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MEMORANDUM TO: Stephen S. Koenick, Chief
Low Level Waste Branch
Division of Decommissioning, Uranium Recovery and Waste Programs

THRU: Christepher McKenney, Chief
Risk and Technical Analysis Branch
Division of Decommissioning, Uranium Recovery and Waste Programs

FROM: Cynthia Barr, Senior Risk Analyst
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SUBJECT: TECHNICAL REVIEW OF THE GENERAL SEPARATIONS AREA 2016 AND 2018 PORFLOW MODELS AND ASSOCIATED DOCUMENTATION SUPPORTING THE F-AREA AND H-AREA TANK FARM FACILITY PERFORMANCE ASSESSMENTS AT THE SAVANNAH RIVER SITE, AIKEN, SOUTH CAROLINA (DOCKET NO. PROJ0734)

The U.S. Nuclear Regulatory Commission (NRC) has performed a technical review of a collection of related documents prepared by the U.S. Department of Energy (DOE) that provides information about recent groundwater modeling updates performed for the Savannah River Site (SRS) General Separations Area (GSA) groundwater flow model. The focus of NRC's technical review is on DOE's updated approach to groundwater modeling, model and data support for its approach, and the impact of the updated approach on GSA performance assessments (PAs). This technical review report is focused on the SRS Tank Farms and is associated with several monitoring factors listed in NRC's F-Area and H-Area Tank Farm Facilities (FTF and HTF) monitoring plan entitled, "U.S. Nuclear Regulatory Commission Plan for Monitoring Disposal Actions Taken by the U.S. Department of Energy at the Savannah River Site F-Area and H-Area Tank Farm Facilities in Accordance with the National Defense Authorization Act for Fiscal Year 2005" [available using Agencywide Documents Access and Management System (ADAMS) Accession No. ML15238A761], issued in October 2015, including the following:

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- Monitoring Factor 4.2, "Calcareous Zone Characterization,"
- Monitoring Factor 4.3, "Environmental Monitoring,"
- Monitoring Factor 6.2, "Model and Parameter Support, and
- Monitoring Factor 6.3, "Tank Farm PA Revisions"

The purpose of the GSA flow model is to provide information on groundwater flow vectors (flow direction and speed) for use in "local" flow and transport models on the GSA including the FTF and HTF PA flow and transport models. Hence, the GSA flow model affects dilution and travel times of key radionuclides to the compliance boundary in DOE's PAs. As indicated by NRC staff analyses (e.g., Barr et al., 2013), dilution is expected to reduce radionuclide concentrations released from the tanks by one to two orders of magnitude during transport to the compliance boundary downgradient from the tank farm facilities. Uncertainty in the amount of dilution in the far-field model is expected to be less than an order of magnitude for all the disposal facilities and was considered of moderate risk-significance in previous NRC staff evaluations. Travel times can affect the amount of radiological decay and attenuation of key radionuclides to the compliance boundary in the far-field model. Increased travel times would lead to increased radiological decay for relatively short-lived radionuclides and increased travel times coupled with sorption could lead to significant reductions in radionuclide concentrations during transport to the compliance boundary for relatively sorptive, non-continuous sources. Increased travel times could lead to reductions in radionuclide concentrations of an order of magnitude or more for certain key radionuclides such as Strontium (Sr)-90, Cesium (Cs)-137, and Plutonium (Pu)-239. Furthermore, travel time can be important if DOE relies on the timing of risk-significant releases that lead to doses above the performance objective occurring beyond the compliance period.

In this report, there is no significant change to the NRC staff overall conclusions from the FTF and HTF TERs regarding compliance of DOE disposal actions with Title 10 of the Code of Federal Regulations (10 CFR) Part 61 performance objectives. The NRC staff concludes that the updated GSA PORFLOW model makes nominal improvements to the predecessor 2004 GSA PORFLOW model used for the FTF and HTF PAs. Consistent with previous findings, NRC staff continues to regard the far-field model as being of moderate risk-significance. In addition, DOE should consider the following in future updates to the GSA PORFLOW model to increase accuracy and reduce uncertainty in contaminant flow and transport modeling:

- More extensive calibration in the areas of interest for waste disposal activities, including FTF and HTF, and evaluation of calibration statistics local to these areas;
- Hydraulic conductivity measurements near HTF and other areas where additional data collection is important to model calibration to reduce uncertainty in calibrated parameters;
- Evaluation of more recent baseflow measurements for model validation consistent with the time over which water level measurements were averaged to develop calibration targets, and consideration of uncertainty in baseflow to Upper Three Runs Creek when evaluating model performance;
- Evaluation of the sensitivity of the results to changes in recharge, and other parameters;
- Sensitivity analysis to identify observations and parameters most important to the results where additional data collection could be conducted to reduce model uncertainty; and
- More extensive analysis of the impact of flow model and parameter uncertainty on the results of the PAs.

Collection of new data and more focused calibration near the Saltstone Disposal Facility (SDF) appear to have led to more significant changes in the modeled flow field in this area. A separate technical review report will be published related to the impact of the updated model on the SDF PA.

Enclosure:
Technical Review of 2016 and 2018 GSA PORFLOW Model Documentation

SUBJECT: TECHNICAL REVIEW OF THE GENERAL SEPARATIONS AREA 2016 AND 2018 PORFLOW MODELS AND ASSOCIATED DOCUMENTATION SUPPORTING THE F-AREA AND H-AREA TANK FARM FACILITY PERFORMANCE ASSESSMENTS AT THE SAVANNAH RIVER SITE, AIKEN, SOUTH CAROLINA (DOCKET NO. PROJ0734) **DATE: December 17, 2019**

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Technical Review of 2016 and 2018 General Separations Area PORFLOW Model Documentation

Date: December 17, 2019

Technical Reviewers:

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Primary 2018 GSA PORFLOW Documents Reviewed:

1. Q-SQP-G-00004. Whiteside, T.S. "Software Quality Assurance Plan for PEST." Revision 0, Aiken, SC: Savannah River National Laboratory. May 2016. [ML18117A444].

2. SRNL-STI-2015-00115. Flach, G.P. "Velocity Field Calculation for Non-Orthogonal Numerical Grids." Revision 0, Aiken, SC: Savannah River National Laboratory. March 2015. [ML19345D296].

3. SRNL-STI-2015-00351. Hiergesell, R.A., G.A. Taylor, M.A. Phifer, T.S. Whiteside, and G.P. Flach. "General Separations Area (GSA) Groundwater Model Calibration Targets." Revision 0, Aiken, SC: Savannah River National Laboratory. August 2015. [ML18107A071].

4. SRNL-STI-2016-00261. Bagwell, L.A. and G.P. Flach. "General Separations Area (GSA) Groundwater Flow Model Update: Program and Execution Plan." Revision 0, Aiken, SC: Savannah River National Laboratory. April 2016. [ML18107A108].

5. SRNL-STI-2016-00516. Bagwell, L.A., P.L. Bennett, and G.P. Flach. "General Separations Area (GSA) Groundwater Flow Model Update: Hydrostratigaphic Data." Revision 0, Aiken, SC: Savannah River National Laboratory. February 2017. [ML19067A177].

6. SRNL-STI-2017-00008. Flach, G.P., L.A. Bagwell, and P.L. Bennett. "Groundwater Flow Simulation of the Savannah River Site General Separations Area." Revision 1, Aiken, SC: Savannah River National Laboratory. September 6, 2017. [ML18081A304].

7. SRNL-STI-2018-00336. Wohlwend, J.L. "Updated General Separations Area (GSA) Groundwater Model Calibration Targets." Revision 0, Aiken, SC: Savannah River National Laboratory. July 2018. doi: 10.2172/1463289. [ML19053A383].

8. SRNL-STI-2018-00643. Flach, G.P. "Updated Groundwater Flow Simulations of the Savannah River Site General Separations Area." Revision 0, Aiken, SC: Savannah River National Laboratory. January 15, 2019. [ML19053A383].

9. SRNL-TR-2015-00061. Flach, G.P. "Code Selection for General Separations Area Flow Simulation and Model Calibration." Revision 0, Aiken, SC: Savannah River National Laboratory. March 2015. [ML18117A347].

PA Impact Documentation:

1. SRNL-STI-2017-00445. Flach, G.P. and T. Hang. "Impacts of Updated GSA Groundwater Flow Models on the FTF, HTF and SDF PAs." Revision 0, Aiken, SC: Savannah River National Laboratory. September 6, 2017. [ML18081A308].

2. SRNL-STI-2018-00624. Hamm, L.L., S.E. Aleman, T.L. Danielson, and B.T. Butcher. "Special Analysis: Impact of Updated GSA Flow Model on E-Area Low-Level Waste Facility Groundwater Performance." Revision 0, Aiken, SC: Savannah River National Laboratory. December 2018. [ML19345D316].

3. SRNL-STI-2018-00652. Flach, G.P. and T. Hang. "PORFLOW Simulations Supporting the Saltstone Performance Assessment." Revision 0, Aiken, SC: Savannah River National Laboratory. December 2018. [ML19345D317].

4. SRR-CWDA-2017-00068. Mangold, J. and B. Lester. "Evaluation of Impacts to FTF and HTF PA Doses Due to the Update of the GSA Database." Revision 0, Aiken, SC: Savannah River Remediation, LLC. October 2017. [ML18081A322].

5. SRR-CWDA-2017-00068. Mangold, J. "Evaluation of Impacts to FTF and HTF PA Doses Due to the Update of the GSA Database," Revision 1, Aiken, SC: Savannah River Remediation, LLC. September 2019. [ML18081A322].

Summaries of the primary documents describing the Savannah River Site (SRS) General Separations Area (GSA) PORFLOW modeling update, listed above, are provided in Appendix A, along with related documents describing Performance Assessment (PA) impacts.

In preparation for a planned 2018 E-Area PA revision, DOE decided that SRS's 2004-era GSA/PORFLOW model (WSRC-TR-2004-00106) would be replaced with a new PORFLOW v. 6.42.3 (later 6.42.4) groundwater flow and contaminant transport model (i.e., GSA 2016) that would be developed using newly available site data, and calibrated for its material properties using automated inverse modeling procedures with the semiautomated "Parameter ESTimation"/optimization software (PEST) v. 13.6 in estimation mode (SRNL-STI-2015-00351; SRNL-TR-2015-00061). More recent site characterization and groundwater monitoring data are available for use in model development, calibration, and validation than were used 15 years ago during development of the previous GSA/PORFLOW model (WSRC-TR-2004-00106). Subsequently, further refinement of the preferred GSA 2016 material property model in 2018 (i.e., GSA 2018) corrected and updated the material property model calibration targets, represented recent closure of the H-Area Ash Basin and construction of E-Area Low-Level Waste Facility (LLWF) Slit Trench operational covers with new local recharge boundary conditions, and incorporated some GSA contaminant plume information from the GSA groundwater monitoring program into model calibration and validation efforts (SRNL-STI-2018-00643).

This technical review report (TRR) reviews DOE documentation supporting the GSA 2016 and GSA 2018 groundwater models, with a focus on topics that are risk-significant, and DOE documentation of its evaluation of the perceived impacts of the groundwater model updates on PA contaminant transport modeling for F-Area Tank Farm Facility (FTF) and H-Area Tank Farm Facility (HTF). Although the focus of this TRR is on the Tank Farms, because the GSA model domains also encompass the Saltstone Disposal Facility (SDF), some information on the SDF is also included in this TRR. A separate TRR will be prepared documenting staff's more thorough review of the impact of the updated GSA model on the SDF PA.

<u>NRC Staff Evaluation</u>:

Background

DOE issued waste determinations and associated PAs for the FTF, HTF, and SDF on the GSA of the SRS near Aiken, South Carolina. Nuclear Regulatory Commission (NRC) staff reviewed DOE's waste determinations and PAs and issued Technical Evaluation Reports (TERs) summarizing the results of its reviews (NRC, 2011 [FTF TER]; NRC, 2012 [most recent SDF TER]; and NRC, 2014 [HTF TER]). Each of the PAs relied on the same saturated zone flow model constructed for the entire GSA (referred to as the 2004 GSA/PORFLOW model) to simulate contaminant fate and transport for each of the disposal facilities in separate local transport models. During its review, NRC staff identified a number of issues with the 2004 GSA/PORFLOW flow model and parameters and documented these issues in its TERs. In its FTF TER, for example, NRC staff indicated that DOE should provide greater transparency and traceability of flow model calibration, including consideration of more extensive calibration focused strictly on the disposal facility's immediate area of interest. In the HTF TER, NRC staff more strongly indicated that the model may not be sufficiently calibrated local to HTF and recommended that DOE study uncertainty in well water-level calibration targets and provide support for hydraulic conductivity assignments (e.g., K_h [horizontal hydraulic conductivity] was artificially lowered locally near HTF during the calibration process but the calibrated values were not corroborated by characterization data). Importantly, NRC staff recommended that DOE consider conducting pumping tests to provide support for the final calibrated hydraulic conductivities in upper aquifer zones near HTF.

To provide context for the risk-significance of TER findings, NRC staff performed extensive modeling and barrier analysis to prioritize technical issues and focus its monitoring activities. The GSA flow model provides information on groundwater flow vectors (flow direction and speed) used in the "local" FTF and HTF flow and transport models as described above. Hence, the GSA flow model affects dilution and travel times of key radionuclides to the compliance boundary in DOE's PAs. As indicated by NRC staff analyses (e.g., Barr et al., 2013), dilution is expected to reduce radionuclide concentrations released from the tanks by one to two orders of magnitude during transport to the compliance boundary downgradient from the tank farm facilities. Uncertainty in the amount of dilution in the far-field model is expected to be less than an order of magnitude for all the disposal facilities and was considered of moderate risk-significance in previous NRC staff evaluations. Travel times can affect the amount of radiological decay and attenuation of key radionuclides to the compliance boundary in the far-field model. Increased travel times would lead to increased radiological decay for relatively short-lived radionuclides[1] and increased travel times coupled with sorption could lead to significant reductions in radionuclide concentrations during transport to the compliance boundary for relatively sorptive[2], non-continuous (pulse) sources. Increased travel times could lead to reductions in radionuclide concentrations of an order of magnitude or more for certain

[1] Short-lived with respect to the travel time to the compliance boundary.
[2] Radionuclides with transport times to the compliance boundary (considering retardation due to sorption) that exceed the source release time.

key radionuclides such as Sr-90, Cs-137, and Pu-239. Furthermore, travel time can be important if DOE relies on the timing of risk-significant releases that lead to doses above the performance objective occurring beyond the compliance period. Due to the difficulty in updating the regional flow model for the GSA, upon which the individual waste disposal facility PAs are based, and due to the moderate risk-significance of the far-field flow model, NRC staff did not expect DOE to address far-field modeling issues in the short-term and instead planned to monitor DOE's progress in this area under longer-term PA maintenance activities under Monitoring Area 6, "Performance Assessment Maintenance", Monitoring Factor (MF) 6.2, "Parameter and Model Support", and MF 6.3, "Tank Farm PA Revisions". DOE has recently completed activities related to two updates of the GSA PORFLOW model. As part of its monitoring responsibilities, NRC staff reviewed DOE's documentation to assess the potential impact of the revised models on PA modeling

NRC staff also developed two related MFs under MA 4, "Natural System Performance", related to far-field model performance. MF 4.2, "Calcareous Zone Characterization", describes NRC staff's intent to monitor DOE's efforts to reduce uncertainty related to the potential performance impact of calcareous zones located in the lower aquifer zone of the Upper Three Runs Aquifer (UTRA-LAZ). While DOE notes that no noticeable impact of calcareous zones on hydraulic head or contaminant transport is reflected in groundwater monitoring data, NRC staff concluded that additional information was needed to support the decision that the zones need not be explicitly considered in DOE's models. Tracer testing or downhole imaging of water velocities could be used to better understand the influence of these zones on contaminant transport.

