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GoldSim E-Area Low-Level Waste Facility Vadose Zone Model Benchmarking

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EXECUTIVE SUMMARY

This report documents the development and benchmarking of the E-Area Low-Level Waste Facility (ELLWF) GoldSim Engineered and Slit Trench (ET and ST) vadose zone models. Subsequent activities (beyond the scope of this effort) will couple the GoldSim-based vadose zone models to the GoldSim aquifer model, with the intent of performing stochastic analyses that couple all pertinent fate and transport processes from the ground surface up to the 100-m Point of Assessment (POA). The benchmarking presented within this report focuses on the Slit Trench 06 (ST06) hydrostratigraphic location that resides within the center set of slit trenches. These GoldSim-based vadose zone models are generic models capable of being benchmarked to any of the other trench locations within E-Area.

This is a key component of the effort to include uncertainty quantification and sensitivity analysis (UQSA) in the next revision of the E-Area Performance Assessment (PA). This report describes the model and shows results obtained from benchmarking the GoldSim transport simulations under a deterministic mode (using nominal best estimate parameter settings) to best-estimate deterministic results obtained using the PORFLOW vadose zone model. The P PORFLOW model is three-dimensional while the GoldSim model represents a simplified one-dimensional treatment. The GoldSim ET and ST vadose zone models were able to reproduce PORFLOW peak fluxes, with acceptable accuracy for ET Case01 (Intact) and ST Case01 (Intact), as shown in Table ES-1 and Table ES-2, respectively. The GoldSim ET and ST vadose zone models were able to reproduce PORFLOW peak fluxes, with acceptable accuracy for ET Case11b (Subsided) and ST Case11b (Subsided), as shown in Table ES-3 and Table ES-4, respectively. The detailed comparison of radionuclide and tracer fluxes from the waste zone and to the water table are discussed in Section 5 and summarized in Section 6.

Note that the parameter settings established are universal in nature and are independent of radionuclide and its progeny. The close agreement between the two models provides confidence that GoldSim will provide adequate results that will reflect the behavior of vadose zone transport under off-nominal operating conditions for sensitivity and uncertainty analysis.

Table ES-1. Comparison of GoldSim and PORFLOW peak fluxes to the water table and peaks times ET Case01 (Intact).

	PORFLOW		GoldSim		Ratio	
	Max Flux	Max Time	Max Flux	Max Time	GoldSim/PORFLOW	
Nuclides	Ci/yr	Year	Ci/yr	Year	Ci/Ci	yr/yr
C-14	1.143E-01	1092	1.183E-01	1092	1.04E+00	1.00
H-3	4.169E+03	21	5.113E+03	21	1.23E+00	1.00
I-129	1.202E-04	691	1.265E-04	692	1.05E+00	1.00
Np-237	6.971E-04	1072	7.977E-04	1052	1.14E+00	0.98
U-233	2.045E-08	5000	2.084E-08	5000	1.02E+00	1.00
Th-229	1.806E-09	5000	1.838E-09	5000	1.02E+00	1.00
Sr-90	3.478E-11	1031	2.475E-11	1072	7.12E-01	1.04
Tc-99	6.449E-03	571	6.594E-03	552	1.02E+00	0.97

Nuclides	PORFLOW Max Flux	PORFLOW Max Time	GoldSim Max Flux	GoldSim Max Time	Ratio GoldSim/PORFLOW	
	Ci/yr	Year	Ci/yr	Year	Ci/Ci	yr/yr
U-238	2.322E-17	5000	5.851E-22	5000	2.52E-05	1.00
U-234	3.261E-19	5000	8.187E-24	5000	2.51E-05	1.00
Th-230	2.529E-22	5000	4.271E-27	5000	1.69E-05	1.00
Ra-226	1.714E-12	5000	1.803E-12	5000	1.05E+00	1.00
Pb-210	2.105E-14	5000	2.215E-14	5000	1.05E+00	1.00
	mol/yr		**mol/yr**			
Tracer	2.329E-01	21	2.852E-01	21	1.22E+00	1.00

Table ES-2. Comparison of GoldSim and PORFLOW peak fluxes to the water table and peaks times ST Case01 (Intact).

Nuclides	PORFLOW Max Flux	PORFLOW Max Time	GoldSim Max Flux	GoldSim Max Time	Ratio GoldSim/PORFLOW	
	Ci/yr	Year	Ci/yr	Year	Ci/Ci	yr/yr
C-14	7.006E-02	1222	6.617E-02	1223	9.44E-01	1.00
H-3	3.582E+03	20	5.104E+03	20	1.43E+00	0.99
I-129	9.655E-05	731	1.087E-04	712	1.13E+00	0.97
Np-237	4.556E-04	1132	4.745E-04	1092	1.04E+00	0.96
U-233	1.871E-08	5000	1.9501E-08	5000	1.04E+00	1.00
Th-229	1.639E-09	5000	1.649E-09	5000	1.01E+00	1.00
Sr-90	3.060E-11	991	2.114E-11	1072	6.91E-01	1.08
Tc-99	6.3502E-03	611	6.484E-03	592	1.02E+00	0.97
U-238	2.279E-17	5000	9.280E-26	5000	4.07E-09	1.00
U-234	3.200E-19	5000	1.299E-27	5000	4.06E-09	1.00
Th-230	2.487E-22	5000	5.009E-31	5000	2.01E-09	1.00
Ra-226	1.147E-12	5000	1.196E-12	5000	1.04E+00	1.00
Pb-210	1.403E-14	5000	1.462E-14	5000	1.04E+00	1.00
	mol/yr		**mol/yr**			
Tracer	1.999E-01	21	2.823E-01	20	1.41E+00	0.99

Table ES-3. Comparison of GoldSim and PORFLOW peak fluxes to the water table and peaks times ET Case11b (Subsided).

