGO045D	209.6	229.6	0.9	6.07	-1	14.56	H	H	-	H	A
BGO046B	140.4	150.4	0.88	2.33	-1	12.6	H	L	-	H	-
BGO046C	178	188	0.86	0.14	-1	8.22	H	L	-	L	-
BGO046D	202.1	212.1	0.88	11.5	-1	14.98	H	H	-	H	A
BGO047A	86.8	96.8	0.95	3.06	-1	13.87	H	L	-	H	-
BGO047C	178.6	188.6	0.86	0.46	-1	9.64	H	L	-	L	-
BGO047D	203.4	213.4	0.91	15.9	-1	15.32	H	H	-	H	A
BGO048C	176.7	186.7	0.92	2.15	-1	10.39	H	L	-	H	-
BGO048D	202	212	0.75	11	-1	13.88	L	H	-	H	-
BGO049A	75.1	85.1	0.93	0.48	-1	10.83	H	L	-	H	-
BGO049C	166	176	0.91	0.88	-1	11.19	H	L	-	H	-
BGO049D	218.5	238.5	0.87	0.73	-1	9	H	L	-	L	-
BGO050A	90.5	100.5	0.89	0.4	-1	10.84	H	L	-	H	-
BGO050C	162.5	172.5	0.77	0.33	-1	9.08	L	L	-	L	A
BGO050D	208	228	0.83	1.61	-1	11.42	H	L	-	H	-
BGO051A	75.1	85.1	0.91	10.5	-1	18.21	H	H	-	H	A
BGO051AA	29.2	39.2	0.67	0.99	-1	8.17	L	L	-	L	A
BGO051B	117.1	127.1	0.82	5.39	-1	2.9	H	H	-	L	D
BGO051C	175.1	185.1	0.87	1.51	-1	12.6	H	L	-	H	-
BGO051D	220	240.1	0.82	0.24	-1	6.81	H	L	-	L	-
BGO052A	81.7	91.7	0.89	4.15	-1	17.23	H	H	-	H	A
BGO052AA	36.6	46.6	0.9	4.52	-1	12.24	H	H	-	H	A
BGO052B	126.7	136.7	0.82	0.53	-1	7.08	H	L	-	L	-
BGO052C	178.7	188.7	0.79	2.69	-1	12.46	H	L	-	H	-
BGO052D	219.4	239.4	0.76	0.11	-1	5.14	L	L	-	L	A
BGO053A	78.6	88.6	0.95	0.36	-1	9.13	H	L	-	L	-
BGO053AA	38.8	48.8	0.96	1.12	-1	12.15	H	L	-	H	-
BGO053B	143.4	153.4	0.88	0.11	-1	6.21	H	L	-	L	-
BGO053C	183.1	193.1	0.93	2.3	-1	9.76	H	L	-	L	-
BGO053D	225.2	245.2	0.87	1.94	-1	12.18	H	L	-	H	-
BGX001A	114.1	124.1	0.93	0.01	-1	6.23	H	L	-	L	-
BGX001C	176	186	0.85	0.36	-1	9.44	H	L	-	L	-
BGX001D	214.7	234.7	0.86	1.65	-1	10.45	H	L	-	H	-

(1) Well ID	(2) z bot (ft)	(3) z top (ft)	(4) %sand	(5) slug Kh (ft/d)	(6) pump Kh (ft/d)	(7) modl Kh (ft/d)	(8) sand trend	(9) slug trend	(10) pump trend	(11) model trend	(12) Agree/ Dis-agree
BGX002B	137.2	147.2	0.72	0.21	-1	5.64	L	L	-	L	A
BGX002D	181.1	191.1	0.86	0.34	-1	9.14	H	L	-	L	-
BGX003D	201.6	221.6	-1	1.85	-1	11.21	-	L	-	H	D
BGX004A	106.8	116.8	0.92	1.83	-1	12.66	H	L	-	H	-
BGX004C	170.7	180.7	0.87	1.16	-1	12.16	H	L	-	H	-
BGX004D	203.8	223.8	0.66	2.89	-1	1.01	L	L	-	L	A
BGX005D	195	215	-1	1.45	-1	10.76	-	L	-	H	D
BGX006D	191	211	-1	3.57	-1	14.2	-	L	-	H	D
BGX007D	194.1	214.1	0.9	20.4	-1	18.68	H	H	-	H	A
BGX009D	212.4	232.4	0.88	0.36	-1	10.51	H	L	-	H	-
BGX010D	216.2	236.2	-1	0.52	-1	8.44	-	L	-	L	A
BGX012C	174.1	184.1	-1	1.11	-1	8.96	-	L	-	L	A
BGX012D	223.7	243.7	-1	0.36	-1	7.83	-	L	-	L	A
FC001A	96.7	101.7	-1	1.47	-1	10.39	-	L	-	H	D
FC001B	151.8	156.8	-1	0.07	0.05	1.3	-	L	L	L	A
FC001C	183.9	188.9	-1	0	-1	1.7	-	L	-	L	A
FC002A	53.1	57.1	-1	8.39	1.2	5.23	-	H	L	L	A
FC002B	78.8	83.8	-1	0.59	0.12	5.23	-	L	L	L	A
FC002D	159.2	164.2	-1	2.73	-1	11.82	-	L	-	H	D
FC002E	188.9	193.9	-1	6.01	-1	13.41	-	H	-	H	A
FC002F	207.3	212.3	-1	1.9	-1	3.17	-	L	-	L	A
FC003B	61.2	66.2	-1	11.9	-1	22.03	-	H	-	H	A
FC003C	121	126	-1	1.66	-1	11.09	-	L	-	H	D
FC003D	165.9	170.9	-1	0.15	-1	4.92	-	L	-	L	A
FC003E	185.7	190.7	-1	1.39	-1	10.63	-	L	-	H	D
FC004B	76.1	81.1	-1	8.03	-1	10.44	-	H	-	H	A
FC004E	176.4	181.4	-1	4.79	-1	16.21	-	H	-	H	A
FC005B	34.6	39.6	-1	0.04	-1	11	-	L	-	H	D
FC005C	70	75	-1	0	-1	11	-	L	-	H	D
FC005D	136.4	141.4	-1	13	-1	0.55	-	H	-	L	D
FSB088C	158.4	168.4	-1	4.5	-1	10.78	-	H	-	H	A
FSB088D	202.1	222.1	-1	0.65	-1	9.19	-	L	-	L	A
FSB089C	156.1	166.1	0.87	0.52	-1	10.78	H	L	-	H	-
FSB089D	201.9	221.9	0.8	2.92	-1	9.19	H	L	-	L	-
FSB090C	158.1	168.1	-1	1.08	-1	9.59	-	L	-	L	A