The second related MF under MA 4, "Natural System Performance", is MF 4.3, "Environmental Monitoring." NRC staff has previously evaluated groundwater monitoring well data, as well as DOE's tank farm monitoring well networks under this MF. NRC staff uses DOE environmental monitoring reports to assess the adequacy of DOE's PA models in predicting contaminant flow and transport in the subsurface at FTF and HTF. A separate TRR that more thoroughly evaluates recently published environmental monitoring reports will be issued concurrently with this TRR.

Evaluation of Model Construction and Hydrostratigraphy

The GSA 2016 and 2018 PORFLOW model computational meshes have the same lateral, upper, and lower boundaries as the previous 2004 model (WSRC-TR-2004-00106), and up to 21 model layers (see Appendix B of SRNL STI-2017-00008, Rev. 1). Although not discussed in documentation, the GSA 2016 and GSA 2018 model meshes were further refined relative to the mesh of the previous model, which had used areally larger mesh elements near the model boundaries than it had in the center. The new model mesh is comprised of areally square mesh elements throughout the domain, including the edges, and all mesh elements are approximately of the same lateral size, i.e., ~61 m × ~61 m [~200 ft × ~200 ft] (SRNL STI-2017-00008, Rev. 1; SRNL-STI-2018-00643). The number of model layers for each hydrostratigraphic unit (HSU) also appears consistent with the predecessor (2004) GSA/PORFLOW model. The Gordon Aquifer Unit (GAU) consists of two model layers; the Gordon Confining Unit (GCU) consists of two model layers, where present; the Lower Aquifer Zone (LAZ) of the Upper Three Runs Aquifer (UTRA) has one to five model layers, where present; the Tan Clay Confining Unit (TCCU) consists of two model layers, where present; and the Upper Aquifer Zone (UAZ) of the UTRA is represented by up to 10 layers.[3] Where an HSU is represented with less than the

[3] The UAZ of the UTRA is further divided into the Transmissive Zone (TZ) immediately above the TCCU, and the combined A/AA or AAA zone above the TZ. The TZ has one to three model layers, where present; and the AAA zone

maximum number of model layers, the difference is due to outcropping of HSUs and truncation of model layers at the surface to avoid creation of very thin layers in areas where aquifers, aquitards, and confining units pinch out (e.g., see representative cross-section in Figure 3-1 of SRNL-STI-2017-00008, Rev. 1, which shows relatively uniform model layer thicknesses).

More recent site characterization data (Cone Penetrometer Test or CPT curves, geophysical logs, and lithologic core descriptions) collected since the predecessor Flow and Contaminant Transport (FACT) model was first constructed were selected[4] and imported into RockWorks. The selected new borehole data were merged with existing data, which were used as a baseline to aid with interpretation of the new borehole data. In some cases, the baseline data were reinterpreted. Interpretations were made along section lines that were oriented to the geologic strike and dip (SRNL-STI-2016-00516). RockWorks was used to produce altitude contour maps (using a 20 m square grid) from the pick elevations for each HSU using geostatistical methods. The grid data were imported to ArcGIS software to produce raster data, which were then interpolated to more than 45,000 GSA PORFLOW model element locations. Although new wells were drilled after development of the GSA PORFLOW 2016 model that could have been used to determine tops of HSUs for the GSA PORFLOW 2018 model, no effort was made to use additional well information collected between development of the GSA PORFLOW 2016 and 2018 models.

DOE's PORFLOW update execution plan stated that they intended to evaluate both (i) the incremental impact of including new monitoring data, and (ii) the incremental impact of using the newly refined hydrostratigraphy model (SRNL-STI-2016-00261); but it is unclear to NRC staff that the latter impact evaluation was ever performed. Nonetheless, the approach to update the model layers using what appears to be a more internally consistent and complete set of hydrostratigraphic picks is expected to lead to improvements in model performance. NRC staff has no significant issues associated with DOE's updated hydrostratigraphic model. Future updates to the hydrostratigraphy and any impact analysis will be evaluated under MF 6.2, "Model and Parameter Support", and MF 6.3, "Tank Farm PA Revisions".

Evaluation of Boundary Conditions

A combined recharge/drain boundary condition was applied to the top boundary using a new option in PORFLOW version 6.42.3. A general head boundary condition of 55 m [180 ft] was applied to the base of the GSA 2016 and GSA 2018 models. This corrected an unintentional error in the boundary condition applied to the base of the GSA/PORFLOW 2004 model, which had been 59 m [195 ft] (SRNL STI-2017-00008, Rev. 1). Side boundary conditions were unaltered during recent model updates. For the UTRA, no-flow boundary conditions were imposed on all sides, generally beneath streams, except for on the west end, where a specified hydraulic head was prescribed. For the GAU, no-flow boundary conditions were prescribed beneath the Upper Three Runs Creek (UTR; northern boundary) and specified hydraulic heads were prescribed along the remaining lateral model boundaries. NRC staff has no significant

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has one to seven model layers, where present. While the UAZ is divided into the TZ and AAA, hydrostratigraphic "picks" are only actually made for the top of the TCCU (cf. WSRC-TR-99-00248). The separation of the TZ from the AAA in the UAZ was based on earlier work by Flach and associated model calibration (SRNL-STI-2017-00008, Rev. 1). The total thickness of the TZ is approximately 10 m (30 ft). The TZ correlates with the Irwinton Sand Member of the Dry Branch Formation (Fallaw and Price, 1992); due to its transmissive nature, it is thought to be the primary pathway for contaminant transport in the UAZ.

[4] Selection of new borehole data for use in constructing the HSU surfaces favored locations where original data were sparse and where new borehole data were relatively long, deep, and continuous.

issues associated with the assignment and corrective reassignment of model boundary conditions.

Evaluation of Hydraulic Conductivity

Hydrogeologic units at the GSA were characterized for hydraulic conductivity through the mid-1990s with data obtained from approximately 85 large- and small-scale pumping tests, 481 slug tests, and 258 laboratory permeability tests; these hard data were extrapolated further in association with approximately 37,500 visually based descriptions of recovered sediment core using correlations to mud fraction (WSRC-TR-96-0037; WSRC-TR-96-0399, Rev. 1, Vol. 2). Approximately two decades ago, drilling was supplanted by CPTs for field characterization, and DOE notes that relatively little borehole data-based hydraulic conductivity data has recently been gathered, as a result (SRNL-STI-2017-00008, Rev. 1).

DOE indicates that groundwater monitoring data play a more significant role in defining the calibrated model hydraulic conductivity field, and no attempt was made to update the existing datasets (SRNL-STI-2017-00008, Rev. 1). In response to an NRC staff question during the August 2018 Onsite Observation Visit (OOV), for example, DOE indicated that it has not obtained recent additional hydraulic conductivity data in the vicinity of H-Area, despite NRC staff's TER conclusion regarding the likely need for collection of additional hydraulic conductivity data to improve model calibration (NRC, 2014). Hydraulic conductivity data could have been used to better constrain calibration parameters in the updated GSA PORFLOW models in an area of the GSA model domain that is especially problematic with respect to model calibration, given in part to its position on a groundwater divide.

During the March 2019 OOV, DOE provided information about the evolution of the modeled vertical hydraulic conductivity, K_v, of the GCU/Green Clay throughout the history of flow modeling of the GSA. Whereas the GSA/PORFLOW model assumed a K_v of 3×10^{-6} m/d (1×10^{-5} ft/d) for the GCU (WSRC-TR-2004-00106), the GSA 2016 model adopted a value of 2.3×10^{-5} m/d (7.5×10^{-5} ft/d) to achieve better agreement with well water-level calibration targets (SRNL STI-2017-00008, Rev. 1), honor longstanding unit characterization data (WSRC-TR-96-0399, Rev. 1) and regional groundwater flow modeling (WSRC-TR-99-00248), which indicated GCU $K_v \cong 3 \times 10^{-5}$ m/d (1×10^{-4} ft/d). The GSA 2018 model update reverted to assuming a K_v of 3×10^{-6} m/d (1×10^{-5} ft/d) for the GCU to better match contaminant plume data (SRNL-STI-2018-00643). Because the GCU K_v assigned to the GSA 2018 model was 7.5 times smaller than that assigned to the GSA 2016 model, groundwater leakage into the GAU was reduced and groundwater travel preferentially occurred to a greater degree in the shallow, near-surface HSUs (SRNL-STI-2018-00643). As a result, fewer particle trajectories exhibit kinks that illustrate water passing into the GAU, and the particle trajectories tend to discharge at the ground surface more quickly than if travel partially occurred in the GAU (SRNL-STI-2018-00643).

The change in GCU K_v in the GSA 2018 model does not appear to be supported by previous investigations and characterization data. DOE indicates that the change in GCU K_v was based on backwards particle tracking simulations, alone. The backwards particle tracking simulations indicated that the lower GCU K_v better matched the expected source of contaminant plumes in a small area of the model domain outside the area of interest for the PAs reviewed by the NRC (particle tracks were associated with the mixed waste management facility or MWMF). It appears that no effort was made to evaluate the sensitivity of calibration results to this rather significant change to the GCU K_v; therefore, NRC staff will continue to evaluate the appropriateness of the selected value for the GSA 2018 model. NRC staff will continue to monitor DOE developments related to hydraulic conductivity assignments under MF 6.2, "Model and Parameter Support", and MF 6.3, "Tank Farm PA Revisions".

Another source of uncertainty in the GSA groundwater flow and transport models continues to be the treatment of so-called calcareous "soft zones," located in the UTRA-LAZ (WSRC-TR-99-4083; SRNL-TR-2012-00160) in two horizons (i.e., in the Santee Formation and in the lowermost Dry Branch Formation). NRC first identified this technical issue during the FTF review (NRC, 2011). During the FTF, SDF, and HTF reviews, DOE provided additional information regarding the occurrence and impact of soft zones on groundwater flow and contaminant transport (e.g., SRR-CWDA-2010-00128; SRNL-TR-2012-00160; WSRC-TR-99-4083). In its FTF and HTF TERs, NRC concluded that additional information was needed to assess the potential impact of calcareous zones in the GSA on groundwater flow and contaminant transport (ML15238A761). DOE could monitor flow velocities at well-screen elevations both consistent and inconsistent with known soft zones to assess the presence or absence of local fast flow paths. The GSA 2016 and 2018 PORFLOW modeling updates have not yet addressed the NRC-staff-identified issues related to the treatment of calcareous soft zone hydraulic conductivities in the UTRA-LAZ. DOE previously suggested, however, a potential willingness to perform outcrop mapping of seeps (NRC, 2011) and tracer tests, which could provide new model support. NRC staff are monitoring DOE developments in this area under MF 4.2, "Calcareous Zone Characterization", MF 6.2, "Model and Parameter Support", and MF 6.3, "Tank Farm PA Revisions".

Evaluation of Soil Characteristic Curves

The GSA 2016 and 2018 PORFLOW model domains continue to include the vadose zone to enable varying seepline locations and recharge between and within optimization case iterations. Previously, pseudo-soil-characteristic curves that exhibit less non-linearity than actual characteristic curves were used for all soil types in the vadose zone and the saturated hydraulic conductivity field was made relatively uniform and isotropic in the vadose zone (when compared to the saturated zone) to encourage vertical flow. The pseudo-soil-characteristic curves used in the GSA 2016 and GSA 2018 models were generated from the tabulated values in Table 1. These values are different from those previously used (cf. Figure 2-7 in WSRC-TR-2004-00106). However, in all cases, the approach used attempts to facilitate flow of infiltrating groundwater from the land surface to the water table and appears to be a reasonable modeling simplification to simulate vadose zone flow in the regional GSA 2016 and 2018 models, which are focused on saturated zone flow.

Saturation	Suction Head
0.4	10
0.7	5
0.9	2
1	0

a

Saturation	Relative Permeability
0.4	1
0.6	1
0.8	1
1	1

b

Table 1 - Saturation vs. Suction Head (a) and Saturation vs. Relative Permeability (b) in the GSA 2016 and GSA 2018 Models

Evaluation of Recharge

For the GSA 2016 and GSA 2018 PORFLOW model updates, no additional recharge data were used to inform the surficial boundary condition beyond new assumptions related to the effectiveness of existing or planned closure caps and retirement of seepage basins. Therefore, a recharge rate estimate of 380 mm/yr [15 in/yr] (SRNL-STI-2017-00008, Rev. 1) for the GSA was employed, and the parameter was assumed to be uniform away from seepage faces/basins (SRNL-STI-2017-00008, Rev. 1). Seepage areas/basins were assigned a local maxima of ~457 to ~483 mm/yr [~18 to ~19 in/yr]. An average recharge rate over the model domain of ~300 mm/yr [~12 in/yr] (SRNL-STI-2017-00008, Rev. 1) was reported. The range of uncertainty for the uniform recharge rate estimate is 254 to 406 mm/yr [10 to 16 in/yr] (WSRC-TR-99-00248).

GSA 2016 and GSA 2018 simulations assumed uniform recharge. DOE indicates that local recharge across the GSA may vary with elevation, topography, and vegetation cover, and stated that large-scale variation in topography could increase recharge in the center of the model and decrease recharge elsewhere. However, DOE noted that Figures 6-27, -30, -31 and -32 (SRNL-STI-2017-00008, Rev. 1) do not provide compelling evidence for significant, large-scale variations in recharge, and consequently the assumption of uniform recharge was deemed an adequate approximation of physical reality. NRC staff notes that Figures 7-13 through 7-16 show spatial bias in the residuals with the model underpredicting head in the UTRA-UAZ (and in some cases in the UTRA-LAZ) at higher head values, and overpredicting hydraulic head in the UTRA-LAZ at lower head values. Therefore, support for DOE's assumption that uniform recharge is adequate could be improved.

With respect to assumptions regarding the impact of engineered covers, DOE argues that studies of the performance of kaolin closure caps suggest that if they are not overlain by a geomembrane and at least 1.8 m [6 ft] of soil in humid environments, such as at SRS, the caps will return to background infiltration rates within a 2-to-4-yr period (SRNL-STI-2015-00351). For this reason, the capped E-Area MWMF, and the capped F- and H-Area seepage basins were not modeled as reduced infiltration zones in the GSA 2016 and GSA 2018 model updates, but the E-Area Low-Level Radioactive Waste Disposal Facility (LLRWDF)[5] and Old Radioactive Waste Burial Ground (ORWBG)/GSA Consolidation Unit closure caps incorporated a geomembrane that significantly reduces local infiltration. Therefore, the local cap recharge rate at the location of these modeled facilities was set to 10 percent of the 381 mm/yr [15 in/yr] recharge rate (SRNL-STI-2017-00008, Rev. 1), or to 38.1 mm/yr [1.5 in/yr]. In contrast, previous groundwater flow modeling supporting the 2008 E-Area PA had assumed that no E-Area closure caps were in place (SRNL-STI-2018-00624). For the GSA 2018 model update only, the H-Area Ash Basin, which has been removed from service, was assumed to not be a source of artificially enhanced recharge (SRNL-STI-2018-00643). Conversely, operational covers recently placed over closed E-Area slit trenches were assumed to reduce local recharge in the updated GSA 2018 model (SRNL-STI-2018-00643).

DOE assumed recharge was constant (i.e., was not treated as a calibration parameter) to reduce PEST runtime and sidestep issues associated with mathematical non-uniqueness (SRNL-STI-2017-00008, Rev. 1). DOE justified this assumption stating that recharge and hydraulic conductivity cannot both be independently estimated unless stream baseflow measurements are included in the set of calibration targets along with well water-level elevations. DOE also indicates that this approach allows stream baseflow data to be used for model validation (SRNL-STI-2017-00008, Rev. 1).