	PORFLOW		GoldSim		Ratio	
	Max Flux	Max Time	Max Flux	Max Time	GoldSim/PORFLOW	
Nuclides	Ci/yr	Year	Ci/yr	Year	Ci/Ci	yr/yr
C-14	1.095E-01	1092	1.164E-01	1092	1.06E+00	1.00E+00
H-3	4.169E+03	21	5.015E+03	21	1.20E+00	1.00E+00
I-129	1.127E-04	691	1.240E-04	692	1.10E+00	1.00E+00
Np-237	6.627E-04	1072	7.830E-04	1052	1.18E+00	9.81E-01
U-233	2.044E-08	5000	2.054E-08	5000	1.00E+00	1.00E+00
Th-229	1.806E-09	5000	1.815E-09	5000	1.00E+00	1.00E+00
Sr-90	7.610E-03	249	2.915E-04	271	3.83E-02	1.09E+00
Tc-99	6.244E-02	46	6.991E-02	46	1.12E+00	1.00E+00
U-238	3.590E-11	5000	1.461E-13	5000	4.07E-03	1.00E+00
U-234	5.029E-13	5000	2.043E-15	5000	4.06E-03	1.00E+00
Th-230	1.009E-15	5000	2.578E-18	5000	2.56E-03	1.00E+00
Ra-226	1.838E-12	5000	1.780E-12	5000	9.68E-01	1.00E+00
Pb-210	2.259E-14	5000	2.187E-14	5000	9.68E-01	1.00E+00
	mol/yr		**mol/yr**			
Tracer	2.329E-01	21	2.798E-01	21	1.20E+00	1.00E+00

Table ES-4. Comparison of GoldSim and PORFLOW peak fluxes to the water table and peaks times ST Case11b (Subsided).

	PORFLOW		GoldSim		Ratio	
	Max Flux	Max Time	Max Flux	Max Time	GoldSim/PORFLOW	
Nuclides	Ci/yr	Year	Ci/yr	Year	Ci/Ci	yr/yr
C-14	6.753E-02	1222	6.453E-02	1223	9.56E-01	1.00E+00
H-3	3.582E+03	20	5.115E+03	20	1.43E+00	1.00E+00
I-129	9.061E-05	731	1.029E-04	712	1.14E+00	9.74E-01
Np-237	4.350E-04	1132	4.586E-04	1072	1.05E+00	9.47E-01
U-233	1.862E-08	5000	1.941E-08	5000	1.04E+00	1.00E+00
Th-229	1.633E-09	5000	1.639E-09	5000	1.00E+00	1.00E+00
Sr-90	5.458E-03	255	6.568E-03	264	1.20E+00	1.04E+00
Tc-99	4.477E-02	46	6.257E-02	46	1.40E+00	1.00E+00
U-238	3.222E-11	5000	1.579E-12	5000	4.90E-02	1.00E+00
U-234	4.514E-13	5000	2.209E-14	5000	4.89E-02	1.00E+00
Th-230	8.856E-16	5000	2.174E-17	5000	2.45E-02	1.00E+00
Ra-226	1.301E-12	5000	1.361E-12	5000	1.05E+00	1.00E+00
Pb-210	1.594E-14	5000	1.666E-14	5000	1.05E+00	1.00E+00
	mol/yr		**mol/yr**			
Tracer	1.999E-01	21	2.823E-01	20	1.41E+00	9.52E-01

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LIST OF ABBREVIATIONS

BS	Between Segments
CIG	Components-in-Grout
DC	Dynamically Compacted
DU	Disposal Unit
ELLWF	E-Area Low-Level Waste Facility
ET	Engineered Trench
GSA	General Separations Areas
H2	Hole 2
HELP	Hydrologic Evaluation of Landfill Performance
IC	Institutional Control
ILV	Intermediate Level (Waste) Vault
LAWV	Low Activity Waste Vault
LS	Lower Sandy
LVZ	Lower Vadose Zone
NDC	Nondynamically Compacted
PA	Performance Assessment
POA	Point of Assessment
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
ST	Slit Trench
SUA	Sensitivity and Uncertainty Analysis
TC	Tan Clay
UQSA	Uncertainty Quantification and Sensitivity Analysis
US	Upper Sandy
UVZ	Upper Vadose Zone
VZ	Vadose Zone
WT	Water Table
WZ	Waste Zone

1.0 Introduction

The Contaminant Transport Module in the GoldSim® Monte Carlo simulation software (GTG 2018) is utilized to model the release and transport of radiological inventory disposed within engineered and slit trenches. This report presents the benchmarking of the E-Area Low-Level Waste Facility (ELLWF) GoldSim vadose zone model to three-dimensional PORFLOW (ACRI, 2018) ET and ST vadose zone models. This is a key component of the effort to include uncertainty quantification and sensitivity analysis (UQSA) in this revision of the E-Area PA, considering recommendations from the 2015 PA strategic planning team outlined by Butcher and Phifer (2016).

The model can provide both deterministic and stochastic (probabilistic) results and is a sub-model of the GoldSim system model described by Wohlwend (2020).

The Savannah River Site (SRS) ELLWF consists of three types of trench disposal units (DUs): Slit Trenches (STs), Engineered Trenches (ETs), and Component-in-Grout (CIG) Trenches. Only STs/ETs are addressed in the GoldSim vadose zone model as the two CIG trenches are largely unused and therefore being converted into Slit Trenches and the existing nine CIG segments treated as special waste forms (Danielson 2020).