(1) Well ID	(2) z bot (ft)	(3) z top (ft)	(4) %sand	(5) slug Kh (ft/d)	(6) pump Kh (ft/d)	(7) modl Kh (ft/d)	(8) sand trend	(9) slug trend	(10) pump trend	(11) model trend	(12) Agree/ Dis-agree
FSB090D	205.1	225.1	-1	0.34	-1	12.94	-	L	-	H	D
FSB091C	149.1	159.1	0.83	0.14	-1	11.16	H	L	-	H	-
FSB091D	200.9	220.9	0.85	3.82	-1	15.41	H	L	-	H	-
FSB092C	147.6	157.6	-1	0.5	-1	9.19	-	L	-	L	A
FSB092D	201.7	221.7	-1	3.57	-1	8.5	-	L	-	L	A
FSB093C	142	152	0.87	5.27	-1	6.92	H	H	-	L	D
FSB093D	197.9	217.9	0.79	2.32	-1	7.39	H	L	-	L	-
FSB097A	85.8	95.8	0.91	0.85	-1	11.42	H	L	-	H	-
FSB097C	143.8	153.8	0.46	0.26	-1	6.25	L	L	-	L	A
FSB097D	196.9	216.9	0.71	0.08	-1	5.68	L	L	-	L	A
FSB098C	148.4	158.4	0.95	1.55	-1	9.09	H	L	-	L	-
FSB098D	200.3	220.3	0.89	0.05	-1	5.75	H	L	-	L	-
FSB099C	157.2	167.2	0.79	3.03	-1	9.19	H	L	-	L	-
FSB099D	198.1	218.1	0.76	2.38	-1	9.41	L	L	-	L	A
FSB100A	95.8	105.8	0.95	0.37	-1	11.02	H	L	-	H	-
FSB101A	92.9	102.9	0.93	0.33	-1	11.38	H	L	-	H	-
FSB102C	145.9	155.9	-1	5.51	-1	16.13	-	H	-	H	A
FSB103C	147.1	157.1	-1	0.39	-1	3.57	-	L	-	L	A
FSB104C	150.7	160.7	-1	1.67	-1	5.59	-	L	-	L	A
FSB104D	190.4	210.4	-1	23.1	-1	22.32	-	H	-	H	A
FSB105C	141.5	151.5	-1	3.84	-1	6.63	-	L	-	L	A
FSB105D	203.7	223.7	-1	0.62	-1	5.91	-	L	-	L	A
FSB106C	156	166	-1	24	-1	9.71	-	H	-	L	D
FSB107C	150.8	160.8	-1	0.89	-1	11.6	-	L	-	H	D
FSB107D	200.9	220.9	-1	1.38	-1	16.2	-	L	-	H	D
FSB108D	203.8	223.8	-1	0.48	-1	11.27	-	L	-	H	D
FSB110D	191.1	211.1	-1	2.3	-1	10.8	-	L	-	H	D
FSB111C	159	169	-1	10.4	5.39	14.34	-	H	L	H	D
FSB111D	201.7	221.7	-1	1.25	-1	9.81	-	L	-	L	A
FSB112A	81	91	0.84	1.7	-1	11.29	H	L	-	H	-
FSB112C	129.1	139.1	0.63	0.16	-1	4.73	L	L	-	L	A
FSB112D	188.9	208.9	0.86	4.8	-1	14.74	H	H	-	H	A
FSB113A	81	91.3	0.9	0.62	-1	10.22	H	L	-	H	-
FSB113C	154	164	0.85	0.16	-1	10.27	H	L	-	H	-
FSB113D	189.6	209.6	0.85	5.1	-1	13.36	H	H	-	H	A