While availability of baseflow data to help validate the model is useful, NRC staff previously recommended use of baseflow data as a calibration target to avoid issues with non-unique solutions associated with use of well water-level calibration targets alone. Information about baseflow is important to understanding whether the model is well calibrated, particularly in the complex groundwater flow system of the GSA, which includes both deeper and shallower aquifers. While recharge was treated as a constant to allow PEST to fit hydraulic conductivity to water well-level calibration targets, recharge is an uncertain parameter value and more extensive uncertainty and sensitivity analysis related to the impact of homogeneous and constant recharge on the results is needed, particularly given that both the GSA 2016 and GSA 2018 models significantly underpredict baseflow to the UTR and no effort was made to update or evaluate the uncertainty in baseflow.

Comparisons of simulated versus observed baseflow to the UTR show that the calibrated model significantly under-predicts baseflow to the creek. DOE indicates that UTR estimates are uncertain because of (i) the large distance between gaging stations, such that the average rate of gain may not accurately reflect gain along the reach adjoining the model, and (ii) the fraction of groundwater discharge coming from the north and south sides of the UTR is unknown[6]. Dependent on the locations of baseflow measurements on the UTR[7], DOE could divide the UTR into segments and assess goodness-of-fit of modeled versus observed discharge/baseflow to various reaches of the UTR. DOE should also evaluate whether the 50:50 assumption might bias baseflow estimates high or low.

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[5] LLRWDF refers to a RCRA closed facility immediately adjacent to the RCRA closed MWMF and should not be confused with the adjacent Low-Level Waste Facility (LLWF), which refers collectively to all disposal units in the 40.5 ha [100 ac] Solid Waste Management Facility—the LLWF facility continues to operate.

[6] DOE assumes that 50 percent of the baseflow is from the north and 50 percent is from the south of UTR Creek.

[7] NRC requested information on the location of gaging stations on UTR and FMB creeks.

As stated previously, DOE did not quantitatively evaluate uncertainty in baseflow measurements. While NRC staff observed stream gaging stations during the March 2019 OOV (NRC, 2019), DOE contractors working on the GSA PORFLOW model indicated that they were unaware that stream flow data was being collected on GSA streams, which could have been used to develop updated baseflow measurements. If a more representative period of record was used[8] to estimate baseflow (i.e., one that matched the time period over which well water-level measurements were averaged for the purpose of developing calibration targets), the optimized model could be further out of alignment with measured baseflow. Hydrographs of wells with long-term records during the 1973 to 1995 time period and other information could be used to better assess whether the baseflow estimates were biased high or low, and to better quantify the uncertainty in baseflow measurements. However, DOE could also more directly address this issue by evaluating more recent stream flow data and developing updated baseflow information. As stated above, DOE should also evaluate the sensitivity of the results to recharge rates. NRC will continue to monitor these technical issues under MF 6.2, "Model and Parameter Support", and MF 6.3, "Tank Farm PA Revisions".

Evaluation of Calibration Targets

DOE focused updated GSA groundwater model calibration on reproducing steady-state hydraulic heads/well water-level elevations (i.e., "model calibration targets") (SRNL STI-2017-00008, Rev. 1; SRNL-STI-2018-00643). Using an Excel™-based data-processing tool—the Well Hydrograph Analysis Tool (WHAT; SRNL-STI-2015-00034; SRNL-STI-2018-00336)—SRNL staff analyzed GSA water-well data from the Environmental Restoration Data Management System (ERDMS) database to determine a representative subperiod (referred to as the "Base Period") from the full data record that best reflected long-term steady-state groundwater levels on the GSA for use in generating water-level calibration-target elevations (SRNL-STI-2015-00351; SRNL-STI-2018-00336). Wells having historical GSA water-level data became common after 1987. Water-well data associated with time periods characterized by what DOE described as anomalously low or high precipitation totals were intentionally avoided due to the impact of the transient anomalies on water-level elevations across the GSA; therefore, the Base Period is a period during which the running average of precipitation events (as measured onsite at F- and H-Area weather stations) remained relatively constant (SRNL-STI-2015-00351; SRNL-STI-2018-00336). Water-level data collected during time periods when engineered modifications[9] impacted the natural groundwater flow system of the GSA were also intentionally avoided. Using these criteria, the selected Base Period for generating GSA well water-level calibration targets extended from January 1, 2004, through August 1, 2014, for the GSA 2016 model and was extended further through April 1, 2018, for the GSA 2018 model because these recent subperiods followed completion of major environmental remediation actions on the GSA and were otherwise relatively free from transient, precipitation-induced adjustments to long-term regional groundwater levels, thereby providing relatively stable,

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[8] SRNL-STI-2017-000008, Rev. 1 (Section 2.1) indicates that the period of record used to develop baseflow estimates is 1973 to 1995 and that stream baseflows may be biased high relative to the well water-level calibration targets, because rainfall and water levels were higher on average during the 1973–1995 period compared to the 2004–2014 period (Figure 3-2 in Hiergesell et. al., 2015). However, Figure 3-2 from SRNL-STI-2015-00351, Rev. 0, shows a negative cumulative departure from long-term average rainfall for almost all of the 1973 to 1995 time period so it is unclear that average well water levels would be biased high during this time period, although there was a marked increase in rainfall in the early 1990s.

[9] Engineered modifications associated with the environmental remediation program included installation of closure caps, remedial barrier walls, and pump-and-treat water extraction/injection from/to GSA wells, and particularly at the F- and H-Area Seepage Basins.

representative hydrologic conditions and well water-level calibration targets for steady-state groundwater flow modeling (SRNL-STI-2015-00351; SRNL-STI-2018-00336).

The WHAT was used, at first, to process water-level measurements associated with wells during the 2004 to 2014 period and to auto-generate well hydrographs for that period (SRNL-STI-2015-00351). A total of 28,374 water-level measurements from 666 GSA wells were originally used to generate well hydrographs through August 1, 2014 (SRNL-STI-2015-00351); later, 45,667 water-level measurements from 731 wells were used in an analysis (SRNL-STI-2018-00336) that supported the GSA 2018 model update. Wells having fewer than four measured water levels during the Base Period were not considered (SRNL-STI-2015-00351). Spurious measurements (i.e., erroneous or those having an anthropogenic cause) were removed from the hydrographs and water-level elevation statistics were computed from the remaining data for each well.

The version of the WHAT tool that was used to develop GSA 2016 model well water-level calibration targets was found, after-the-fact, to have miscalculated certain water-level elevation statistics, but not the mean water level of each well, which became a potential model calibration target; the WHAT tool was later modified to correct the previous statistical miscalculations (SRNL-STI-2018-00336). Importantly, however, more recent work using the WHAT tool revealed that 26 previously used well water-level calibration targets had been errantly associated with inappropriate HSUs (i.e., hydrostratigraphic units) during the GSA 2016 model update (SRNL-STI-2018-00336), which would have negatively impacted the associated PEST inverse modeling exercises and the final set of calibration parameters. As a result, all well-screen HSU designations were re-evaluated prior to initiating the GSA 2018 model update (SRNL-STI-2018-00336).

For the GSA 2018 model, new mean well water-level calibration targets were defined for 339 UTRA-UAZ wells, 294 UTRA-LAZ wells, 81 GAU wells, 6 TCCZ wells, 9 wells that breach multiple HSUs, and 2 wells screened below the GAU in the Crouch Branch Confining Unit (CBCU), for a total of 731 well water-level calibration targets. In particular, Z-Area well data acquired during the period from 2014 to 2018 was available for use as GSA 2018 calibration targets (SRNL-STI-2018-00336). Between GSA 2016 and GSA 2018 updates, the number of Z-Area wells screened in the UTRA-UAZ increased from three to six, and those screened in the UTRA-LAZ increased from 7 to 11 (SRNL-STI-2018-00643).

Uncertainty in the calibration targets was considered by weighting the calibration targets (or residuals). For example, the hydraulic head residuals were weighted by uncertainty in the water level measurements (i.e., the standard error of the mean) for each well with a lesser weight given to calibration targets exhibiting a larger range of variability in the transient well record, and a greater weight to calibration targets estimated from more water level elevation data (SRNL-STI-2017-00008, Rev. 1). SRNL-STI-2015-00351, Appendix C, provides statistics for each calibration target. Geographic weights were also applied to account for clustering or sparsity of water-well calibration targets across the GSA. The assigned geographic weights for each calibration target/water well are documented in SRNL-STI-2015-00351, Appendix D.

A third type of weighting factor accounted for calibration target density differences between the GSA groundwater aquifers (or HSUs). Equal weight was given to each aquifer by defining a hydrostratigraphic weighting factor, as the inverse of the fraction of the calibration targets associated with each aquifer. Each overall weighting factor, w_i, was limited to a maximum value of 10, or ~10× the median weight, to avoid overemphasis of geographically isolated calibration targets (see SRNL-STI-2017-00008, Rev. 1, Appendix C for overall weight value for each calibration target). In summary, an overall weighting factor, w_i, for the hydraulic head residual from each well i was assigned to account for (i) water-level elevation uncertainty and temporal variability, (ii) the geospatial relationship of the well and its data to other wells and their data (data clustering/sparsity), (iii) and other biases.

As stated in NRC staff's HTF TER (NRC, 2014), NRC recommended DOE improve model calibration particularly local to the H-Area to provide confidence that the modeled level of dilution in the HTF PA was not overstated. NRC staff specifically indicated in its TER that DOE should continue to study uncertainty in calibration targets. Most notably, NRC staff indicated that ongoing remedial activities and operations may have influenced water levels in H-Area wells, confounding the model-calibration process, which is intended to represent long-term conditions in the absence of these types of activities (e.g., ML13196A135 and ML13246S133). Anthropogenic sources of water may have influenced water levels, leading to challenges in calibrating the far-field model. As further stated in the SDF TER (NRC, 2012), calibration that is focused on the waste disposal facility area of interest is particularly desirable. Specifically, with respect to calibration targets at SDF, NRC staff noted the scarcity of data in the area of interest and noted that calibration statistics for all of the GSA does not provide helpful information on the goodness-of-fit of the model to long-term conditions that are local to SDF.

DOE attempted to reduce uncertainty in calibration targets and improve the calibration process through (i) the review of water-level data and associated uncertainty, (ii) the review of operational activities that may have influenced water-level measurements, (iii) review of variability in rainfall data, and (iv) through consideration of biases introduced into the calibration process due to the distribution (clustering) of monitoring well locations. While these activities are expected to have significantly improved the calibration process and reduced uncertainty in the calibration targets, stronger support could have been provided regarding the approach used. For example, DOE did not demonstrate the correlation between rainfall rates and water levels at representative wells on the GSA to lend support to its use of rainfall data as a surrogate for hydraulic head. Figure A-9 in SRNL-STI-2015-00351 shows a fairly stable hydraulic head for well FOB 13D during the 2004 to 2010 time period and then a more significant drop in hydraulic head spanning late 2010 to early 2011, while other wells appear to have a different pattern of response to changes in rainfall rates (see Appendix B, SRNL-STI-2015-00351). DOE could have presented hydrographs for representative wells with long-term data, and/or presented average water levels over various averaging periods to strengthen the basis for the selected time period. Statistical analysis could have been conducted to evaluate the representativeness and assumed stability of the time period selected. For example, Figure 3-2 in SRNL-STI-2015-00351 shows the cumulative departure from long-term average rainfall curve (long-term average rainfall from 1961 to present) with data from the 2004 to 2014 time period showing positive cumulative departure from long-term average rainfall. Additionally, what might be considered significant variability in the cumulative departure from long-term average rainfall appears to occur over this time period.

While DOE developed new wells at Z-Area (e.g., wells beginning with "ZBG" in SRNL-STI-2015-00351, Appendix B) to increase the number of calibration targets in this area of the GSA, the new wells have only been sampled for a couple of years. Therefore, the average water-levels for the newer wells may be biased with respect to the long-term average. As discussed previously, DOE does consider uncertainty in the measurements by weighting the residuals by the inverse of the standard error of the mean, thereby giving preference to calibration targets with a longer period of record. Additionally, wells with less than 4 measurements are omitted from consideration as calibration targets.

Having a technically defensible set of calibration targets is important to ensuring that the model is well calibrated and does not potentially overestimate dilution factors or travel times. While DOE made significant improvements in the calibration process through re-evaluation of calibration targets, additional support for the approach used to develop the calibration targets could be provided, as described here. NRC staff will continue to monitor DOE's efforts in this area under MF 6.2, "Parameter and Model Support", and MF 6.3, "PA Maintenance".

Evaluation of PORFLOW Model Calibration

Parameter Estimation

Using optimization algorithms, such as PEST v. 13.6, to calibrate the input parameters of groundwater models improves the fit of the model to site data, provides statistical information about model uncertainty, and minimizes analyst effort. PEST interfaces with a PORFLOW model by creating model input parameter files and analyzing output text files, which it parses and compares to output from prior model runs. After obtaining initial hydraulic head residuals from the preliminary layer-cake and heterogeneous hydraulic conductivity simulations, PORFLOW model calibration was performed using PEST to vary model input parameters (i.e., hydraulic conductivity, but not recharge) and to calculate the impact of those variations on model output (i.e., hydraulic head) (Doherty, 2016a,b; Q-SQP-G-0004). PEST ran the PORFLOW model and iterated through hydraulic conductivity variations, either for a specified number of times or until parameter values stabilized and convergence criteria were met, per the PEST control file (Doherty, 2016a,b; Q-SQP-G-0004). DOE contractors elected to operate PEST in the estimation mode, using the Gauss–Marquardt–Levenberg method (Watermark Numerical Computing, 2016, Sections 3.3.2 and 3.7) to iteratively adjust hydraulic conductivities in a manner that minimizes an objective function or fitting criterion of the form

$$\varphi = \sum_i (w_i r_i)^2$$

where r_i is the i^{th} hydraulic head residual (i.e., modeled hydraulic head−calibration target) and w_i is the weight estimate assigned to the i^{th} hydraulic head residual; when w_i = unity for all i, the optimization function is unweighted and all residuals, r_i, are treated as if they are equally important to minimize (SRNL-STI-2017-00008, Rev. 1). PEST performs regression using this weighted least-squares optimization method to maximize the efficiency of parameter estimation, giving the i^{th} hydraulic head residual, r_i, an influence or weight, w_i, over the associated hydraulic conductivity estimate. In estimation mode, PEST requires a mathematically well-posed inverse problem; that is, the number of well water-level calibration targets (knowns) must equal or exceed the number of hydraulic conductivities estimated (unknowns). The hydraulic properties of the GAU and the GCU were stated by DOE to be moderately certain, based upon data support and prior modeling studies (SRNL STI-2017-00008, Rev. 1); therefore, PEST optimization of hydraulic conductivity fields was focused solely on the UTRA zones and TCCZ to improve mathematical well-posedness (unique solution available based on the data) and reduce computational time. On the other hand, the UTRA-UAZ was divided into the TZ and the AAA zones, which increased the number of hydraulic conductivity parameters involved in PEST estimation (SRNL STI-2017-00008, Rev. 1).

GSA 2016 and 2018 Model Calibration

During GSA 2016 model calibration, four different optimization/calibration cases were assessed for goodness of fit. Each round of PEST optimization generally considered a 2 × 2 matrix of the following four cases: estimation of layer-cake vs. heterogeneous hydraulic conductivity fields, and use of unweighted vs. weighted hydraulic head residuals (SRNL-STI-2017-00008, Rev. 1). Altogether, 53 PEST simulations were conducted. All optimization cases run with PEST included global multipliers to the baseline (or initial) UTRA-LAZ, TCCZ, TZ, and AAA zone hydraulic conductivity fields (SRNL-STI-2017-00008, Rev. 1). Elliptical or polygonal regions were added locally to the model for H- and Z-Areas to improve model calibration. During discussion with DOE at the August 2018 OOV, DOE indicated that model calibration at the H-Area was challenging (SRNL-STI-2017-00008, Rev. 1), likely due to its location on a topographic high/groundwater divide.