STs are below-grade earthen disposal units with vertical side slopes making them inaccessible by vehicle. Waste is typically deposited at the top on one end and pushed into the unit (bulk waste) or crane lifted into place (containerized waste). Each ST is generally laid out in a series of five narrow parallel trench rows. In the typical layout, each trench row is designed to be 20 feet deep, 20 feet wide, and 656 feet long with ten feet to 14 feet of undisturbed soil separating each parallel trench row. The areal layout of a single slit trench is shown in Figure 1-1. A set of five, 20-foot wide trench rows, are grouped together within a nominal 157-foot wide by 656-foot long disposal unit footprint forming a single ST. The vertical cross-section of slit segments in the upper vadose zone (UVZ) and the lower vadose zone (LVZ) is shown in .Figure 1-2

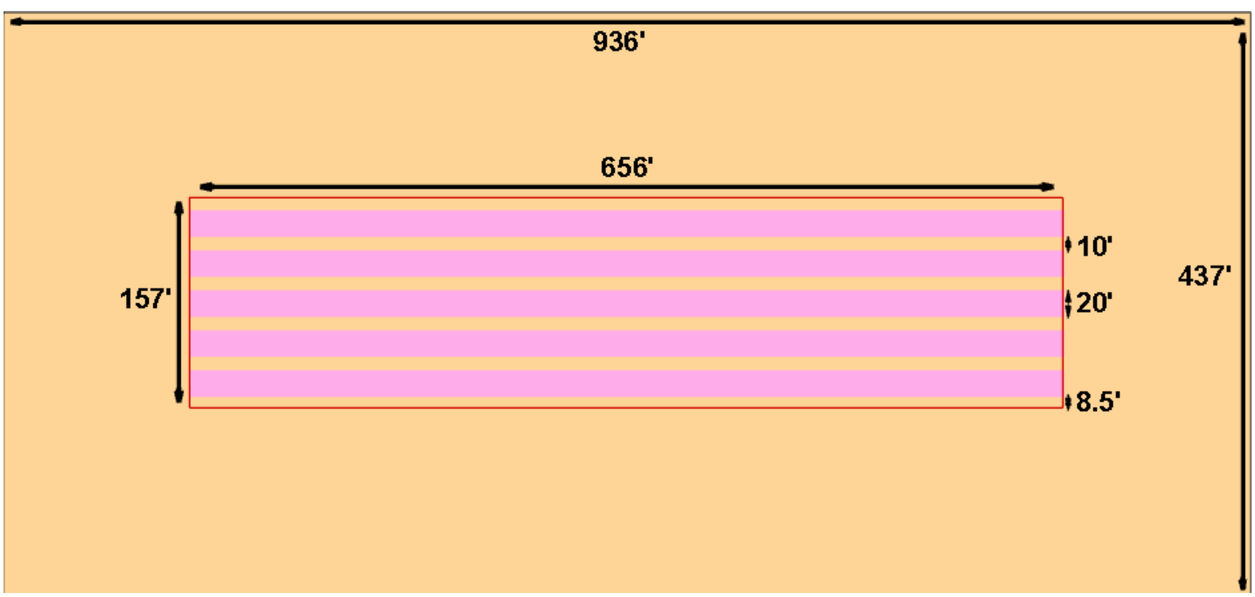

Figure 1-1. Areal layout of slit segments within a single slit trench.

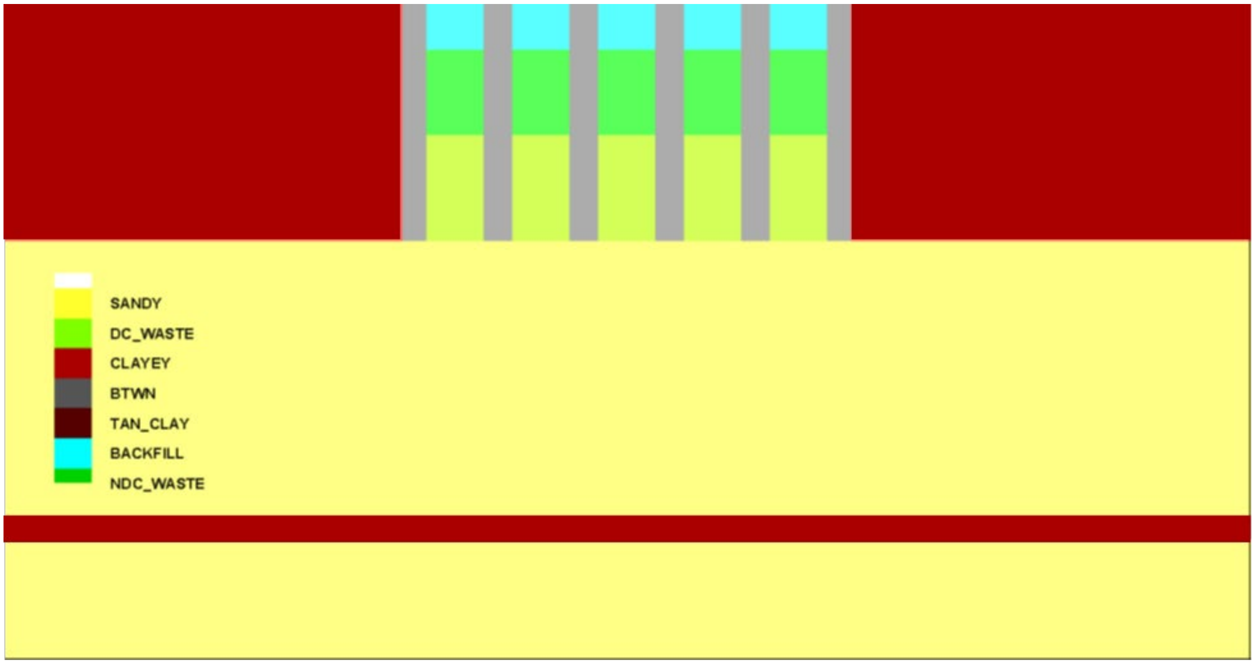

Figure 1-2. Vertical cross-section of slit segments in the UVZ and LVZ.