(1) Well ID	(2) z bot (ft)	(3) z top (ft)	(4) %sand	(5) slug Kh (ft/d)	(6) pump Kh (ft/d)	(7) modl Kh (ft/d)	(8) sand trend	(9) slug trend	(10) pump trend	(11) model trend	(12) Agree/ Dis- agree
FSB114A	95.2	105	0.9	0.44	-1	2.57	H	L	-	L	-
FSB114C	158	168	0.94	0.42	-1	12.89	H	L	-	H	-
FSB114D	197.7	217.8	0.88	3.5	-1	10.19	H	L	-	H	-
FSB115C	163.8	173.8	0.89	0.36	-1	6.17	H	L	-	L	-
FSB115D	182.5	192.5	0.89	3.8	-1	13.95	H	L	-	H	-
FSB116C	160.5	170.5	0.81	0.69	-1	8.47	H	L	-	L	-
FSB116D	186.4	196.4	0.88	1.1	-1	10.85	H	L	-	H	-
FSB117D	189.7	209.7	-1	2.5	-1	13.6	-	L	-	H	D
FSB118D	191.3	211.3	-1	1.1	-1	12.21	-	L	-	H	D
FSB119D	193.1	213.1	-1	0.6	-1	9.2	-	L	-	L	A
FSB120A	99	109	0.92	0.65	-1	6.92	H	L	-	L	-
FSB120C	150.7	160.7	0.89	1.7	-1	9.29	H	L	-	L	-
FSB120D	196.5	216.5	0.88	3.4	-1	10.11	H	L	-	H	-
FSB121C	148.4	158.4	0.9	11	-1	17.44	H	H	-	H	A
FSB121DR	191.3	211.3	0.89	0.27	-1	10.03	H	L	-	H	-
FSB122C	160	170	0.85	2.6	-1	13.6	H	L	-	H	-
FSB122D	186.6	206.6	0.88	1.6	-1	12.42	H	L	-	H	-
FSB123C	155.3	165.3	0.93	6.7	-1	13.88	H	H	-	H	A
FSB123D	194.1	214.1	0.93	3.9	-1	15.23	H	L	-	H	-
FSL001D	208.5	228.6	-1	0.58	-1	6.66	-	L	-	L	A
FSL002D	208.7	228.8	-1	0.25	-1	6.37	-	L	-	L	A
FSL003D	205.9	226	-1	0.88	-1	8.96	-	L	-	L	A
FSL004D	204	224.1	-1	0.79	-1	9.72	-	L	-	L	A
FSL005D	203.5	223.7	-1	3.02	-1	9.95	-	L	-	L	A
FSL006D	202.1	222.1	-1	0.89	-1	10.3	-	L	-	H	D
FSL007D	199.5	219.6	-1	0.59	-1	10.55	-	L	-	H	D
FSL008D	202.7	222.8	-1	0.41	-1	8.53	-	L	-	L	A
FSL009D	201.4	221.5	-1	0.56	-1	8.99	-	L	-	L	A
HAA001A	94.9	104.9	0.93	5.34	-1	0	H	H	-	L	D
HAA001AA	13.6	23.6	0.43	9.89	-1	16.85	L	H	-	H	-
HAA001B	119.3	129.3	0.9	0.75	-1	9.53	H	L	-	L	-
HAA001C	147.4	157.4	0.87	0.57	-1	6.34	H	L	-	L	-
HAA001D	261.8	281.8	0.44	1.35	-1	2.24	L	L	-	L	A
HAA002AA	29.4	39.4	0.89	25.25	-1	22.33	H	H	-	H	A
HAA002D	260.3	280.4	0.51	0.01	-1	1.18	L	L	-	L	A