While early optimization runs resulted in a reduced objective function, relative to the objective functions produced by the first four cases that were run with limited optimization,

- The calibrated water tables east of H-Area were too elevated;
- The goodness-of-fit was marginal in Z-Area, with its few, isolated calibration targets;
- Local perturbations were deemed excessively large;
- Calibrated hydraulic conductivities were questioned (e.g., significant reduction in the vertical hydraulic conductivity of the AAA close to the value of the recharge rates, 1.2×10^{-6} cm/s was needed to better match calibration targets at H-Area); and
- The calibrated ellipses created sharp changes within PA areas.

Additional PEST simulations were conducted to address these issues by:

- Considering separate local polygons for H-Area and Z-Area;
- Also allowing local perturbations in the LAZ;
- Limiting local perturbations of hydraulic conductivities to half an order of magnitude; and
- Imposition of lower bounds on hydraulic conductivities of the AAA zone: $K_h > 3 \times 10^{-4}$ cm/s, and $K_v > 1 \times 10^{-5}$ cm/s.

As a result, an improved match to Z-Area well water-level calibration targets was attained, local K perturbations were more reasonable overall, and particularly in the AAA zone, and sharp changes within PA areas of interest were avoided (SRNL-STI-2017-00008, Rev. 1). The K_v of the TCCZ along Fourmile Branch (FMB) was too low, however, which resulted in large, positive, localized residuals near FMB.

The preferred remedy, implemented during the next optimization round, mathematically simulated a conceptual model whereby the competency of the TCCZ along FMB (where the TCCZ crops out or is very shallow) is limited by pine tree tap roots or some other phenomena (SRNL-STI-2017-00008, Rev. 1). A multiplier was applied to hydraulic conductivity along FMB within [15 ft] of the ground surface and conductivity within [15 ft] of the ground surface over the entire model domain was also constrained by a lower bound. Although calibration near FMB improved, the resulting calibrated water table east of H-Area remained too elevated.

During the next round of optimization, the H-Area and Z-Area polygons were replaced with smaller polygons to limit the extent of perturbations (SRNL-STI-2017-00008, Rev. 1). Weighted optimization produced better agreement with the few isolated calibration targets in Z-Area, at the expense of residuals associated with areas having more abundant calibration targets. The cases employing the newly altered polygons produced more acceptable water table elevations east of H-Area.

As a result of an internal, informal peer review at SRS, the following recommendations were implemented in subsequent calibration iterations:

- A multiplication factor constraint on the local H-Tank Farm polygon was broadened from half to one order of magnitude to allow additional adaptation of the local hydraulic conductivity field;
- PORFLOW v. 6.42.4 replaced use of PORFLOW v. 6.42.3, because of a newly featured, advantageous option to use harmonic averaging of material properties at computational cell interfaces, which is important for more accurate simulation of groundwater flow perpendicular to hydrostratigraphic units, such as through the GCU; and
- GCU K_v was allowed to vary between 3×10^{-6} and 3×10^{-5} m/d [10^{-5} and 10^{-4} ft/d] in new sensitivity and optimization runs instead of being held fixed at 3×10^{-5} m/d [10^{-4} ft/d].

Calibrations continued with an investigation of the effects of varying the GCU K_v, vadose zone K_{sat}, and PORFLOW Newton iterations; results indicated that:

- The optimal GCU K_v was found to be approximately 2.3×10^{-5} m/d [7.5×10^{-5} ft/d];
- Alteration of the vadose zone conductivity is unnecessary for numerical stability; and
- 400 PORFLOW steady-state Newton iterations (4 outer-loop and 100 inner-loop iterations) produced an adequately converged numerical solution.

The final round of input parameter estimation/model optimization explicitly tested goodness-of-fit for layer-cake vs. heterogeneous hydraulic conductivity fields and unweighted vs. weighted hydraulic head residuals. The layer-cake, weighted model was recommended as the baseline groundwater simulation for PAs and related analyses in the first revision[10] of the GSA 2016 model update report (SRNL-STI-2017-00008, Rev. 1) because:

- The layer-cake conductivity field was more parsimonious, requiring fewer assumptions and input parameters;
- The layer-cake conductivity field produced a better fit to well water-level calibration targets compared to the heterogeneous conductivity field, for both unweighted and weighted optimization;
- Weighted optimization accounted for data uncertainty, spatial density of wells, and number of wells per HSU;
- Outside of the local H-Area and Z-Area calibration zones, weighted optimization produced a reasonable TZ hydraulic conductivity, consistent with hydrogeologic conceptual models associated with the F- and H-Area seepage basins and the E-Area ORWBG (e.g., WSRC-RP-99-4202, WSRC-RP-2000-4169, SRNS-RP-2017-00134); nevertheless, modeled heads were biased low near the F- and H-Area seepage basins (SRNL-STI-2018-00643); and
- Weighted optimization produced particle tracks from the E-Area ORWBG that discharged to FMB, consistent with tritium plume observations emanating from that site (e.g., WSRC-TR-96-0037; WSRC-TR-96-0411). Unweighted optimization, however, resulted in errant particle trajectories that originated from the west end of the ORWBG and crossed into and through the GCU into the GAU, short of Fourmile Branch.

NRC staff note that in addition to lack of support for hydraulic conductivity assignments for the UTRA-UAZ in the H-Area polygon (calibrated values are lower than existing data on hydraulic conductivity), the modeled flow field appears to be sensitive to changes in calibration parameters. For example, particle tracks in Figure 7-39 for the 2004 GSA/PORFLOW model

[10] In Rev. 0 of the GSA 2016 model update report, the unweighted, layer-cake model had been preferred.

are markedly different than particle tracks for any of the PEST simulations 47–53 (see Figures 7-40 through 7-43) with the latter indicating that sources located in H-Area would ultimately discharge to the UTR (SRNL-STI-2017-00008, Rev. 1)[11]. This could be due to the assignment of GCU vertical hydraulic conductivity to ~7.5 × 10^{-5} cm/s, allowing relatively more flow into the GAU and more particles discharging to UTR. However, this rather important result was not discussed or evaluated in the report.

A subsequent calibration target update (SRNL-STI-2018-00336) found that 26 well screens previously had been misassigned to unaffiliated HSUs, and some hydraulic head residuals may be attributed to this misassignment. Furthermore, the GSA 2016 baseline model still yielded questionable calibrated hydraulic conductivity values in certain portions of the model. As one example, within the local Z-Area polygon, the calibrated horizontal hydraulic conductivity of the TZ was considerably lower than that assigned globally, as well as lower than that assigned to the UTRA-LAZ in the same polygon, which fundamentally disagrees with the TZ being more conductive than other aquifer zones in the UTRA (SRNL-STI-2018-00643).

For the GSA 2018 model update, the recommended GSA 2016 baseline material property model (layer-cake, weighted optimization) was recalibrated. No alteration to previously assumed GAU material properties was made during the recalibration, and only the UTRA HSUs (i.e., AAA, TZ, TCCZ, and LAZ) were optimized for hydraulic conductivity distributions using PEST. Especially noteworthy, a uniform GCU K_v of 3 × 10^{-6} m/d [1.0 × 10^{-5} ft/d] was assigned based on a study which suggested a 7.5× reduction of the previously assumed value would yield an improved particle trajectory match to MWMF plume data. As stated previously, this rather significant change to a vertical hydraulic conductivity value, which was initially characterized as being fairly certain (and so not considered a calibration parameter) requires additional support.

GSA 2018 recalibration of the preferred GSA 2016 model sought to minimize hydraulic head residuals observed around the F- and H-Area seepage basins, which were biased too low in the final GSA 2016 baseline material property model (SRNL-STI-2017-00008, Rev. 1). Because calibration in the 2016 effort was hampered by mis-assignment of HSUs, it is unclear why the preferred GSA 2016 model was the starting point for model calibration in the 2018 effort. It would have been advisable for DOE contractors to use the same starting point as the 2016 effort so as not to potentially bias the end point. Recalibration of the layer-cake, weighted optimization hydraulic conductivity model commenced using a local F- and H-Area seepage-basins polygon (SRNL-STI-2018-00643), in addition to the existing H-Area and Z-Area polygons (SRNL-STI-2017-00008, Rev. 1) for localized material property calibration. In the GSA 2016 model, DOE noted that plume trajectories for Z-Area exhibited too great a vertical flow component relative to the lateral flow component. In contrast, the GSA 2018 recalibrated hydraulic conductivities for the Z-Area TZ, in particular, provided a better match to the conceptual model than did results from the GSA 2016 optimization. That is, Z-Area TZ became more transmissive: the horizontal hydraulic conductivity became identical to that of the global TZ zone and was higher than the local LAZ horizontal hydraulic conductivity; this result was consistent with the hydrogeologic conceptual model (SRNL-STI-2018-00643).

In previous TERs, and more recently in the March 2019 OOV, NRC staff noted that calibration and evaluation of calibration statistics local to the waste disposal facility PA areas of interest (e.g., FTF, HTF, and SDF) would be desirable (NRC, 2014; NRC, 2019). The velocity field for

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[11] In contrast, the 2004 GSA/PORFLOW model shows the same particle track to the northeast of H-Area discharging to McQueen Branch, and particle track from the southwest discharging to FMB.

the local PA models is generated with a mass-conserving linear interpolation scheme directly from the regional GSA velocity model; thus, the local transport models do not necessitate a separate flow model with their own boundary conditions and material property assignments. In lieu of basing the local flow models on the larger GSA modeled flow field, DOE could use boundary conditions from the regional model or define boundaries based on interpretation of monitoring well data to construct local flow models that could be further calibrated in the areas of interest. During the March 2019 OOV, NRC staff indicated that calibration local to the waste disposal facilities would be expected to greatly improve model performance in the areas of interest (ML19143A084). Calibration results local to the HTF show that the residuals are biased low in the UTRA-UAZ and -LAZ for the 2016 model. For example, Figure 1 shows the distribution of head residuals in the UTRA-UAZ and -LAZ for PEST simulation no. 51 from the 2016 model (see Appendix D, SRNL-STI-2017-00008 for data associated with this figure). The results clearly show spatial bias in the residuals in the UTRA-UAZ and -LAZ with heads significantly underpredicted in the LAZ in the area of interest. Results of the final 2018 model show calibration targets that are too high in the UTRA-UAZ and too low in the UTRA-LAZ, resulting in an overestimate of the vertical hydraulic gradient in the final calibrated model (see Figure 2). The final calibrated model does not appear well calibrated at HTF. Poor calibration is risk-significant because it could lead to a significant overestimation of dilution and travel times to the compliance boundary, thereby decreasing groundwater concentrations and dose. In the future, DOE should provide information on calibration statistics local to the waste disposal facility areas of interest to provide a more accurate portrayal of the goodness-of-fit of the model to local calibration targets. NRC staff are monitoring DOE developments in this area under MF 6.2, “Model and Parameter Support”, and MF 6.3, “PA Maintenance”.

<u>Model Validation</u>

The GSA groundwater flow and transport model updates were generally undertaken according to an execution plan described in the report SRNL-STI-2016-00261. This report, in part, described a plan to assemble and evaluate the completeness, representativeness, and accuracy of baseflow data used to validate the previous GSA groundwater model (WSRC-TR-96-0399, Rev. 1, Vol. 2), as well as that of more recent baseflow data collected subsequent to the publication of the GSA/FACT model, and to develop optimization weighting factors for stream baseflow so that it could be used to calibrate, or at least to validate, the updated groundwater model. Matching baseflow data for affected HSUs and model output is important to ensuring that a non-unique solution, which does not adequately describe the flow field, does not result from parameter estimation and model calibration. However, this planned work to integrate more recent stream baseflow data into the calibration/validation process has not been accomplished to date. During the March 2019 OOV, GSA numerical modeling staff acknowledged that they were unaware that monthly streamflow data continue to be measured at select locations on the GSA (ML19143A084).

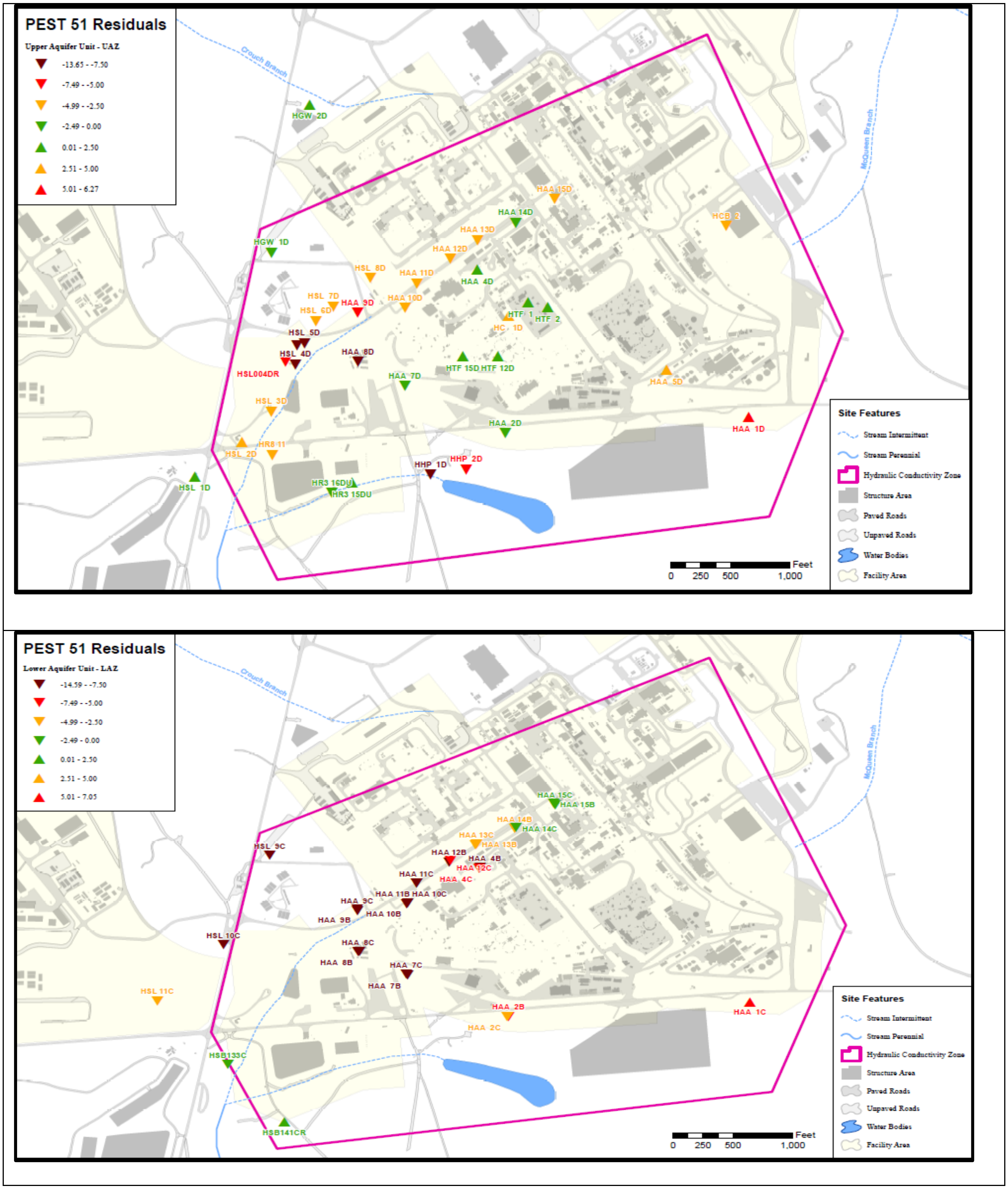

Figure 1 - GSA 2016 Model Residuals UTRA-UAZ (top panel) and UTRA-LAZ (bottom panel) for PEST Simulation 51.