ETs are also below grade earthen disposal units. ETs are vehicle-accessible with an open trench design spanning the entire width and length of the disposal unit footprint (nominal size, 656 feet long and 157 feet wide). The areal layout of a central engineered trench with covers is shown in Figure 1-3. To allow vehicle accessibility, trench sides are laid back with slopes ranging from 1.25:1 (horizontal:vertical) to 1.5:1. This design allows forklift and crane access to the interior of the trench for stacking of containerized waste primarily consisting of B-25 boxes and SeaLand containers. The vertical cross-section of a central engineered trench in the UVZ and LVZ is shown in Figure 1-4.

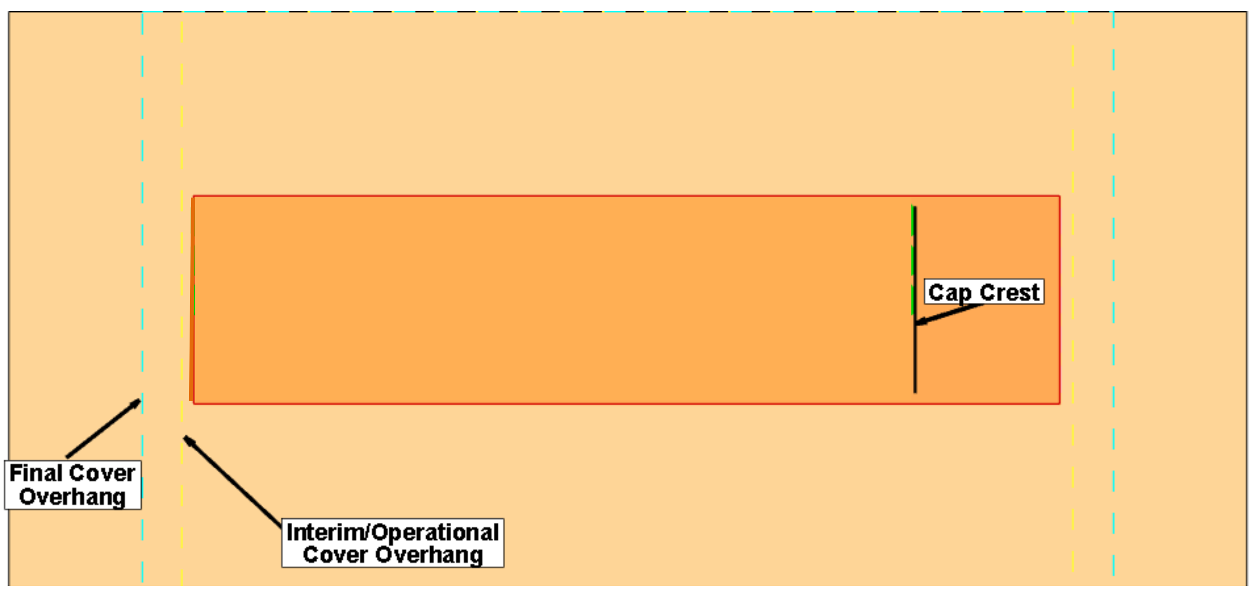

Figure 1-3. Areal layout of a central engineered trench with covers.