(1) Well ID	(2) z bot (ft)	(3) z top (ft)	(4) %sand	(5) slug Kh (ft/d)	(6) pump Kh (ft/d)	(7) modl Kh (ft/d)	(8) sand trend	(9) slug trend	(10) pump trend	(11) model trend	(12) Agree/ Dis-agree
HAA003A	96.8	106.8	0.91	0.64	-1	10.19	H	L	-	H	-
HAA003AA	6.5	16.5	0.66	0.41	-1	8.12	L	L	-	L	A
HAA003B	125.9	135.9	0.81	0.33	-1	6.87	H	L	-	L	-
HAA003C	163.3	173.3	0.85	0.13	-1	5.17	H	L	-	L	-
HAA005A	100.7	110.7	-1	8.69	-1	0	-	H	-	L	D
HAA005C	177.7	187.7	-1	3.3	-1	8.11	-	L	-	L	A
HAA006A	95.6	105.6	0.99	1.41	-1	13.6	H	L	-	H	-
HAA006AA	25.8	35.8	0.89	0.24	-1	8.07	H	L	-	L	-
HAA006B	131.3	141.4	0.81	0.08	-1	4.46	H	L	-	L	-
HAA006C	161.1	171.1	0.9	23	-1	19.12	H	H	-	H	A
HAA006D	247.1	267.2	0.77	1.29	-1	7.8	L	L	-	L	A
HC001A	89.5	94.5	0.92	0.56	-1	14	H	L	-	H	-
HC001B	133.5	138.5	-1	1.28	-1	0.92	-	L	-	L	A
HC001C	183.5	188.5	-1	4.28	0.95	0.96	-	H	L	L	A
HC001D	206.5	211.5	-1	1.17	-1	9.49	-	L	-	L	A
HC001E	251.5	256.5	-1	12.3	-1	12.44	-	H	-	H	A
HC002A	72.2	77.2	0.91	2.83	-1	13.96	H	L	-	H	-
HC002B	85.7	90.7	-1	1.17	-1	14	-	L	-	H	D
HC002C	135.7	140.7	-1	0.34	-1	0.91	-	L	-	L	A
HC002D	178.2	183.2	-1	3.59	-1	0.96	-	L	-	L	A
HC002E	205.7	210.7	-1	2.16	0.62	8.16	-	L	L	L	A
HC002F	250.7	255.7	-1	12.3	1.8	12.44	-	H	L	H	D
HC002H	154.7	164.7	-1	0.85	-1	0.92	-	L	-	L	A
HC003A	65.6	70.6	0.91	12.5	2.6	15.41	H	H	L	H	-
HC003B	104.1	109.1	-1	12	-1	5.17	-	H	-	L	D
HC003E	202.1	207.1	-1	2.45	-1	8.98	-	L	-	L	A
HC003F	240.6	245.6	-1	14.6	-1	14.61	-	H	-	H	A
HC004A	150	155	0.78	1.54	0.35	8.09	H	L	L	L	A
HC004B	200	205	-1	1.01	0.23	7.76	-	L	L	L	A
HC005A	156.5	161.5	0.82	0.42	-1	8.87	H	L	-	L	-
HC005B	198	203	-1	4.73	-1	10.62	-	H	-	H	A
HC006A	156.2	161.2	0.88	1.55	0.24	3.45	H	L	L	L	A
HC006B	210.2	215.2	-1	2.17	0.42	7.34	-	L	L	L	A
HC008B	132.5	137.5	-1	5.99	1.2	12.3	-	H	L	H	D
HC008C	187.3	192.3	-1	4.73	0.5	10.03	-	H	L	H	D

(1) Well ID	(2) z bot (ft)	(3) z top (ft)	(4) %sand	(5) slug Kh (ft/d)	(6) pump Kh (ft/d)	(7) modl Kh (ft/d)	(8) sand trend	(9) slug trend	(10) pump trend	(11) model trend	(12) Agree/ Dis- agree
HC010B	164.8	169.8	-1	0.91	-1	11.04	-	L	-	H	D
HC011C	190.8	195.8	-1	1.01	-1	8.82	-	L	-	L	A
HC012B	177.3	182.3	-1	5.09	-1	11.36	-	H	-	H	A
HC013B	193.3	198.3	-1	0.45	0.09	3.05	-	L	L	L	A
HC015B	163	168	-1	4.09	-1	15.78	-	L	-	H	D
HC035D	87.8	92.8	0.89	0.19	-1	11.46	H	L	-	H	-
HCA004A	103.7	113.7	0.91	8.53	-1	1.57	H	H	-	L	D
HCA004AA	33.6	43.6	0.97	13.9	-1	25.44	H	H	-	H	A
HCA004B	126.6	136.6	0.81	0.19	-1	5.56	H	L	-	L	-
HCA004C	153.8	163.8	0.92	1.59	-1	11.86	H	L	-	H	-
HMD002D	190.8	210.8	0.89	4.14	-1	12.96	H	H	-	H	A
HMD003D	187.7	207.7	0.91	0.26	-1	10.66	H	L	-	H	-
HSB069A	83.1	93.1	0.93	8.79	-1	21.75	H	H	-	H	A
HSB070C	164.9	174.9	-1	0.25	-1	5.27	-	L	-	L	A
HSB071C	171.9	181.9	-1	0.22	-1	4.91	-	L	-	L	A
HSB100C	153	163	-1	1.39	-1	10.55	-	L	-	H	D
HSB100D	216.9	236.9	-1	1.77	-1	10.45	-	L	-	H	D
HSB101C	166.3	176.3	0.81	4	1.68	10.44	H	L	L	H	D
HSB101D	216.1	236.1	0.73	2.7	-1	8.8	L	L	-	L	A
HSB102C	166.7	176.7	-1	2	-1	7.37	-	L	-	L	A
HSB102D	216.3	236.3	-1	0.31	-1	10.52	-	L	-	H	D
HSB103C	159.2	169.2	0.76	3.15	-1	10.39	L	L	-	H	D
HSB103D	213.7	233.7	0.81	3.02	-1	17.61	H	L	-	H	-
HSB104C	163.5	173.5	-1	0.64	-1	5.83	-	L	-	L	A
HSB104D	210.6	230.6	-1	24.65	-1	13.58	-	H	-	H	A
HSB105C	152.2	162.2	0.86	4.28	-1	10.84	H	H	-	H	A
HSB105D	211.8	231.8	0.57	36.15	-1	8.84	L	H	-	L	-
HSB106C	158.7	168.7	-1	24.4	-1	12.61	-	H	-	H	A
HSB106D	210.7	230.7	-1	13.2	-1	18.52	-	H	-	H	A
HSB107C	159.3	169.3	0.9	0.98	-1	11.24	H	L	-	H	-
HSB107D	215.1	235.1	0.5	9.28	-1	17.53	L	H	-	H	-
HSB108C	186	196	-1	0.98	-1	0.12	-	L	-	L	A
HSB108D	212	232	-1	7.28	-1	16.29	-	H	-	H	A
HSB109C	168.4	178.4	0.82	0.95	-1	7.53	H	L	-	L	-
HSB109D	213	233	0.81	5.23	-1	10.77	H	H	-	H	A