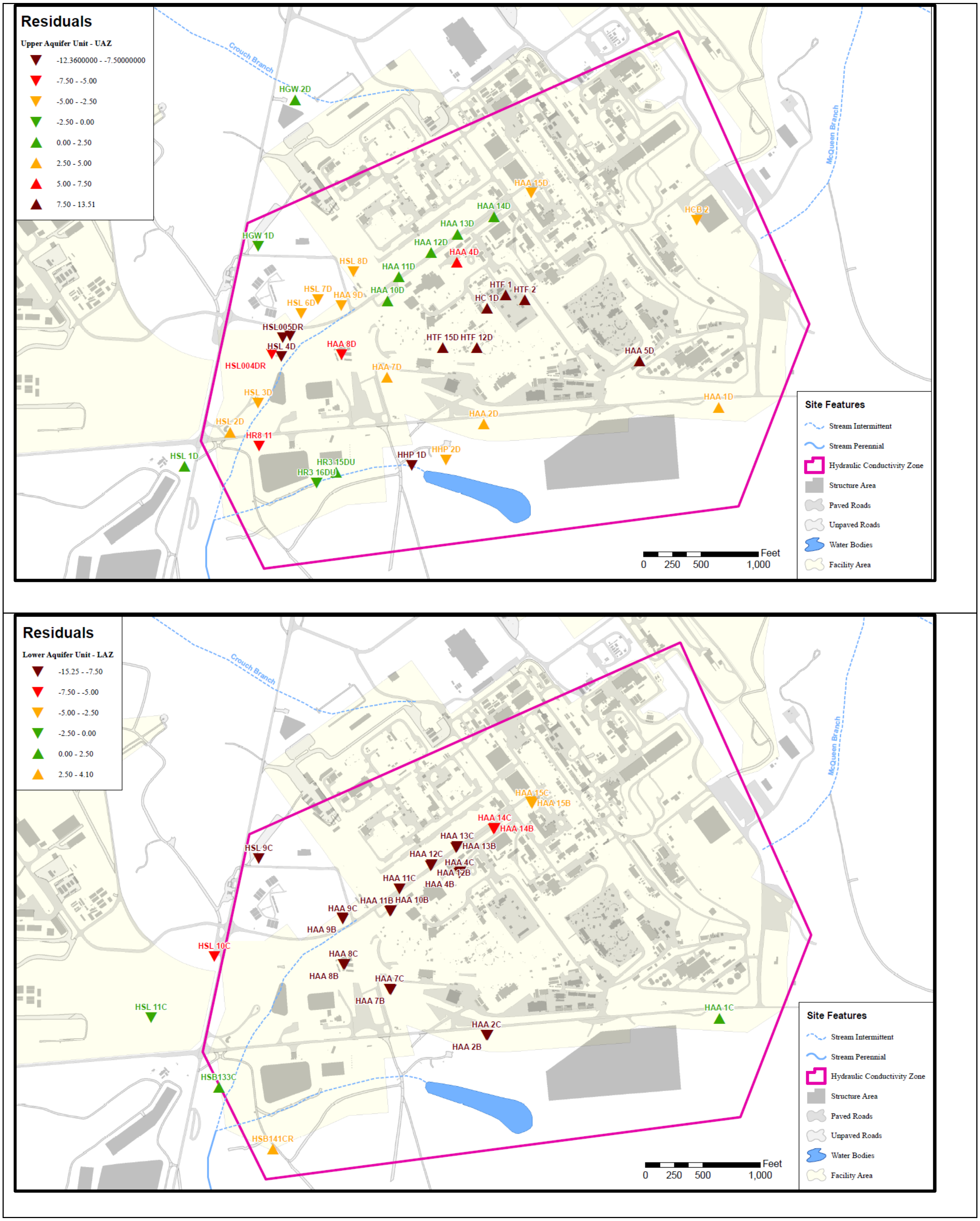

Figure 2 - GSA 2018 Model Residuals UTRA-UAZ (top panel) and UTRA-LAZ (bottom panel).

As stated above, the stream baseflow data used for the GSA 2016 and 2018 PORFLOW model validation analysis were not from the recent Base Period used to develop head calibration targets; instead, they were the same data used to validate earlier GSA groundwater models (WSRC-TR-96-0399, Rev. 0; WSRC-TR-2004-00106)[12]. Uncertainty associated with these stream baseflow model validation targets was never quantified (SRNL-STI-2017-00008, Rev. 1). SRS personnel continue to collect monthly streamflow data at a number of locations on or adjacent the GSA (J. Thibault, personal communication, March 2019 OOV findings). As discussed previously, DOE should evaluate more recent stream flow data consistent with the time period over which water-levels are averaged for the purpose of developing baseflow calibration targets. Furthermore, DOE should assess the uncertainty in the baseflow measurements, as well as consider use of the baseflow measurements in the optimization process rather than simply use them for model validation.

For the GSA 2016 model, the final calibrated set of four groundwater models was assessed and the models were all found to conserve mass on both a global and hydrostratigraphic unit basis, with cumulative inflow and outflow differing by only a few tenths of one percent (SRNL-STI-2017-00008, Rev. 1). For the GSA 2018 model, the final single calibrated groundwater model was also found to conserve mass, with overall inflow and outflow differing by only 0.22 percent, and on an individual aquifer basis, inflows and outflows differed by 0.29 percent or less (SRNL-STI-2018-00643). GSA 2016 model results were also investigated for satisfaction of Darcy's Law, using an independent set of calculations on saturated cells (SRNL-STI-2017-00008, Rev. 1). For both the GSA 2016 and GSA 2018 models, simulated seepage faces were compared with surveyed seeplines, and generally found to agree (SRNL-STI-2017-00008, Rev. 1; SRNL-STI-2018-00643).

Groundwater monitoring data can provide model calibration and validation information from which to assess the adequacy of DOE's far-field groundwater model for evaluating risk from the tank farm disposal facilities (ADAMS Accession No. ML15238A761). Tritium plume data from the E-Area ORWBG was used to select the preferred optimized model. The weighted layer-cake model was stated to outperform the unweighted layer-cake model in that tritium was found to discharge to FMB, consistent with tritium plume observations emanating from that site, compared to the unweighted model which saw transport to the underlying GAU. The GSA 2018 model update also benefited from comparisons to contaminant plume data (SRNL-STI-2018-00643).

While it is difficult to pinpoint an exact source of historical contaminant releases on the GSA due to the potential for multiple sources to have contributed to development of plumes, NRC staff thinks that using backward particle tracking from modeling would be helpful for evaluating contaminant sources (ML19143A084). Additionally, NRC staff have modeled hypothetical sources from different tanks and have reviewed the resulting vertical distribution of contaminants to evaluate the adequacy of the monitoring well networks at FTF and HTF (ML12272A124 and ML18051B154). NRC staff are monitoring DOE developments in this area under MF 4.3, "Environmental Monitoring", MF 6.2, "Model and Parameter Support", and MF 6.3, "PA Maintenance".

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[12] The U.S. Geological Survey conducted streamflow monitoring on and adjacent to the GSA during the period from 1973 to 2002. For the GSA/FACT and GSA/PORFLOW models, the portion of this historical record collected during the period from 1973 to 1995 was used, in part, to estimate baseflows for the GSA, along with hydrologic budget studies (DPST-86-658), and E and Z-Area baseflow data (WSRC RP-92-1360; WSRC-RP-94-218).

Model Uncertainty

Model uncertainty stems from uncertainties associated with the (i) conceptual model, which is implemented numerically, and (ii) input parameters, such as material properties (i.e., hydraulic conductivity fields defined by calibrated global and local multipliers of originally assumed fields), recharge distribution, and stream baseflow. Uncertainty in the hydraulic conductivity distribution of the GSA 2016 model was thought to be less for the GAU and GCU, although the vertical hydraulic conductivity value for the GCU appears to be more uncertain than characterized with order of magnitude changes between modeling campaigns. The hydraulic conductivity of the UTRA-UAZ and particularly the AAA appears to be relatively uncertain (SRNL-STI-2017-00008, Rev. 1). Variability amongst the final calibrated set of four GSA 2016 groundwater models and any other earlier material property parameter sets exhibiting similar degrees of fit to the well water-level calibration targets indicates the degree of conceptual model uncertainty inherent in the GSA 2016 model. The range of uncertainty in GSA recharge produces a similar level of uncertainty in groundwater flowrates in the shallow aquifers of the GSA; improved knowledge of the GSA recharge distribution and associated stream baseflows (especially for UTR and Crouch Branch) could reduce this uncertainty (SRNL-STI-2017-00008, Rev. 1).

For both the GSA 2016 and GSA 2018 models, DOE provides 95 percent confidence limits for each estimated parameter output from PEST. Based on the results, the uncertainty in the hydraulic conductivity of the AAA, in particular, is quite large (e.g., multiplier range of 5.7×10^{-9} to 9.6×10^{7} for PEST simulation no. 51 for Z-Area and comparable values for H-Area in SRNL-STI-2017-00008, Rev. 1; multiplier range of 8×10^{-7} to 1.3×10^{4} for H-Area in SRNL-STI-2018-00643). The large parameter range indicates that multiple sets of parameters are available to match calibration targets, which could possibly be due to the insensitivity of the parameter value to overall calibration. However, this explanation appears unlikely given the need to create hydraulic conductivity zones for the UAZ local to H-Area and/or Z-Area to improve model calibration in multiple modeling campaigns.

Because the low UAZ hydraulic conductivities are inconsistent with the hydrogeologic conceptual model of the GSA, additional data collection appears warranted to provide support for the final calibrated model parameters. Installation of new monitoring wells, which would also provide useful hydrostratigraphic information, as well as new well water-level data for use as calibration targets, would improve model calibration. If constraints on new well construction make it difficult to collect additional data, DOE can propose other approaches to reducing the uncertainty in calibrated hydraulic conductivities. Alternatively, further review of calibration targets in the waste disposal facility areas of interest and potential anthropogenic sources of recharge could explain the poor model calibration at H-Area. New calibration targets could be developed and the model re-calibrated, obviating the need to collect additional hydraulic conductivity data. As stated above, additional calibration local to the waste disposal facility area of interest is also needed to improve model performance. If additional data collection and model calibration are performed, codes such as PEST and UCODE can be used to identify observations and calibration parameters most beneficial to reducing predictive uncertainty.

Other approaches are also available to collect hydraulic conductivity information about the GSA and to better understand contaminant flow and transport processes. For example, DOE has used the electromagnetic borehole flowmeter (EBF) to measure the vertical distribution of the local K_h of a layered aquifer along wellbores at SRS and recently provided NRC with a number of related reports for review. NRC staff supports use of EBF data to provide a better understanding of the hydrogeological conceptual model of the GSA and to help parameterize the GSA groundwater flow model. The ambient-condition (i.e., non-pumping) EBF test can provide upward or downward flow gradient information within site aquifers. The EBF is particularly suitable for use in confined aquifers with fully penetrating, fully perforated boreholes that are naturally packed (not gravel- or filter-packed), and when pumped at low flow rates that minimize head losses through and flow redistribution around the instrument (Dinwiddie et al., 1999).[13] EBF tests provide a capability to identify preferential flow pathways within an aquifer (e.g., could be helpful in determining the importance of calcareous zones near GSA facilities) and to correlate gamma logs with K_h (SRT-ESS-96-453).[14] Model support could also come in the form of comparisons of monitoring data to model results (e.g., flow directions and rates) at H-Area. Flow velocity data could be used to better evaluate model performance.

DOE did not evaluate the impact of uncertainty on the modeling results using the predictive feature in PEST. Although this was scoped in SRNL-STI-2016-00261, DOE apparently did not accomplish this task. DOE should include an evaluation of uncertainty in the model results that could include Darcy velocity, which is directly related to the amount of dilution in the model and also affects radiological decay for relatively short-lived constituents (i.e., those constituents whose half-lives approach travel times to the point of compliance) in future modeling efforts.

Comparisons of GSA 2016, GSA 2018, and 2004 GSA/PORFLOW Model and PA Model Impacts

DOE used particle tracking, with 10-yr markers, in a comparison of the GSA 2016 model (SRNL-STI-2017-00008, Rev. 1) to the previous GSA/PORFLOW model (WSRC-TR-2004-00106). As before, any sharp kinks observed in particle trajectories represents the location where a particle passes from the overlying unit into the GAU. DOE notes the particle tracking simulations used the same seed locations for consistency, which likely means that some seed locations in the new simulations were above the water table, which used to be 1.1 m [3.5 ft] higher. The new models benefit from use of the velocity field correction for non-orthogonal meshes (SRNL-STI-2015-00115), in addition to inverse modeling parameter estimation. The new models indicate slower groundwater flow, which DOE indicates likely results from use of a lower recharge rate and lower water-table elevation, which either reduced the saturated thickness of the highly transmissive TZ in some areas or else placed it entirely in the vadose zone in other portions of the model domain. In addition, lateral flow above the GCU is reduced because of the increased leakage into and through it (i.e., its K_v was increased nearly eight-fold in the GSA 2016 model) to the underlying GAU. Other differences in particle trajectories must necessarily be related to the material property distribution differences between the old model and the four newly calibrated GSA 2016 models.

DOE again used particle tracking, with 10-yr markers, in a comparison of the GSA 2018 model (SRNL-STI-2018-00643) to the previous GSA 2016 model (SRNL-STI-2017-00008, Rev. 1). As discussed above, the results for H-Area are markedly different for the two models with particle paths in the 2018 model seeded at HTF discharging to McQueen Branch (seed started

[13] According to WSRC-TR-2000-00170, bypass flow around the EBF instrument may not be a serious problem in typical SRS monitoring wells when using the 2.5-cm [1-in] instrument for pumping tests; however, the report recommended conducting pre-test estimates of bypass flow to select an appropriate pumping rate that would reduce bypass flow to an insignificant level, thus laying the groundwork for obtaining high-quality K_h estimates.

[14] For wells where adjacent CPT data were available, the CPT-inferred hydraulic conductivities based on tip resistance, sleeve friction, pore pressure, and resistivity data were found to be dissimilar to EBF-estimated K_h, and WSRC-TR-2000-00170 placed a higher value on the EBF-derived K_h values. With one problematic well, WSRC-TR-2000-00170 demonstrated the scale-up of high-resolution K_h data to more model-domain-relevant scales. This work illustrated how EBF data could be used in a real sense to parameterize a GSA PORFLOW model, if EBF data were strategically collected on the GSA.

just to the northeast of HTF) and FMB (seed started just to the southwest of HTF) instead of HTF particle tracks terminating at the UTR. DOE notes that because the GCU hydraulic conductivity is lower for the GSA 2018 model (1×10^{-5} versus 7.5×10^{-5} ft/d), groundwater leakage into the GAU is lower and groundwater travel is shallower. Fewer pathlines exhibit kinks and pathlines tend to discharge at the ground surface earlier (SRNL-STI-2018-00643).

DOE also evaluated the impact of the updated GSA 2016 and GSA 2018 flow models on the results of PAs for FTF, HTF, and SDF (SRNL-STI-2017-00445; SRR-CWDA-2017-00068). SRNL-STI-2017-00445 notes that slower groundwater velocity in eastern Z-Area results in higher I-129 concentrations at the 100-m boundary and UTR seepline. Evaluation of impacts to the SDF will be evaluated more thoroughly in a separate TRR.