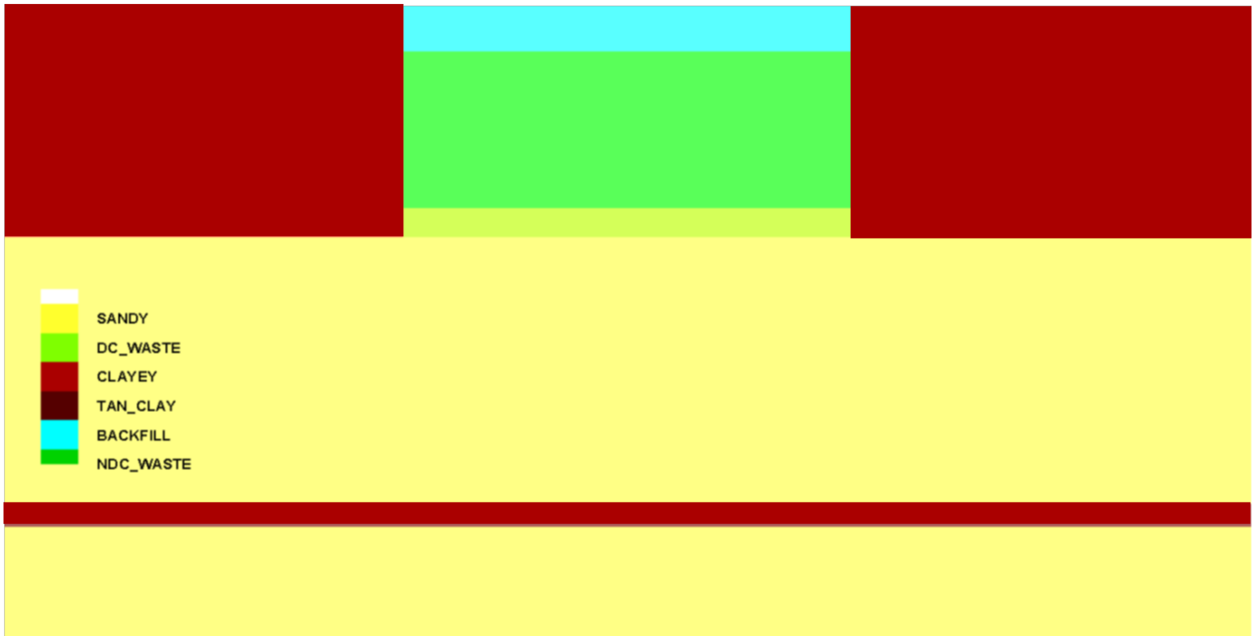

Figure 1-4. Vertical cross-section of a central engineered trench in the UVZ and LVZ.

2.0 Overview of Vadose Zone Models

PORFLOW three-dimensional vadose models of a centrally located slit and engineered trench were developed by Danielson (2019) using the depth to water table and hydrostratigraphic surfaces beneath Slit Trench 6 (Bagwell and Bennett, 2017). The upper boundary condition of the PORFLOW models is defined by time dependent infiltration rates to account for the operational period (uncovered), institutional control period (interim cover), the post-closure period (final cover – intact case, subsided cases and long-term degradation). The final cover overhangs the trench by 40 feet and the interim cover overhangs the trench by 10 feet. The operational stormwater runoff (geomembrane) cover is assumed to be applied to an ST four years after the placement of the last waste package but was not implemented in this study as the timing of each operational cover installation is unique. This early cover has the same overhang and infiltration rate as the interim cover.

The ET and ST trench models include intact and subsidence cases (Case01 and Case11b, respectively). Subsidence refers specifically to non-crushable containers and vessels that do not collapse during dynamic compaction but are assumed to fail catastrophically immediately upon installation of the final closure cap resulting in localized cap subsidence referred to as "holes" in the closure cap. Subsidence cases were investigated using only a single discrete hole with a specific dimension and location as discussed in Section 3.0. The intact and subsidence cases both include dynamic compaction of the waste zone. Dynamic compaction of the waste zone and subsidence are assumed to occur at the end of institutional control (IC).

The vadose zone model represents three porous media zones comprising the disposal system including: the waste zone (WZ), upper vadose zone (UVZ), and lower vadose zone (LVZ). The hydraulic properties within these zones employ the following six material types defined by Nichols (2020): STETboxesBC, STETboxesAC, SThybridBC, SThybridAC, ClayeySoil (UVZ), and SandySoil (LVZ).

ELLWF Trench GoldSim Models were built using the Contaminant Transport Module in GoldSim version 12.1.3 #192 (March 13, 2019). GoldSim's cell pathway element was used to build a column and network of cells for modeling the advective and diffusive transport of radionuclides below the operational soil cover to the water table in the ST and ET, respectively. The cell pathway allows inventory transfer within the waste zone during dynamic compaction. The cell pathway accommodates back diffusion which can occur after dynamic compaction of the waste zone. The GoldSim ET trench model includes intact and subsidence cell pathway elements. The GoldSim ST trench model includes intact, between segment and subsidence cell pathway elements.

Vertical Darcy velocities and water saturations from the PORFLOW vadose zone flow simulations are extracted for each steady-state simulation (time period) and averaged within user specified material zones for the GoldSim vadose zone (VZ) model. Volume-averaged vertical Darcy velocities are computed for the porous media zones (WZ, UVZ and LVZ) in each cell pathway column for input to the GoldSim VZ model. Transport properties of ET boxed and ST hybrid waste (pre and post dynamic compaction), UVZ and LVZ were extracted from the PORFLOW VZ model and included in the GoldSim VZ model.

Seven parent radionuclides and their progeny (half-life > 1 year) were modeled in the PORFLOW and GoldSim vadose zone models. The parent radionuclides include C-14, H-3, I-129, Np-237, Sr-90, Tc-99 and U-238. A conservative tracer was also modeled for assessing mass balance of fluxes from the waste zone and to the water table. The radionuclide data for the species modeled are obtained from the SRNL Radionuclide-Dose data package (Kaplan 2016) and given in Table 2-1.

Table 2-1. Radionuclide data for species modeled.

Species ID	Atomic Weight (g/mol)	Half-life (year)	Sp. Act. (Ci/mol)	Daughter
C-14	14	5.7000E+03	6.2719E+01	
H-3	3	1.2320E+01	2.9018E+04	
I-129	129	1.5700E+07	2.2770E-02	
Np-237	237	2.1440E+06	1.6674E-01	U-233
U-233	233	1.5920E+05	2.2456E+00	Th-229
Th-229	229	7.3400E+03	4.8705E+01	
Sr-90	90	2.8790E+01	1.2417E+04	
Tc-99	99	2.1110E+05	5.2100E+08	
U-238	238	4.4680E+09	8.0012E-05	U-234
U-234	234	2.4550E+05	1.4562E+00	Th-230
Th-230	230	7.5380E+04	4.7426E+00	Ra-226
Ra-226	226	1.6000E+03	2.2343E+02	Pb-210
Pb-210	210	2.2200E+01	1.6103E+04	

Best estimate soil/water partition coefficients (K_ds) for the various solid materials are defined for each chemical element in the model (not each radionuclide species, e.g., a single K_d is assigned to all isotopes of uranium). Clayey and Sandy sediment K_ds are assigned to radionuclides in the different material zones in the vadose zone model (i.e., WZ, UVZ, and LVZ) based on the chemical characteristics of the material types.