(1) Well ID	(2) z bot (ft)	(3) z top (ft)	(4) %sand	(5) slug Kh (ft/d)	(6) pump Kh (ft/d)	(7) modl Kh (ft/d)	(8) sand trend	(9) slug trend	(10) pump trend	(11) model trend	(12) Agree/ Dis-agree
HSB110C	171.4	181.4	-1	0.71	-1	6.64	-	L	-	L	A
HSB110D	211.4	231.4	-1	23.87	-1	13.96	-	H	-	H	A
HSB111C	140.7	150.7	0.73	1.65	-1	11.7	L	L	-	H	D
HSB111E	211.7	231.7	0.89	38.2	-1	8.64	H	H	-	L	D
HSB112C	140.6	150.6	-1	4.17	-1	10.57	-	H	-	H	A
HSB113C	151.7	161.7	0.84	0.99	-1	9.4	H	L	-	L	-
HSB113D	216.2	236.2	0.65	4.73	-1	13.53	L	H	-	H	-
HSB114C	185.6	195.6	-1	2.86	-1	10.38	-	L	-	H	D
HSB114D	212.8	232.8	-1	3.46	-1	13.71	-	L	-	H	D
HSB115C	182.8	192.8	0.84	0.46	-1	1.15	H	L	-	L	-
HSB115D	213.9	233.9	0.74	1.47	-1	10.19	L	L	-	H	D
HSB116C	180.5	190.5	-1	4.36	-1	7	-	H	-	L	D
HSB116D	214.5	234.5	-1	1.71	-1	8.53	-	L	-	L	A
HSB117A	84.8	94.8	0.91	0.16	-1	10.18	H	L	-	H	-
HSB117C	165.1	175.1	0.88	0.57	-1	9.68	H	L	-	L	-
HSB117D	200.3	220.3	0.71	7.2	-1	15.35	L	H	-	H	-
HSB118A	91	101	0.86	12	-1	12.6	H	H	-	H	A
HSB122A	85.4	95.4	0.86	6.8	-1	14.11	H	H	-	H	A
HSB125C	145.6	155.6	-1	0.86	-1	9.65	-	L	-	L	A
HSB125D	199.4	219.4	-1	5.67	-1	14.69	-	H	-	H	A
HSB126C	176.3	181.3	-1	56.7	-1	4.46	-	H	-	L	D
HSB126D	190.5	200.5	-1	1.29	-1	10.35	-	L	-	H	D
HSB127C	148.4	158.4	-1	0.82	-1	14.16	-	L	-	H	D
HSB127D	197.8	217.8	-1	13.63	-1	17.44	-	H	-	H	A
HSB129C	147.8	157.8	-1	0.55	-1	7.89	-	L	-	L	A
HSB129D	185.2	205.2	-1	2.78	-1	14.49	-	L	-	H	D
HSB130C	159.9	169.9	-1	70.85	94.5	59.89	-	H	H	H	A
HSB130D	182.1	202.1	-1	0.45	0.26	4.84	-	L	L	L	A
HSB131C	148.5	158.5	-1	136	-1	32.47	-	H	-	H	A
HSB131D	195.7	205.7	-1	6.77	65.96	21.26	-	H	H	H	A
HSB132C	168.6	178.6	-1	0.28	-1	4.99	-	L	-	L	A
HSB132D	206.5	226.5	-1	6.3	-1	15.17	-	H	-	H	A
HSB133D	208.5	228.5	-1	0.08	-1	8.66	-	L	-	L	A
HSB134C	149.1	159.1	-1	1.31	-1	10.74	-	L	-	H	D
HSB134D	205.8	225.8	-1	7.01	-1	19.06	-	H	-	H	A