During the FTF and HTF reviews, NRC staff raised technical issues associated with the degree of dispersion in DOE's models (ML112371715 and ML14094A496). NRC staff suggested that DOE evaluate the impact of grid resolution and dispersivity on the PA results. NRC staff specifically noted that use of a relatively large longitudinal dispersivity could result in excessive vertical dispersion if the primary direction of flow was vertical due to the strong vertical gradient at the tank farm facilities. In SRR-CWDA-2017-00068, Rev. 1, DOE evaluates the impact of (i) grid resolution and (ii) a new numerical dispersion model on the impacts of the PA using the updated GSA 2018 model. Updates to the dispersion model include the upwinding of diffusivities at cell faces (versus harmonic averaging) and the use of the full dispersion tensor (off-diagonal terms in addition to diagonal terms), as well as use of the four-parameter "stratified" model (longitudinal horizontal (α_{LH}), longitudinal vertical (α_{LV}), transverse horizontal (α_{TH}), and transverse vertical (α_{TV}) dispersivities versus use of a simpler two-parameter model). Sensitivity cases included two sets of two cases: (i) one set using the GSA 2004 and (ii) one set using the GSA 2018 flow fields and the following two variants: (i) updated dispersion model, and (ii) updated dispersion model with grid refinement. Comparisons between the 2004 and 2018 models show significantly lower flow rates and flow directions slightly shifted towards the north for particles seeded at FTF. For HTF, the flow rates are variable and the flow directions are shifted slightly towards the north (see Figure 3).

NRC staff note substantial difference in flow rates (signified by the red circles on Figure 3 that represent 10-yr time markers) from many tanks at HTF, and most notably the risk-significant Type II tanks located to the south-central at the tank farm. This result could have a substantial impact on dose associated with relatively short-lived radionuclides in alternative cases (e.g., release of short-lived radionuclides from the annulus of Tank 16 through preferential pathways). Additionally, the change in the HTF model results could be important if risk-significant doses are pushed out beyond the compliance period. Therefore, NRC staff will continue to monitor the impact of the GSA 2018 model in future PA updates, including a more in-depth evaluation of the impact of the new GSA 2018 model on PA results after receipt of the modeling files from DOE.

The results of the impact assessments for the 2016[15] and 2018 models show doses could be 2 to 3 times higher than previous tank farm PA results. Most notably, the 100,000-yr peak dose from Tank 18 could be 2.5 times higher (compare 6 mSv/yr to 15 mSv/yr). The updated GSA 2018 model resulted in generally higher peak doses at FTF and lower peak doses at HTF. Use of the four-parameter dispersion model appeared to have a significant impact on the results (i.e., increased the dose). Grid refinement also led to modest increases in dose. DOE's change to a four-parameter dispersion model and higher grid resolution addresses NRC staff's concerns in these areas. Furthermore, the results of the impact assessment are generally consistent with

[15] The impact assessment for the GSA 2016 model was evaluated in SRR-CWDA-2017-00068, Rev. 0.

(i) statements made in NRC's TER evaluations regarding the risk-significance of flow model uncertainty, and (ii) NRC staff's prioritization of far-field/flow model related MFs in NRC's monitoring plan for the tank farm facilities. Therefore, despite the uncertainties in the updated model, NRC staff continues to consider the flow model to be of moderate risk-significance, although NRC is still reviewing the impact of increased travel time and lower dilution rates for certain sources (e.g., submerged or partially submerged tanks at HTF with significant quantities of short-lived and other key radionuclides in alternative cases).

Quality Assurance

PORFLOW v. 6.42.3 and 6.42.4 underwent an extensive suite of software quality assurance tests (SRNL-STI-2016-00724; SRNL-STI-2017-00167) and is said to have produced acceptable results (SRNL-STI-2017-00008, Rev. 1); however, the QA documents were not available for review. A more recent SRNL report that documents the software quality assurance testing of PORFLOW v. 6.42.9 (SRNL-STI-2018-00275), however, was available for review.
PEST v. 13.6 also underwent software quality assurance testing and passed (Q-SQP-G-00004). The NRC staff will continue to evaluate whether DOE software quality assurance practices are being implemented effectively during future onsite observation visits and technical reviews.

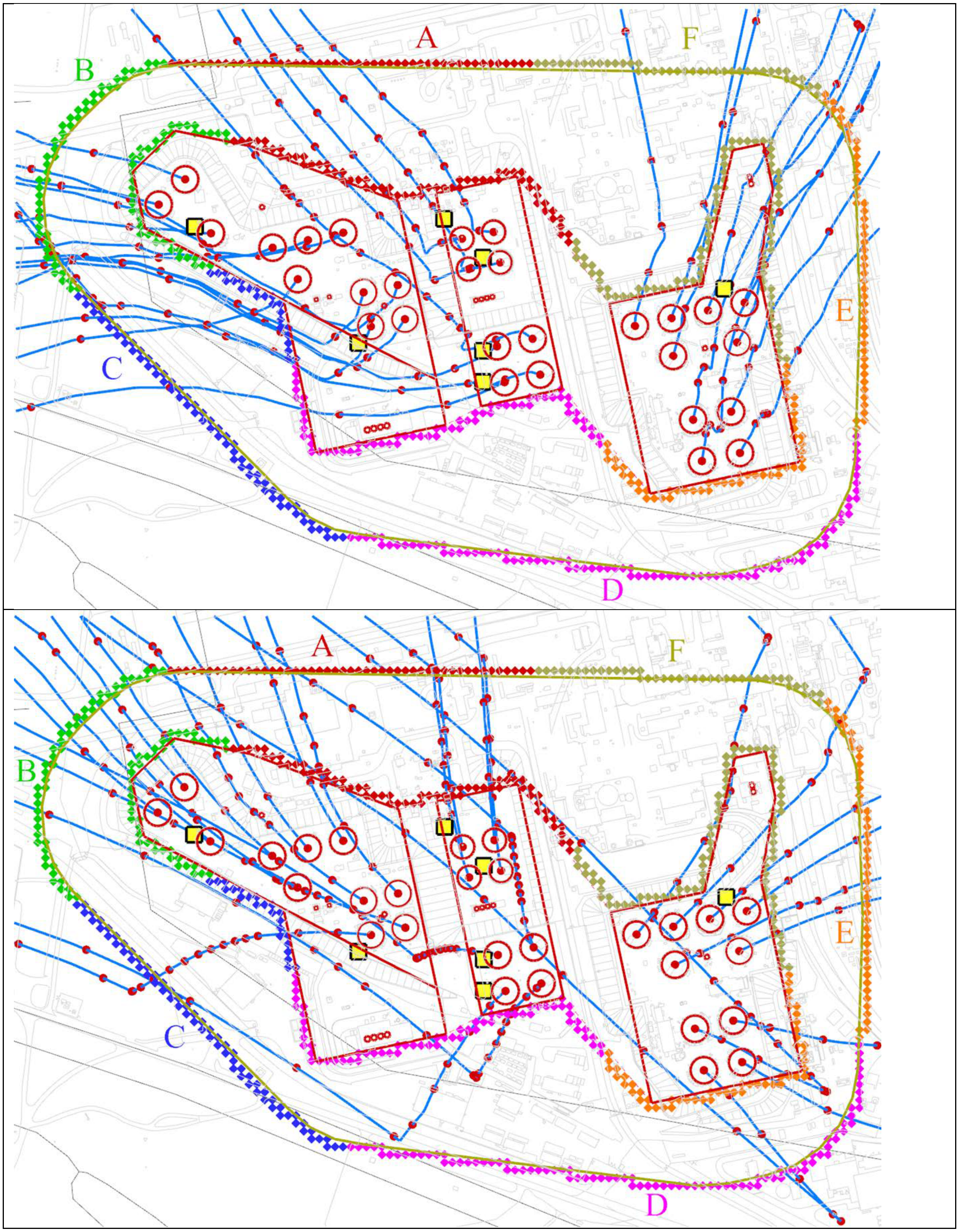

Figure 3 - Comparison of Particle Tracks from 2004 and 2018 Models with Updated Dispersion Model and Grid Refinement. Image Credit: Figures 2.3-8 and 2.3-10 from SRR-CWDA-2016-00078, Rev. 1.

	Tanks 5 & 6 SA (GSA_2004)	GSA_2004 + TENSor	GSA_2004 + TENSor + Refinement	GSA_2018 + TENSor	GSA_2018 + TENSor + Refinement
1,000-Year Peak Dose Results					
Peak Dose (mrem/yr)	0.43	0.76	0.96	0.85	1.1
Year of Peak Dose	704	706	704	702	698
Sector of Peak Dose	Sector E	Sector D	Sector D	Sector E	Sector D
10,000-Year Peak Dose Results					
Peak Dose (mrem/yr)	3.3	6.6	9.4	7.0	7.6
Year of Peak Dose	10,000	6,094	10,000	6,052	10,000
Sector of Peak Dose	Sector E	Sector D	Sector D	Sector E	Sector E
20,000-Year Peak Dose Results					
Peak Dose (mrem/yr)	45	91	97	64	80
Year of Peak Dose	20,000	19,992	20,000	20,000	19,994
Sector of Peak Dose	Sector C	Sector B	Sector C	Sector D	Sector C
100,000-Year Peak Dose Results					
Peak Dose (mrem/yr)	617	1,148	1,625	1,382	1,547
Year of Peak Dose	41,320	41,530	40,930	42,300	41,540
Sector of Peak Dose	Sector E	Sector D	Sector D	Sector E	Sector E

	Type I and Type II Tanks SA (GSA_2004)	GSA_2004 + TENSor	GSA_2004 + TENSor + Refinement	GSA_2018 + TENSor	GSA_2018 + TENSor + Refinement
1,000-Year Peak Dose Results					
Peak Dose (mrem/yr)	0.19	0.30	0.39	0.20	0.31
Year of Peak Dose	774	786	778	780	562
Sector of Peak Dose	Sector B	Sector A	Sector A	Sector B	Sector C
10,000-Year Peak Dose Results					
Peak Dose (mrem/yr)	6.8	14	25	8.7	13
Year of Peak Dose	2,614	2,576	2,572	2,618	2,618
Sector of Peak Dose	Sector A	Sector A	Sector A	Sector A	Sector A
20,000-Year Peak Dose Results					
Peak Dose (mrem/yr)	34	50	77	38	44
Year of Peak Dose	11,726	11,546	11,548	11,724	11,738
Sector of Peak Dose	Sector A	Sector A	Sector A	Sector A	Sector A
100,000-Year Peak Dose Results					
Peak Dose (mrem/yr)	163	281	427	167	261
Year of Peak Dose	61,360	74,410	81,140	61,270	59,190
Sector of Peak Dose	Sector B	Sector D	Sector E	Sector B	Sector B

Table 2 - Peak Doses at FTF (top) and HTF (bottom) for the Reference (2004) Model and the Updated GSA 2018 Model Considering Sensitivity Cases (i) Updated Dispersion Models, and (ii) Grid Refinement. Table Credit: Tables 3-1 and 3-4 in SRR-CWDA-2016-00078, Rev. 1.

Teleconference or Meeting

During an OOV held on August 13–14, 2018, DOE provided NRC with a briefing on recent and ongoing GSA PORFLOW groundwater model updates [ADAMS Accession No. ML18311A184]. The technical discussion held during the OOV supported NRC's monitoring of DOE disposal actions to assess compliance with §61.41 and §61.42. The technical discussion was most relevant to the following Monitoring Areas and Monitoring Factors in the Tank Farm Monitoring Plan:

- MA 4 (Natural System Performance):
  - MF 4.3 (Environmental Monitoring)
- MA 6 (Performance Assessment Maintenance):
  - MF 6.3 (Tank Farms Performance Assessment Revisions)

The technical discussion at the August 2018 OOV included (i) a brief history of the evolution of the GSA groundwater flow and transport model as it has been developed over the years; (ii) a discussion of the GSA 2016 model development; and a (iii) foreshadowing of the updated GSA 2018 model, which was only months away from being published at the time. Follow-Up Action Items that resulted from the August 2018 technical discussion were:

- DOE was to provide NRC staff with the Annual 2017 Tank Farms Groundwater Monitoring Report and
- DOE was to provide NRC staff with a reference list of DOE documents containing information about GSA EBF-derived hydraulic conductivity data.

Following the August 2018 OOV, DOE fulfilled the action items. For additional details regarding the August 2018 OOV, please refer to SRR's slide presentation (SRR-CWDA-2018-00047, Slide 50) and NRC's meeting summary [ADAMS Accession No. ML18311A184].

During an OOV held on March 18–19, 2019, DOE and NRC staff held a technical discussion of questions that had arisen about the newly updated GSA PORFLOW models. For additional details regarding the March 2019 OOV, please refer to SRR's slide presentations (SRR-CWDA-2019-00022 [ADAMS Accession No. ML19116A208], SRR-CWDA-2019-00028 [ADAMS Accession No. ML19094B051]), SRR-CWDA-2019-00040 [ADAMS Accession No. ML19116A225]} and NRC's meeting summary [ADAMS Accession No. ML19143A084]. The OOV technical discussions were consistent with activities described in NRC's Guidance Memoranda for the August 2018 and March 2019 OOVs [ADAMS Accession Nos. ML18192A328 and ML19016A468].

Follow-up Actions:

NRC staff will continue to monitor DOE's GSA groundwater flow and contaminant transport modeling under Monitoring Areas (MA) 4, "Natural System Performance," and 6, "Performance Assessment Maintenance" (ADAMS Accession No. ML15238A761). NRC staff will continue to monitor natural system performance and PA modeling under MF 4.2, "Calcareous Zone Characterization," and MF 4.3, "Environmental Monitoring." Under Monitoring Area 6, NRC staff will continue to monitor DOE activities associated with the Tank Farm PA maintenance program that are related to NRC recommendations to improve far-field model support and parameter justification, including representation of uncertainty in models and parameters, specifically for this topic, under MF 6.2, “Model and Parameter Support,” and MF 6.3, “Tank Farm PA Revisions.”

Specifically, NRC staff will examine information that DOE generates, including experimental and site characterization data, and related information from the literature, to support model selection and justify parameters. NRC staff also will review DOE methods to characterize data and model uncertainty and propagate the uncertainty through the PAs. A comprehensive list of follow-up action items that includes items prepared following the March 2019 OOV, as well as new items identified in completing this TRR, will be forwarded separately to DOE.

<u>Open Issues</u>:

No open issues resulted from this technical review.

<u>Conclusions</u>:

In this report, there is no significant change to the NRC staff overall conclusions from the FTF and HTF TERs regarding compliance of DOE disposal actions with Title 10 of the Code of Federal Regulations (10 CFR) Part 61 performance objectives. The NRC staff concludes that the updated GSA PORFLOW model makes nominal improvements to the predecessor 2004 GSA PORFLOW model used to support the FTF and HTF PAs. Consistent with previous findings, NRC staff continues to regard the far-field model as being of moderate risk-significance. In addition, DOE should consider the following in future updates to the GSA PORFLOW model to increase accuracy and reduce uncertainty in contaminant flow and transport modeling:

- More extensive calibration in the areas of interest for waste disposal activities, including FTF and HTF, and evaluation of calibration statistics local to these areas;
- Hydraulic conductivity measurements near HTF and other areas where additional data collection is important to model calibration to reduce uncertainty in calibrated parameters;
- Evaluation of more recent baseflow measurements for model validation consistent with the time over which water level measurements were averaged to develop calibration targets, and consideration of uncertainty in baseflow to Upper Three Runs Creek when evaluating model performance;
- Evaluation of the sensitivity of the results to changes in recharge, and other parameters;
- Sensitivity analysis to identify observations and parameters most important to the results where additional data collection could be conducted to reduce model uncertainty; and
- More extensive analysis of the impact of flow model and parameter uncertainty on the results of the PAs.