Clayey sediment K_ds are assigned to radionuclides in the WZ (i.e., waste cells in the model) as the geochemistry of Clayey sediment is assumed to approximate that of the rusted metal waste containers. Sorption coefficients are given in Table 2-2. In the vadose zone model, uncertainty distributions for these best estimate K_d values are derived from Kaplan (2016).

Table 2-2. Mean Soil/Water partition coefficients.

Element	Best Sand *Kd* (mL/g)	Best Clay *Kd* (mL/g)
C	1.0E+00	3.0E+01
H	0.0E+00	0.0E+00
I	1.0E+00	3.0E+00
Np	3.0E+00	9.0E+00
Pb	2.0E+03	5.0E+03
Ra	2.5E+01	1.8E+02
Sr	5.0E+00	1.7E+01
Tc	6.0E-01	1.8E+00
Th	9.0E+02	2.0E+03
U	3.0E+02	4.0E+02

3.0 PORFLOW Vadose Zone Models

PORFLOW three-dimensional vadose models of a central slit and engineered trench were developed using the depth to water table and hydrostratigraphic surfaces beneath slit trench 6 (ST06). ST06 is a centrally located unit in group 3 of the 7 hydrostratigraphic groups shown in Figure 3-1 with a minimum depth to water table of 55 feet and a minimum clay thickness of 2 feet.

Disposal Unit	Avg Depth to WT (ft)	Avg Clay Thickness (ft)	Minimum Depth to WT (ft)	Minimum Clay Thickness (ft)	Percent Subsidence	Number of Models
Slit Trench 8	75.80	11.20	75.18	11.20	2	3
Slit Trench 9	78.05	13.83			2	
Slit Trench 10	77.06	14.19			2	
Slit Trench 11	75.42	12.47			2	
Engineered Trench 4	75.18	11.46			2	
Slit Trench 1	76.32	12.68			0	
Slit Trench 2	76.59	11.29			2	
Slit Trench 3	72.93	7.70	64.31	4.09	4.9	4
Engineered Trench 3	72.14	7.13			0	
Slit Trench 4	68.61	5.70			3.6	
Slit Trench 23	64.31	4.09			2	
Slit Trench 24	61.14	1.93	55.46	1.88	2	3
Slit Trench 5	59.73	1.88			0.54	
Slit Trench 6	58.25	3.08			2	
Slit Trench 7	55.46	2.62			2	
Engineered Trench 1	57.64	16.76	55.04	15.46	0	2
Slit Trench 14	55.04	15.46			2	
Engineered Trench 5	50.80	10.19	46.12	10.19	2	3
Engineered Trench 6	46.12	10.57			2	
Slit Trench 17	49.18	13.35			2	
Slit Trench 18	48.13	12.18			2	
Slit Trench 19	49.33	13.29			2	
Slit Trench 20	48.70	12.59			2	
Slit Trench 21	49.75	12.63			2	
Slit Trench 22	49.75	12.63			2	
Engineered Trench 2	47.87	5.89			2	1
Future Plot 8-1	65.20	5.14	63.15	5.34	2	2
Future Plot 8-2	65.38	5.09			2	
Future Plot 8-3	58.86	5.79			2	

***Red text indicates corner trench

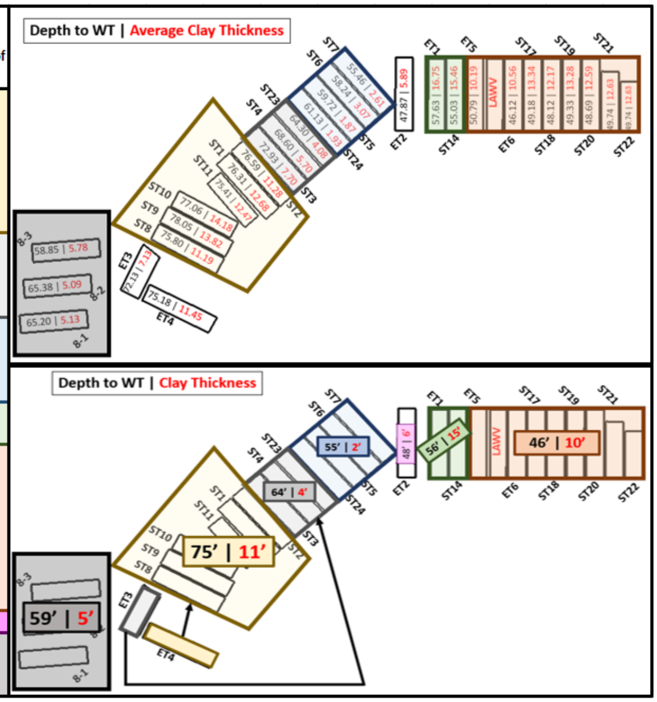

Figure 3-1. Depths and thicknesses of seven hydrostratigraphic groupings for input to PORFLOW models.