(1) Well ID	(2) z bot (ft)	(3) z top (ft)	(4) %sand	(5) slug Kh (ft/d)	(6) pump Kh (ft/d)	(7) modl Kh (ft/d)	(8) sand trend	(9) slug trend	(10) pump trend	(11) model trend	(12) Agree/ Dis- agree
HSB135C	147.3	157.3	-1	20.01	-1	14.56	-	H	-	H	A
HSB136C	160.5	170.5	-1	0.61	-1	4.48	-	L	-	L	A
HSB136D	200.2	220.2	-1	9.05	-1	17.19	-	H	-	H	A
HSB137D	205.3	225.3	-1	2.07	-1	11.8	-	L	-	H	D
HSB139A	87.6	97.6	0.86	3.82	-1	13.12	H	L	-	H	-
HSB139D	206.7	226.7	0.74	6.52	-1	15.21	L	H	-	H	-
HSB140A	81	91	0.9	12	-1	18.2	H	H	-	H	A
HSB140C	161.6	171.6	0.9	0.61	-1	9.01	H	L	-	L	-
HSB140D	194.1	214.1	0.79	4	-1	12.8	H	L	-	H	-
HSB141A	80.6	90.6	0.94	1.9	-1	13.98	H	L	-	H	-
HSB141C	154.7	164.7	0.86	9	-1	13.82	H	H	-	H	A
HSB141D	217.8	237.8	0.72	0.59	-1	8.75	L	L	-	L	A
HSB142C	161.6	171.6	0.9	0.6	-1	10.22	H	L	-	H	-
HSB142D	189.7	199.7	0.62	0.68	-1	0.49	L	L	-	L	A
HSB143C	169.1	179.1	0.93	2.4	-1	14.1	H	L	-	H	-
HSB143D	196.9	216.9	0.75	9.5	-1	12.42	L	H	-	H	-
HSB144A	78.6	88.6	0.95	0.22	-1	15.57	H	L	-	H	-
HSB145C	164.7	174.7	0.8	0.38	-1	6.67	H	L	-	L	-
HSB145D	184.2	194.2	0.88	0.33	-1	7.02	H	L	-	L	-
HSB146A	85.5	95.5	0.87	9.4	-1	16.44	H	H	-	H	A
HSB146C	152.3	162.3	0.76	0.68	-1	7.38	L	L	-	L	A
HSB146D	204	224.1	0.71	1.6	-1	8.1	L	L	-	L	A
HSB147D	215.2	235.2	-1	0.67	-1	7.77	-	L	-	L	A
HSB148C	158.9	168.9	0.78	1.8	-1	10.4	H	L	-	H	-
HSB148D	198.1	218.1	0.87	0.42	-1	9.13	H	L	-	L	-
HSB149D	207	227	-1	2.9	-1	13.21	-	L	-	H	D
HSB150D	206.9	226.9	-1	1.2	-1	13.24	-	L	-	H	D
HSB151C	170.6	180.6	0.88	0.8	-1	10	H	L	-	L	-
HSB151D	197.6	207.6	0.8	2.3	-1	11.65	H	L	-	H	-
HSB152C	173.1	183.1	0.8	0.8	-1	7.25	H	L	-	L	-
HSB152D	197	207	0.87	1.1	-1	10.57	H	L	-	H	-
HSL001D	219.8	239.8	-1	5.51	-1	9.22	-	H	-	L	D
HSL002D	225.2	245.3	-1	1.44	-1	18.88	-	L	-	H	D
HSL003D	233.7	253.8	-1	0.52	-1	10.13	-	L	-	H	D
HSL004D	245	265.1	-1	1.19	-1	8.52	-	L	-	L	A

(1) Well ID	(2) z bot (ft)	(3) z top (ft)	(4) %sand	(5) slug Kh (ft/d)	(6) pump Kh (ft/d)	(7) modl Kh (ft/d)	(8) sand trend	(9) slug trend	(10) pump trend	(11) model trend	(12) Agree/ Dis-agree
HSL005D	247.8	267.7	-1	0.9	-1	10.61	-	L	-	H	D
HSL006A	104.7	114.7	0.92	5.76	-1	0.1	H	H	-	L	D
HSL006AA	18.6	28.6	0.91	5.49	-1	15.19	H	H	-	H	A
HSL006B	127.9	137.9	0.87	0.2	-1	9.33	H	L	-	L	-
HSL006C	157.6	167.6	0.82	4.65	-1	8.37	H	H	-	L	D
HSL006D	243.9	264	0.76	1.32	-1	9.93	L	L	-	L	A
HSL007D	242.3	262.4	-1	1.84	-1	9.93	-	L	-	L	A
HSL008D	248.4	268.4	0.45	1.93	-1	4.8	L	L	-	L	A
M037A	225	227	-1	0.24	-1	7.4	-	L	-	L	A
SDS003A	210.5	230.5	-1	2.75	-1	12.69	-	L	-	H	D
SDS004	185.4	205.4	-1	3.87	-1	12.96	-	L	-	H	D
SDS007A	75	80	-1	0.06	-1	16.96	-	L	-	H	D
SDS012A	136.4	141.4	0.92	1.21	-1	1.79	H	L	-	L	-
SDS012B	186.7	191.7	0.88	0.08	-1	7.02	H	L	-	L	-
SDS017	196.6	216.6	-1	3.31	-1	11.4	-	L	-	H	D
YSC001C	197.5	207.5	0.91	2.4	-1	12.4	H	L	-	H	-
YSC002D	197.9	218	0.83	1.19	-1	11.82	H	L	-	H	-
YSC004C	195.9	205.9	0.8	1.26	-1	9.72	H	L	-	L	-
YSC005A	116	121	0.99	0.71	-1	10.43	H	L	-	H	-

APPENDIX B – DESIGN CHECKING COMMENTS AND RESPONSES/RESOLUTIONS.