Other conclusions include the following:

- Additional support should be provided for the period of record used to develop calibration targets, and DOE should continue to evaluate uncertainty in calibration targets (e.g., due to the presence of anthropogenic sources of water);
- Due to the mis-assignment of HSUs in the 2016 modeling effort and the use of the 2016 preferred model as the starting point for the 2018 modeling effort, it is unclear what effect the mis-assignment had on the calibration process for both the 2016 and 2018 modeling efforts. In the future, NRC staff suggest that DOE initiate calibration from a less biased starting point; and

- A rather significant result of the GSA 2018 model appears to be significantly lower flow rates from Type II and other tanks at HTF. NRC will continue to monitor the impact of this result on HTF PA monitoring results, including the results of alternative cases.

Collection of new data and more focused calibration near the Saltstone Disposal Facility (SDF) appear to have led to more significant changes in the modeled flow field in this area. A separate technical review report will be published related to the impact of the updated model on the SDF PA.

References

Aadland, R.K., J.A. Gellici and P.A. Thayer. "Hydrogeologic Framework of West-central South Carolina." South Carolina Department of Natural Resources, Water Resources Division Report 5, 1995. [ML071710088].

Barr, Cynthia, C. Grossman, G. Alexander, L. Parks, M. Fuhrmann, J. Shaffner, C. McKenney, R. Pabalan, D. Pickett, and C.Dinwiddie. "Transition from Consultation to Monitoring—NRC's Increasingly Focused Review of Factors Important to F-Area Tank Farm Performance –13153." WM2013 Conference. Phoenix, Arizona. February 2013.

Dinwiddie, C.L., N.A. Foley, and F.J. Molz. "In-Well Hydraulics of the Electromagnetic Borehole Flowmeter." *Ground Water,* Vol. 37, No. 2. 1999.

Doherty, J. "PEST Model-Independent Parameter Estimation User Manual Part I: PEST, SENSAN and Global Optimisers." 6th edition. Watermark Numerical Computing: Brisbane, Aus. 2016a.

Doherty, J. "PEST Model-Independent Parameter Estimation User Manual Part II: PEST Utility Support Software." 6th edition. Watermark Numerical Computing: Brisbane, Aus. 2016b.

DPST-85-904. Looney, B.B., M.W. Grant, and C.M. King. "Estimation of Geochemical Parameters for Assessing Subsurface Transport at the Savannah River Plant." Savannah River Plant: Aiken, SC. 1987.

DPST-86-658. Parizek, R.R. and R.W. Root, Jr. "Development of a Ground-Water Velocity Model for the Radioactive Waste Management Facility." Savannah River Plant: Aiken, SC. 1986.

ERD-EN-2003-0126. Brewer, K., T. Fogle, A. Stieve, and C. Barr. "Uncertainty Analysis with Site-Specific Groundwater Models: Experiences and Observations." Presented at the MODFLOW and More Conference: Golden, CO. September 2003.

Fallaw, W.C. and V. Price. "Outline of Stratigraphy at the Savannah River Site," in *Geological Investigations of the Central Savannah River Area, South Carolina and Georgia* (Field Trip Guidebook)." Carolina Geological Society: Augusta, GA. November 1992.

Graham, J. "Polydec function." Lecture in Statistics 544 Course. Missoula, MT: University of Montana, Missoula. 2015. <<www.math.umt.edu/graham/>> Accessed 24 May 2019.

NRC. "Summary of Teleconference between the U.S. Nuclear Regulatory Commission Staff and the U.S. DOE Representatives Concerning Responses to RAIs Related to Closure of F-Tank Farm, Savannah River Site." Memo to File, from James Shaffner. August 17, 2011. [ML112070958].

NRC. "Discussion of NRC Comments and Requests for Additional Information Needed to Complete Preparation of a Technical Evaluation Report for Consultation Regarding the H-Area Tank Farm at Savannah River Site." Presentation made by NRC staff at Public Meeting in Aiken, SC. August 29, 2013.

NRC. "2012 Technical Evaluation Report for the 2009 Performance Assessment for the Saltstone Disposal Facility at the Savannah River Site." May 4, 2012. [ML121170309].

NRC. "Technical Review of Environmental Monitoring and Site-Specific Distribution Coefficient Reports." Memo from C.S. Barr to G.F. Suber. March 31, 2015. [ML12272A124].

NRC. "U.S. Nuclear Regulatory Commission Plan for Monitoring Disposal Actions Taken by the U.S. Department of Energy at the Savannah River Site F-Area and H-Area Tank Farm Facilities in Accordance with the National Defense Authorization Act for Fiscal Year 2005." U.S. Nuclear Regulatory Commission: Washington, DC. October 2015. [ML15238A761].

NRC. "Technical Review of Environmental Monitoring Reports for F-Area and H-Area Tank Farm Facilities (PROJ0734)." Memo from C.S. Barr to M. Arribas-Colon. April 20, 2018. [ML18051B153].

NRC. "Guidance for the August 13–14, 2018, Monitoring Onsite Observation Visit to the Savannah River Site F and H Area Tank Farms." Memo from R.L. Gladney to A. Kock, July 12, 2018. [ML18192A328].

NRC. "U.S. Nuclear Regulatory Commission August 13–14, 2018, Onsite Observation Visit Report for the Savannah River Site Tank Farms." Letter to Mr. Daniel Ferguson from Mr. Bo Pham. February 6, 2019. [ML18311A184].

NRC. "U.S. Nuclear Regulatory Commission March 18–19, 2019, Onsite Observation Visit Report for the Savannah River Site Tank Farms." Letter to A. White from P. Holahan. August 13, 2019. [ML19143A084].

Q-SQP-G-00004. Whiteside, T.S. "Software Quality Assurance Plan for PEST." Rev. 0. Savannah River National Laboratory: Aiken, SC. May 2016.

SRNL-L3200-2010-00016. Aleman, S.E. and G.P. Flach. "Acceptance Testing for PORFLOW version 6.30.1 (Technical Memo)." Savannah River National Laboratory: Aiken, SC. September 1, 2010.

SRNL-STI-2015-00034. Hiergesell, R.A, and G.A. Taylor. "General Separations Areas (GSA) Groundwater Level Measurement Analysis." Rev. 0. Savannah River National Laboratory: Aiken, SC. February 2015.

SRNL-STI-2015-00115. Flach, G.P. "Velocity Field Calculation for Non-Orthogonal Numerical Grids." Rev. 0. Savannah River National Laboratory: Aiken, SC. February 2015.

SRNL-STI-2016-00724. Whiteside, T.S. "PORFLOW 6.42.3 Testing and Verification Document." Rev. 0. Savannah River National Laboratory: Aiken, SC. December 2016.

SRNL-STI-2017-00167. Whiteside, T.S. "PORFLOW 6.42.4 Testing and Verification Document." Rev. 0. Savannah River National Laboratory: Aiken, SC. March 2017.

SRNL-STI-2018-00012. Flach, G.P. "Recommended Aquifer Grid Resolution for E-Area PA Revision Transport Simulations (Technical Memorandum)." Rev. 0. Savannah River National Laboratory: Aiken, SC. January 3, 2018.

SRNL-STI-2018-00275. Whiteside, T.S. “PORFLOW 6.42.9 Testing and Verification Document.” Rev. 0. Savannah River National Laboratory: Aiken, SC. June 2018.

SRNL-STI-2018-00624. Hamm, L.L., S.E. Aleman, T.L. Danielson, and B.T. Butcher. “Special Analysis: Impact of Updated GSA Flow Model on E-Area Low-Level Waste Facility Groundwater Performance.” Rev. 0. Savannah River National Laboratory: Aiken, SC. December 2018.

SRNL-TR-2012-00160. Bagwell, L. “A Review of Subsurface Soft Zones at Savannah River Site with Emphasis on H Area Tank Farm (U).” Rev. 0. Savannah River National Laboratory: Aiken, SC. July 2012. [ML13080A339].

SRNS-RP-2017-00134. “Annual Corrective Action Report for the F-Area Hazardous Waste Management Facility, the H-Area Hazardous Waste Management Facility, and the Mixed Waste Management Facility (U).” Volume I. Savannah River Nuclear Solutions: Aiken, SC. April 2017.

SRR-CWDA-2009-00017. “Performance Assessment for the Saltstone Disposal Facility at the Savannah River Site.” Rev. 0. Savannah River Remediation, LLC: Aiken, SC. October 2009 (Supporting document) [ML101590008].

SRR-CWDA-2010-00128 (Part 1). “Performance Assessment for the H-Area Tank Farm at the Savannah River Site.” Rev. 1. Savannah River Remediation, LLC: Aiken, SC. November 2012. [ML13045A499].

SRR-CWDA-2018-00047. Romanowski, L. “Savannah River Site F and H Area Tank Farms NRC Onsite Observation Visit, August 13–14, 2018.” Rev. 1. Savannah River Remediation, LLC: Aiken, SC. August 2018. [ML18247A080].

SRR-CWDA-2019-00022. Romanowski, L. “Savannah River Site F and H Area Tank Farms NRC Onsite Observation Visit, March 18–19, 2019.” Rev. 1. Savannah River Remediation, LLC: Aiken, SC. April 2019. [ML19116A208].

SRR-CWDA-2019-00028. Flach, G. “General Separations Area Groundwater Flow Modeling (Discussion Supporting NRC Onsite Observation Visit, March 18–19, 2019).” Rev. 0. Savannah River Remediation, LLC: Aiken, SC. April 2019. [ML19094B051].

SRR-CWDA-2019-00040. “Savannah River Site F and H Area Tank Farms NRC Onsite Observation Visit, March 18–19, 2019 (Photos—GSA Streams Field Observation 3/18/2019).” Rev. 0. Savannah River Remediation, LLC: Aiken, SC. April 2019. [ML19116A225].

SRS Drawing No. C-CT-E-00083. “E-Area Low Level Waste Facility (ELLWF) Conceptual Closure Cap – Overall Site Plan (Engineering Drawing).” Rev. A. Savannah River Nuclear Solutions: Aiken, SC. July 20, 2016.

SRS Drawing No. C-CT-E-00084. “E-Area Low Level Waste Facility (ELLWF) Conceptual Closure Cap – Details (Engineering Drawing).” Rev. A. Savannah River Nuclear Solutions: Aiken, SC. July 20, 2016.

SRT-ESS-96-453. “ESS Borehole Flowmeter Capability.” Westinghouse Savannah River Company Inter-office Memorandum from M.A. Phifer to Distribution. 1996. [ML18241A140].

Watermark Numerical Computing. "PEST, Model-Independent Parameter Estimation, User Manual Part I: PEST, SENSAN and Global Optimisers." 6th Edition. 2016.

WSRC-RP-91-013. Aadland, R.K., M.K. Harris, C.M. Lewis, T.F. Gaughan and T.M. Westbrook, "Hydrostratigraphy of the General Separations Area, Savannah River Site (SRS), South Carolina (U)." Westinghouse Savannah River Company, LLC: Aiken, SC. January 1991. doi: 10.2172/10136555.

WSRC-RP-92-1360. "Radiological Performance Assessment for the Z-Area Disposal Facility (U)." Westinghouse Savannah River Company, LLC: Aiken, SC. 1992.

WSRC-RP-94-218. "Radiological Performance Assessment for the E-Area Vaults Disposal Facility (U)." Westinghouse Savannah River Company, LLC: Aiken, SC. 1994.

WSRC-RP-2002-4166. Brewer, K.E. and C.S. Sochor. "Flow and Transport Modeling for D-Area Groundwater (U)." Westinghouse Savannah River Company, LLC: Aiken, SC. October 2002.

WSRC-TR-96-0037. Flach, G.P., L.L. Hamm, M.K. Harris, P.A. Thayer, J.S. Haselow and A.D. Smits. "Groundwater Flow and Tritium Migration from the SRS Old Burial Ground to Fourmile Branch (U)." Westinghouse Savannah River Company, LLC: Aiken, SC. April 1996.

WSRC-TR-96-0399 (Vol. 1). Smits, A.D., M.K. Harris, K.L. Hawkins, and G.P. Flach. "Integrated Hydrogeological Model of the General Separations Area, Volume 1: Hydrogeological Framework." Rev. 0. Westinghouse Savannah River Company, LLC: Aiken, SC. August 1997. [ML101600583].

WSRC-TR-96-0399 (Vol. 2). Flach, G.P. and M.K. Harris. "Integrated Hydrogeological Modeling of the General Separations Area, Volume 2: Groundwater Flow Model (U)." Rev. 1. Westinghouse Savannah River Company, LLC: Aiken, SC. April 1999. [ML101600586].

WSRC-TR-96-0411. Harris, M.K. and G.P. Flach. "Corrective Measures Study Modeling Results for the Southwest Plume—Burial Ground Complex/Mixed Waste Management Facility (U)." Westinghouse Savannah River Company, LLC: Aiken, SC. January 1997.

WSRC-TR-99-00248. Flach, G.P., M.K. Harris, R.A. Hiergesell, A.D. Smits and K.L. Hawkins. "Regional Groundwater Flow Model for C, K, L, and P Reactor Areas, Savannah River Site, Aiken, SC (U)." Rev. 0, Westinghouse Savannah River Company, LLC: Aiken, SC. September 1999.

WSRC-TR-99-00282. Aleman, S.E. and L.L. Hamm. "FACT (Version 2.0)—Subsurface Flow and Contaminant Transport Documentation and User's Guide (U)." Rev. 0. Westinghouse Savannah River Company, LLC: Aiken, SC. March 2000. [ML13078A223].

WSRC-TR-99-4083. Aadland, R.K., R.J. Cumbest, K. Whaley, R.L. Gelinas, W. Parker, F.H. Syms, C. Rothammer. "Significance of Soft Zone Sediments at the SRS." Rev. 0. Westinghouse Savannah River Company, LLC: Aiken, SC. September 1999. [ML113320466].

WSRC-TR-2000-00170. Flach, G.P., F.C. Sappington, W.P. Johnson and R.A. Hiergesell. "Electromagnetic Borehole Flowmeter (EBF) Testing in R-Area (U)." Westinghouse Savannah River Company: Aiken, SC. August 2000. [ML18241A148].

WSRC-TR-2004-00106. Flach, G.P. "Groundwater Flow Model of the General Separations Area Using PORFLOW™ (U)." Rev. 0. Westinghouse Savannah River Company, LLC: Aiken, SC. July 15, 2004. [ML12185A205].

Appendix A
Review Status of SRS GSA PORFLOW Modeling Documents:

Q-SQP-G-00004. Whiteside, T.S. “Software Quality Assurance Plan for PEST.” Revision 0, Aiken, SC: Savannah River National Laboratory. May 2016.

This report documents quality assurance testing and evaluation of the Parameter ESTimation code, PEST, by a DOE contractor. PEST was tested by compiling and running it to solve three different test cases in four different modes of operation. The first test case ensured that PEST reproduced reported results documented in the PEST user manual (Doherty, 2016a); the model that was analyzed was not a PORFLOW model. The second and third test cases examined likely PORFLOW groundwater modeling scenarios (SRNL-TR-2016-00012), and how well PEST converged on a solution for specified model input parameters.

SRNL-STI-2015-00115. Flach, G.P. “Velocity Field Calculation for Non-Orthogonal Numerical Grids.” Revision 0, Aiken, SC: Savannah River National Laboratory. March 2015.

This report documents the derivation of the true Darcy velocity components from normal fluxes to cell faces on a non-orthogonal computational mesh to enable accurate particle tracking. In particular, derivations are provided for the routinely encountered (e.g., in SRS GSA PA applications and PORFLOW models) special cases of perfectly vertical side faces in two- and three-dimensions. Each horizontal velocity component is equal to its corresponding horizontal normal flux, while the vertical velocity component is a function of all the normal fluxes. The derived velocity fields are consistent with the normal fluxes, and thus preserve mass. At the request of SRNL, PORFLOW v. 6.42.3 and subsequent versions of PORFLOW have offered this velocity field correction option for non-orthogonal computational meshes.