To simplify mesh generation of models for ETs and STs, the spatial discretization along the x and y directions of the mesh is the same for all models. Figure 3-2 and Figure 3-3 show the common mesh used for ETs and STs for trench units centrally located and along the corners beneath the final closure cap, respectively. Variations along the Z direction occur only to account for differences in the depth to the water table and clayey thickness, but the discretization of the trench is always the same. Therefore, the only difference between the ET and ST models for a particular hydrostratigraphic grouping are the assignments of material types within regions of the mesh corresponding to the disposal unit. More specifically, ETs have uniformly specified waste across the entire DU footprint that corresponds to boxed waste (16-feet-tall before dynamic compaction and 2.5-feet tall after dynamic compaction). STs, on the other hand, have a 10-foot-wide section of upper vadose zone material separating each of the five trench segments and 8.5-foot-wide sections of upper vadose zone material separating trench segments 1 and 5 from the edge of the overall footprint. Additionally, the waste form for STs is assumed to be hybrid waste (16-feet-tall before dynamic compaction and 8.87-feet-tall after dynamic compaction). Because a ST receives both bulk and boxed waste throughout a trench, a "hybrid" waste zone is assumed by combining the two waste types into a set of equivalent properties based on an estimated fraction of each waste type.

The upper boundary condition of the PORFLOW models is defined by time dependent infiltration rates to account for operational time period (uncovered), institutional control period (interim cover), and the end of institutional control (final cover) and beyond (degradation of the final cover). Dyer (2019) identifies bounding conceptual infiltration models pertaining to the final closure cap and provides intact and subsided infiltration estimates based on the area beneath the closure cap occupied by non-crushable containers in each disposal unit. Each unique percent subsidence requires a separate model setup for boundary condition specification. Additionally, a trench that falls along a corner of the final closure cap (e.g., ET3 or ST22) requires a separate model so that so that boundary conditions can be uniquely applied for central vs. corner units. Figure 3-2 and Figure 3-3 show potential hole locations (green rectangles) and final cover geometry (light blue dashed outline) for centrally located and corner trench units, respectively. The hole locations shown were considered for evaluation by Danielson (2019) for both ETs and STs. Hole location 2 (Hole 2) was selected for the ST and ET vadose zone GoldSim model calibration described in this report.

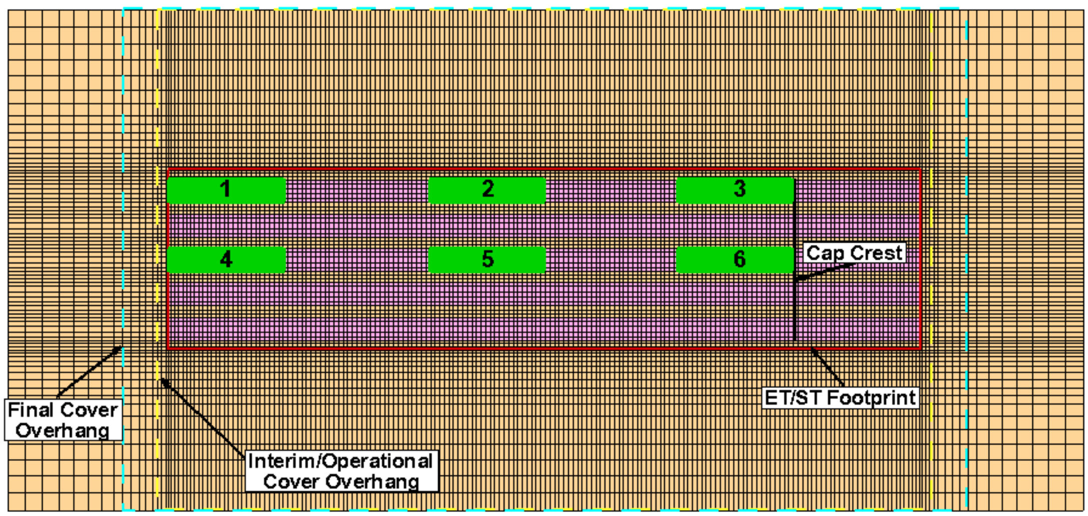

Figure 3-2. Common mesh and discrete hole locations for centrally located ST/ETs.

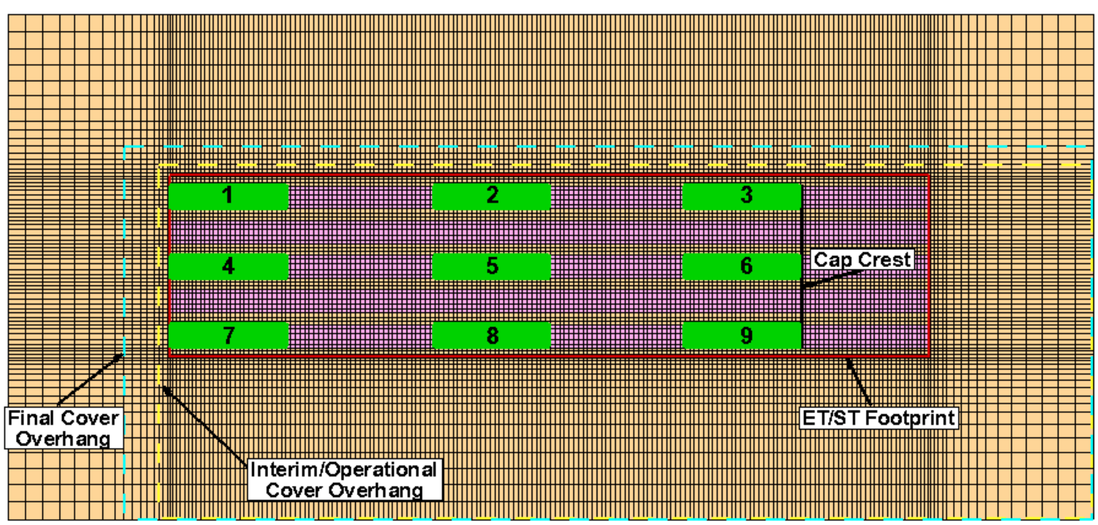

Figure 3-3. Common mesh and discrete hole locations for ST/ETs in corner positions of the final closure cap.