Design checking was performed by S. Aleman.

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#	Section/Page/ Paragraph/Line	Comment	Reviewer Initial	Response/Resolution	Reviewer Concur
1	Page iii	Add ACRi and FACT to acronym list. "Limit" should be "Limited". "tank clay confining unit" should be "Tan Clay Confining Unit"		Agreed	Yes
2	Page 1/P1	State that PORFLOW utilizes control volume discretization		Agreed	Yes
3	Page 1/P2/L1	Eliminate "combined" and "contaminant transport" since you are only interested in translating the steady-state groundwater flow model from FACT.		Agreed; text reworded	Yes
4	Page 1/P2	Where is the procedure or algorithm for translating the Darcy velocity field from FACT to PORFLOW documented?		Process is undocumented; revised text states this fact.	Yes
5	Page 1/P3	Instead of using "drawback" I would just emphasize the differences between the element/cell numbering.		Agreed; "drawback" replaced with "issue"	Yes
6	Page 1/P4	Change "drawback" to "differences". Emphasize using the same code (PORFLOW) for both groundwater flow and transport simulations.		Agreed	Yes
7	Page 1/P5	The verification and validation testing should be addressed in the "Software Quality Assurance Plan for the PORFLOW code" for the version of the code you plan to use for PA work.		Text revised to tie V&V testing for PORFLOW version 5.95.0 documented in present report to the PORFLOW Software QA Plan	Yes
8	Page 3/P2	Highly distorted elements in FACT do not present a problem numerically for the influence matrix formulation or 2-point Gauss-Legendre quadrature. The Gaussian quadrature option provides a superior representation of the Darcian velocity field for highly distorted elements.		Text revised as suggested	Yes
9	Page 3/P2	You mentioned concern about low Courant numbers. Is there any concern about high cell Peclet numbers?		I don't think so. Smaller cells are beneficial: $Pe = \frac{v\Delta x}{D} < 2$ However, "low cell Courant" corrected to read "high cell Courant" number: $Co = \frac{v\Delta t}{\Delta x} < 1$	NC
10	Page 3/P6	Section 2-5 should be Section 2.5		Agreed	Yes
11	Page 3/P7	What was the rationale for applying both recharge/drain and GH boundary conditions at the same node in the GSA/FACT model?		Not sure. Possibly an oversight, or possibly done as a convenience (easy to specify recharge/drain over entire top surface)	Yes

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#	Section/Page/ Paragraph/Line	Comment	Reviewer Initial	Response/Resolution	Reviewer Concur
12	Page 4/Eq. 2-1	Provide the reference for Eq. 2-1.		No reference exists. The equation was invented to mitigate numerical convergence problems. "chosen" added to text for clarification	Yes
13	Page 4/P1	Change section 2-4 to Section 2.4.		Agreed	Yes
14	Page 4/P3	Change section 2-5 to Section 2.5.		Agreed	Yes
15	Page 4/P5	Please clarify explanation on how prescribed head boundary conditions are applied in PORFLOW.		Text rewritten to be more clear.	Yes
16	Page 4/P7	Elaborate on how the recharge/drain or equivalent BC is implemented within the PORFLOW framework.		Additional explanation provided in Section 2.4, now entitled "Implementation of Recharge/Drain BC"	Yes
17	Page 5/P1	Change section 2-5 to Section 2.5. section 2-6 should be changed to Section 2.5.		Agreed	Yes
18	Page 5/P3	What is the justification for setting the horizontal and vertical conductivities in the vadose zone to 0.1 ft/d? Change "straight down" to "vertically downward". How does the homogeneous and isotropic nature of the K field ensure vertical moisture movement in the vadose zone? To ensure vertical moisture movement, the horizontal components of the hydraulic conductivity tensor (product of relative permeability and saturated conductivity) have to be set to zero in the vadose zone. How do you implement that in PORFLOW?		Text rewritten to provide better explanation/justification. The horizontal components are not set to zero, because some horizontal movement is acceptable.	Yes
19	Page 5/P4	The recharge/drain BC introduces numerical nonlinearity. Remove or rewrite sentence discussing numerical instability.		Agreed	Yes
20	Page 5/P5	Why did you not use a Cauchy (mixed) boundary condition to simulate the FACT recharge/drain BC? Can you show mathematically, how the calculation sequence given in Section 2.4 is equivalent to the recharge/drain BC.		Cauchy/mixed BC providing recharge/drain functionality is not offered in PORFLOW. Equation (2-2) is the recharge/drain BC. The rest of the algorithm is a Picard iteration to ensure the boundary pressure is synchronized with the recharge/drain flux	Yes
21	Page 5	Section 2.4 is not really dealing with numerical issues but a code deficiency in PORFLOW to emulate the recharge/drain BC. Perhaps you should try to get the code developers of PORFLOW to implement the recharge/drain BC.		The section has been renamed to "Implementation of Recharge/Drain BC". Good suggestion	Yes
22	Page 6/S2.5/P1	Remove "as high as"		Agreed	Yes