SRNL-STI-2015-00351. Hiergesell, R.A., G.A. Taylor, M.A. Phifer, T.S. Whiteside, and G.P. Flach. “General Separations Area (GSA) Groundwater Model Calibration Targets.” Revision 0, Aiken, SC: Savannah River National Laboratory. August 2015.

This report documents updates made to the Excel™-based Well Hydrograph Analysis Tool (WHAT; SRNL-STI-2015-00034), beyond adding a new dashboard, that expands its capabilities for (i) producing user-defined Time Cuts (a selected subperiod within the full period of record for which isolated analysis of its water level data is needed) and (ii) performing geostatistical analyses[16] of water-level data. Using the WHAT, the best time-period (referred to as the “Base Period”) for generating GSA water-level calibration targets was identified as January 1, 2004 through 2014 inclusive. Additional programming was incorporated in the WHAT to enable a selected set of wells with known coordinates to have their water-level data subjected to geostatistical data analysis to determine uncertainty based on spatial relationships. Appendix A of SRNL-STI-2015-00351 provided a description of the WHAT and an associated user manual. A subsequent document (SRNL-STI-2018-00336) explained that two issues were identified with respect to the work described in this report, namely (i) geostatistical miscalculations embedded

[16] Geostatistical data analysis is used to estimate and distribute geostatistically representative parametric heterogeneity (such as hydraulic head) across a landscape, while preserving actual measured values (such as well water levels) at the spatial locations where they were measured; this method infers the value of a random field (e.g., hydraulic head) at an unobserved location from measured sample data (e.g. discrete water levels).

in the WHAT tool that, regardless, had no impact on the calculated mean water level of calibration targets, and (ii) misassignment of 26 well screens to unrelated HSUs.

<u>SRNL-STI-2016-00261. Bagwell, L.A. and G.P. Flach. "General Separations Area (GSA) Groundwater Flow Model Update: Program and Execution Plan." Revision 0, Aiken, SC: Savannah River National Laboratory. April 2016.</u>

This document described the activities that were associated with (i) updating and re-parameterizing the GSA PORFLOW groundwater flow and transport model, given availability of new site characterization data acquired since 1997, (ii) recalibrating the re-parameterized model using automated inverse-modeling procedures, and (iii) estimating associated uncertainties in the updated model's input parameters. Initial tasks were development of an Excel™-based Well Hydrograph Analysis Tool (WHAT) to aid in evaluation of well water-level elevation data (SRNL-STI-2015-00034; SRNL-STI-2018-00336), data reduction to identify target mean water-level measurements for use in calibrating the steady-state model, and comparison of water-well-construction data with the existing GSA hydrostratigraphic model. Next, the WHAT was used to (i) evaluate rainfall data, and (ii) develop updated water-level model calibration targets, including determination of their geographical weighting factors (SRNL-STI-2015-00351; SRNL-STI-2018-00336). This report also described a plan to assemble and evaluate recent GSA stream baseflow data for use in validating the new groundwater model, but this work was never accomplished. Next, the report describes the tasking associated with performing an updated analysis of more recently available hydrostratigraphic data (cf. SRNL-STI-2016-00516). The stated goal for this particular task was to add more control points and detail to the existing hydrostratigraphic model, but not modify previous interpretations of existing well data, unless warranted. This report summarized the groundwater modeling code-selection work, which was formally documented in SRNL-TR-2015-00061 and described quality assurance (QA) testing performed for the PEST parameter estimation and model calibration software. SRNL-STI-2016-00261 mentioned that development of a related Software Quality Assurance Plan to document PEST QA testing was in progress, but to date, this QA document has not been made available for NRC staff review. Finally, the report described the intended approach to updating the GSA PORFLOW groundwater flow and transport model (cf. SRNL-STI-2017-00008, Rev. 1 and SRNL-STI-2018-00643).

<u>SRNL-STI-2016-00516. Bagwell, L.A., P.L. Bennett, and G.P. Flach. "General Separations Area (GSA) Groundwater Flow Model Update: Hydrostratigraphic Data." Revision 0, Aiken, SC: Savannah River National Laboratory. February 2017.</u>

This document summarizes efforts made to review hydrostratigraphic data that informed the previous groundwater flow model, interpret more recently available site characterization data, and develop a new, larger and more detailed hydrostratigraphic dataset to support updated GSA flow models. Preference was given to identifying new, useful data (i.e., perforation length, perforation depth, and temporal continuity of records) from locations that were previously sparsely characterized. At the beginning of this effort, the baseline dataset included more than 1300 hydrostratigraphic picks (i.e., elevations of hydrostratigraphic boundaries) at more than 400 borehole locations. New top elevations of the Tan Clay Confining Zone (TCCZ), Lower Aquifer Zone (LAZ) of the Upper Three Runs Aquifer Unit, Gordon Confining Unit (GCU), Gordon Aquifer Unit (GAU), and Crouch Branch Confining Unit (CBCU—formerly Meyers Branch Confining System)—were interpreted using professional judgment and baseline hydrostratigraphic picks as a guide. This activity added more than 200 new control points, and more than 600 new hydrostratigraphic picks/interpretations to the model dataset. Boreholes along selected section lines were interpreted first, followed by surrounding boreholes. Where deemed necessary, baseline hydrostratigraphic picks were adjusted. The updated dataset includes 611 picks for the TCCZ, 576 picks for the LAZ, 378 picks for the GCU, 303 picks for the GAU, and 89 picks for the CBCU. The more than 1900 hydrostratigraphic picks across the GSA were then gridded to produce altitude-contour maps with 20 m by 20 m (66 ft by 66 ft) spatial resolution. The five resulting hydrostratigraphic surfaces were krigged with RockWorks high-fidelity option; the GAU and CBCU surfaces were pre-modeled to yield a better fit, given fewer data points at depth; and the surface of the GAU was also smoothed for best fit. The gridded surfaces for each hydrostratigraphic unit were exported from RockWorks, imported to ArcGIS, and converted to raster data. Using the “extract” spatial analysis function in ArcGIS, the raster data were interpolated to calculate the hydrostratigraphic surface elevation at each of the more than 45,000 model nodes. The resulting hydrostratigraphy model of the GSA provides input to subsequent groundwater flow and transport modeling in PORFLOW.

<u>SRNL-STI-2017-00008, Rev. 1. Flach, G.P., L.A. Bagwell, and P.L. Bennett. “Groundwater Flow Simulation of the Savannah River Site General Separations Area.” Revision 1, Aiken, SC: Savannah River National Laboratory. September 6, 2017.</u>

This document summarizes updates of new groundwater monitoring and site-characterization information that were made to the GSA database, capabilities of the PEST v. 13.6 code and the PORFLOW groundwater model calibration approach, PORFLOW calibration results, the recommended baseline groundwater model and three other alternative models for GSA groundwater flow and contaminant transport simulation and estimates of parameter uncertainty.

<u>SRNL-STI-2017-00445. Flach, G.P. and T. Hang. “Impacts of Updated GSA Groundwater Flow Models on the FTF, HTF and SDF PAs.” Revision 0, Aiken, SC: Savannah River National Laboratory. September 6, 2017.</u>

This document evaluates the impacts of the updated GSA groundwater flow model on the FTF, HTF, and SDF PAs. PORFLOW simulations were performed using the older 2004 model that the PAs are based on and the newer 2016 model. Compared with the older model, the final optimized models from the 2016 campaign show that the groundwater velocity in east Z-Area is lower, leading to higher I-129 concentration at the 100-m boundary and Upper Three Runs seepline. Impacts at HTF and FTF were found by DOE to be less significant, although flow was found to be more northward at H-Area and slower flows more toward the northwest at F-Area were observed.

<u>SRNL-STI-2018-00336. Wohlwend, J.L. “Updated General Separations Area (GSA) Groundwater Model Calibration Targets.” Revision 0, Aiken, SC: Savannah River National Laboratory. July 2018.</u>

This document summarizes work undertaken to update the GSA regional groundwater flow model calibration targets in support of an update to the Saltstone Disposal Facility (SDF) PA. In that regard, this effort incorporated additional well data, especially in the Z-Area, to expand the set of groundwater model calibration targets. A modified version of the WHAT tool (SRNL-STI-2015-00034; SRNL-STI-2015-00351) was used to evaluate water level data contained in the ERDMS database. This document revealed that modifications to the WHAT tool were required because the original version did not correctly compute median well-water level, or occasionally, the minimum and maximum water-levels. More importantly, this document revealed that several previously used well calibration targets had been errantly associated with inappropriate HSUs during the GSA 2016 model update.

After removing records from wells that do not present a water-level measurement, wells located outside the GSA boundary, and wells located inside the GSA boundary but with fewer than four water-level measurements, 731 wells and their records were investigated, analyzed, and geographic (polygonal declustering) and inverse-distance weighting factors (Appendix D of report) were assigned for use in PEST-based model calibration.

Although the executive summary of the document suggests that the report would address the incorporation of Mixed Waste Management Facility groundwater plume monitoring data into the set of calibration targets, the topic was never again mentioned.

SRNL-STI-2018-00624. Hamm, L.L., S.E. Aleman, T.L. Danielson, and B.T. Butcher. "Special Analysis: Impact of Updated GSA Flow Model on E-Area Low-Level Waste Facility Groundwater Performance." Revision 0, Aiken, SC: Savannah River National Laboratory. December 2018.

This E-Area special analysis (SA) assessed the potential impact of the updated GSA 2018 groundwater flow and transport model on existing Waste Information Tracking System groundwater inventory limits, given some significantly different particle trajectories emanating from LLWF vaults as observed in new modeling results. The best estimate for groundwater flow directions from the E-Area LLWF STs, Engineered Trenches (ETs), and the Low Activity Waste Vault (LAWV) changed significantly near the east set of STs in the GSA 2018 model representation (SRNL-STI-2018-00643) relative to those represented by modeling for the 2008 E-Area PA, and the revised flow field appeared to potentially create an adverse condition. The document indicated that the primary reason for the change in particle trajectories in the GSA 2018 model update was because of the influence of low-permeability closure caps that had been represented with modified recharge in the model at the location of the ORWBG and LLRWDF. The influence of closure caps on groundwater flow was previously neglected. Updated flow directions that account for the presence of closure caps produced a greater degree of contaminant plume interaction/overlap for disposal units in southeastern E-Area than previously predicted by the 2008 E-Area PA, with potential implications for groundwater disposal limits. This SA developed a new method for addressing plume interaction, which would abandon previously unquantified conservatisms, and its modeling used two different GSA 2018 flow fields: (i) one representing the absence of closure caps, as previously represented for the 2008 PA, and (ii) one based on the presence of a closure cap over the entirety of E-Area (i.e., here the GSA 2018 flow model was re-run with closure cap in place). Improved modeling techniques used to support this SA compensated for the negative impacts of increased E-Area plume interaction. This stochastic SA demonstrated that Solid Waste Management facility could continue to use the Waste Information Tracking System inventory limits for the disposal units that were analyzed and remain confident that the DOE Order 435.1 groundwater protection requirement and groundwater performance objectives would not be exceeded.

SRNL-STI-2018-00643. Flach, G.P. "Updated Groundwater Flow Simulations of the Savannah River Site General Separations Area." Revision 0, Aiken, SC: Savannah River National Laboratory. January 15, 2019.

This document summarizes further refinement of the GSA 2016 PORFLOW groundwater model performed in 2018 to (i) incorporate additional site-characterization information into an updated (and corrected) set of water-level elevation model calibration targets, (ii) represent closure of the H-Area Ash Basin, (iii) represent construction of E-Area LLWF slit trench operational covers, and (iv) incorporate plume information from the MWMF and LLRWDF. The document also summarizes the effort made in this update to lower hydraulic head residuals by adding another local model-calibration zone. The resulting steady-state groundwater flow and contaminant transport model is referred to as "GSA 2018."

SRNL-STI-2018-00652. Flach, G.P. and T. Hang. "PORFLOW Simulations Supporting the Saltstone Performance Assessment." Revision 0, Aiken, SC: Savannah River National Laboratory. December 2018. doi: 10.2172/1487377.

This document supports an ongoing Z-Area Saltstone Disposal Facility PA revision. For the purposes of this technical review, it is of interest because it includes updated GSA 2018 PORFLOW groundwater simulations of I-129 and Tc-99 transport with an improved treatment of plume dispersion. Hydraulic properties for some soils/sediments were also revised for these models, based on E-Area PA maintenance work.

SRNL-TR-2015-00061. Flach, G.P. "Code Selection for General Separations Area Flow Simulation and Model Calibration." Revision 0, Aiken, SC: Savannah River National Laboratory. March 2015.

This document reviewed the pros and cons of the use of various groundwater flow simulation and groundwater model calibration codes and provided DOE's rationale for choosing PORFLOW and PEST for use when conducting the recent update to and optimization of the GSA groundwater flow model.

For the GSA groundwater model update, selection of the PORFLOW v. 6.42 code by Analytic & Computational Research, Inc. (ACRi) (www.acricfd.com/software/porflow) (i) provided a combined, switchable recharge–drain boundary condition (WSRC-TR-99-00282) for simulating variable seepage faces, (ii) leveraged more than 20 years' analyst expertise with PORFLOW and existing pre- and post-processing software infrastructure at SRNL for improved efficiency and reduced project cost, and (iii) provided continuity with previous GSA PA modeling. PORFLOW simulates radioactive decay chains, i.e., progeny ingrowth, in addition to first-order decay for radionuclide transport simulations. Additionally, Flach (2015) has resolved a particle tracking deficiency previously associated with distorted PORFLOW meshes, developing a means to rigorously compute flow velocity using Tecplot and the volumetric flowrate crossing a cell face (SRNL-STI-2015-00115). Table 2-1 of SRNL-TR-2015-00061 compares PORFLOW v. 6.42 to other groundwater flow and transport codes developed by the federal government, which SNRL considered to be competitive alternatives. All codes considered, other than PORFLOW and possibly Amanzi (under development), lack the combined recharge–drain boundary condition.

Selection of the PEST v. 13.3 code for semi-automated parameter estimation/model calibration, prediction, and uncertainty analysis, was based on its general dominance over the environmental application market (i.e., large user base). Table 3-1 of SRNL-TR-2015-00061 presented the key attributes of PEST, whereas Table 3-2 summarized those of UCODE.

SRR-CWDA-2017-00068. Mangold, J. and B. Lester. "Evaluation of Impacts to FTF and HTF PA Doses Due to the Update of the GSA Database." Revision 0, Aiken, SC: Savannah River Remediation, LLC. October 2017.

This document presents an evaluation of how the recent update of the GSA groundwater flow model (GSA 2016) affects resulting doses from the FTF, and HTF PAs. The evaluation employs the use of two PA modeling platforms: PORFLOW (as developed by Savannah River National Laboratory (SRNL)) and GoldSim [as developed by Savannah River Remediation, LLC (SRR)] including member of the public doses and inadvertent intruder doses (10 CFR 61.41 and 61.42, respectively). The report also evaluates the impact of inclusion of off-diagonal dispersitivites and a methodology that considers upwinding diffusivities at cell faces on the results of the transport simulations.

SRR-CWDA-2017-00068. Mangold, J. "Evaluation of Impacts to FTF and HTF PA Doses Due to the Update of the GSA Database." Revision 1, Aiken, SC. Savannah River Remediation, LLL. September 2019.

This document presents an evaluation of how the recent update of the GSA groundwater flow (GSA 2018) model affects resulting doses from the FTF and HTF PAs. The evaluation employs the use of two PA modeling platforms: PORFLOW [as developed by Savannah River National Laboratory (SRNL)] and GoldSim [as developed by Savannah River Remediation, LLC (SRR)] including member of the public doses and inadvertent intruder doses (10 CFR 61.41 and 61.42, respectively). Implementations of an alternative dispersion model and increased grid resolution are also evaluated in this report by means of a sensitivity analysis.