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#	Section/Page/ Paragraph/Line	Comment	Reviewer Initial	Response/Resolution	Reviewer Concur
23	Page 6/S2.5/P2	How much longer were the travel times computed by PORFLOW? What was the cause for the differences, other than recharge flux?		A quantitative comparison of travel times was not done - just visual. Differences in the vertical grids and conductivity fields apparently caused some difference in flow direction and speed. Also differences in spatial averaging/interpolation of the K field by the two codes had an impact	Yes
24	Page 6/S2.5	The changes in conductivity values relative to the GSA/FACT model for the three zones described seem pretty large. Is that an artifact of the geometric averaging of hydraulic conductivities used in PORFLOW.		Differences were larger than anticipated. Seems to be a result of the factors mentioned in #23	Yes
25	Page 11	In Figure 2-6 do you mean "horizontal" or "vertical"		Horizontal as in Kh	Yes
26	Page 12	In Figure 2-8 can you show a line that delineates the water table (red line)?		Water table marker added	Yes
27	Page 13/S3.1	Add a Table 3-2 showing the summary statistics for the GSA/FACT model.		Provided in Table 4-4	Yes
28	Page 13/S3.2	In your discussion, groundwater discharge corresponds to negative fluxes. In Figure 3-7, groundwater discharge areas are indicated by positive values.		Text corrected	Yes
29	Page 14	Add a column to Table 3-2 showing the simulated stream baseflows for the GSA/FACT model.		Provided in Table 4-5	Yes
30	Page 15	What is the significance of the model cross-section at I=50?		Caption revised to indicate slice through E Area	Yes
31	Page 19	See Comment 28.		See Comment 28	Yes
32	Page 20/S4.0	Verification and Validation activities should be addressed in the Software Quality Assurance Plan.		Agreed. The V&V tests performed within this project are now related to the PORFLOW Software QA Plan	Yes
33	Page 20/S4.1	Rename section to Global Mass Balance		Disagree. The section contains both global (Table 4-1) and cell-by-cell mass balances (Table 4-2)	Yes
34	Page 20/S4.1/P1	Darcy's law is implicitly satisfied since it is substituted into the continuity equation.		At the theory level, agreed. The purpose of the test is to ensure that Richards equation has been correctly coded	Yes
35	Page 20/S4.1/P2	Your statement about "the net volumetric flow entering the model grid should be zero" is only true if you do not have any internal sources or sinks.		Agreed. Text revised accordingly	Yes
36	Page 21/Table 4-2	Replacing Table 4-2 with a table showing a detailed water budget would be more useful and informative.		Table 4-1 provides a water budget for the entire model domain. Table 4-2 confirms mass conservation on a cell-by-cell basis	Yes

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#	Section/Page/ Paragraph/Line	Comment	Reviewer Initial	Response/Resolution	Reviewer Concur
37	Page 21/S4.2	Section 4.2 should be assessing particle tracking based on the Darcian velocity field generated by PORFLOW. As mentioned in Comment 34, Darcy's law is implicitly satisfied. The issue to address here is how accurately PORFLOW computes the Darcy velocities from the head solution for distorted and non-distorted meshes. Again, this should be addressed in the Software Quality Assurance Plan.		The purpose of the test is to ensure that Richards equation, which contains Darcy's Law, has been adequately implemented. The independent calculation assumes the mesh is mildly distorted as most. This assumption should be consistent with the GSA/PORFLOW mesh, which was designed to minimize mesh distortion	Yes
38	Page 22/S4.4	Change section 5.5 to Section 5.5.		Agreed.	Yes
39	Page 23/S4.5	Table 4-4 should be complemented with a table showing the GSA/PORFLOW results.		Complementary information provided in Table 3-1	Yes
40	Page 23/S4.6	Table 4-5 should be complemented with a table showing the GSA/PORFLOW results.		Complementary information provided in Table 3-2	Yes
41	Page 24/S4.7	How was the solute transport model calibrated in the GSA/PORFLOW model? There is no mention about transport parameter settings (dispersitivities, etc). Provide a more detailed discussion about solute transport calibration.		Some additional description of transport simulations provided	Yes
42	Page 24/S4.8	Remove discussions on mass conservation and Darcy's law per previous comments.		Discussion now related to PORFLOW Software QA Plan	Yes
43	Page 29/S5.0	A recommendation should be made to update the "Software Quality Assurance Plan for PORFLOW" prior to performing PA analyses.		The limited extent of software QA testing of PORFLOW version 5.95.0 is stated, and caution that additional testing would be required for other uses	Yes
44	Page A-1	Fix table labels. Perhaps go to landscape mode. Set Table Heading Rows to repeat.		Agreed	Yes
45	General	Section 3 should discuss the steady-state groundwater flow simulations. Section 4 should be an assessment of particle tracking and solute transport. V&V should be addressed per Comment 7.		Addressed in other comments	Yes

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#	**Section/Page/ Paragraph/Line**		**Comment**	Reviewer Initial	**Response/Resolution**		Reviewer Concur

Reviewer Name	Sebastian Aleman / SEA Print Name / Initials	______________________ Signature	Phone / Location: 5-8040 / 773-42A	Date 11-May-04
Concurrence Signature QA Reviewer	____________/____________/________		Phone / Location:	Date