The purple mesh areas represent the footprint of five ST segments. Hole 2 is located in the center of ST segment 5 (counting up from the ST segment at the bottom).

The final multilayer soil-geomembrane cover overhangs the trench by 40 feet and the interim (geomembrane only) cover overhangs the trench by 10 feet. The operational stormwater runoff (geomembrane only) cover that is applied to STs four years after the placement of the last waste package has the same overhang and infiltration rate as the interim cover but was not implemented in this study as the timing of each operational cover installation is unique.

Infiltration zones are designated at the top boundary nodes of the PORFLOW vadose zone flow models to account for changes in infiltration due the placement of operational, interim and final covers. The operational stormwater (not included here) and interim covers are assumed to be maintained in their intact condition while the final cover is subject to long term degradation and catastrophic subsidence due to the failure of underlying non-crushable containers. Infiltration zones for PORFLOW vadose zone flow simulations are shown in Table 3-1. A series of PORFLOW LOCAte and BOUNdary FLUX commands were executed for each infiltration zone in the order listed in the table. The Domain infiltration zone contains all top boundary nodes which remain uncovered throughout the simulation period (i.e., background areas adjacent to the closure cap). The intact Case01 for PORFLOW vadose zone simulations include only the top three infiltration zones. The subsidence Case11b for PORFLOW vadose zone simulations includes the additional subsidence infiltration in Hole 2.

Table 3-1. Infiltration zones for PORFLOW vadose zone flow simulations.

Infiltration	Coordinates (lower-left,ft)		Coordinates (upper-right,ft)		Lengths (ft)	
Zone	x	y	x	y	dx	dy
Domain	0.0	0.0	936.0	437.0	936	437
Final cover	100.0	0.0	836.0	437.0	736	437
Interim cover	130.0	0.0	806.0	437.0	676	437
Hole 1	140.0	268.5	240.0	288.5	100	20
Hole 2	368.0	268.5	468.0	288.5	100	20
Hole 3	584.0	268.5	684.0	288.5	100	20
Hole 4	140.0	238.5	240.0	258.5	100	20
Hole 5	368.0	238.5	468.0	258.5	100	20
Hole 6	584.0	238.5	684.0	258.5	100	20
Hole 7	140.0	208.5	240.0	228.5	100	20
Hole 8	368.0	208.5	468.0	228.5	100	20
Hole 9	584.0	208.5	684.0	228.5	100	20

Transient infiltration rates through the top boundary nodes of the PORFLOW vadose zone flow model were separated into a series of 98 steady-state flow simulations which span the simulation period from 0 to 5000 years. The PORFLOW ET and ST infiltration rates through the top of the modeling domain are shown in Figure 3-4.

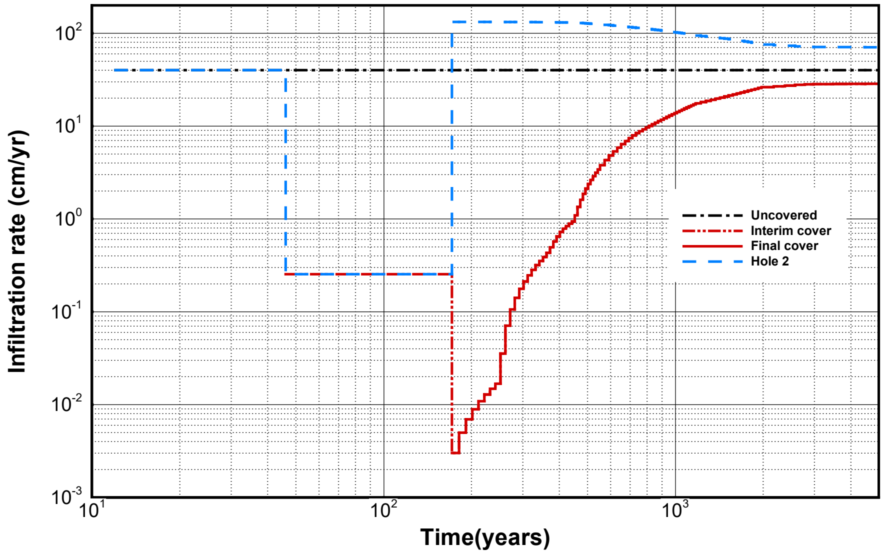

Figure 3-4. PORFLOW ET and ST infiltration rates through the top of the modeling domain.

The PORFLOW vadose zone analysis involves a two-step simulation workflow that proceeds as follows:

- Steady-state vadose zone flow fields are obtained in a sequence of time periods each having a unique set of material properties that represent changes following dynamic compaction. The flow fields include changes in infiltration due to subsidence at the end of IC and placement of operational, interim and final covers (with subsequent degradation).
- Vadose zone contaminant transport models are supplied steady-state flow fields as input to solve the time-dependent transport equations and obtain the total flux from the waste zone and the total flux to the water table for each species.

In the following sections, specific modeling details of PORFLOW ET and ST vadose zone models will be described.

3.1 PORFLOW Central Engineered Trench Vadose Zone Model

The extent of the PORFLOW ET mesh is 201 vertices in the x-direction, 76 vertices in the y-direction and 47 vertices in the z-direction. The length of the mesh in the x, y and z directions is 936 feet, 437 feet and 55 feet, respectively. The engineered trench resides within a 656-foot by 157-foot region in the interior of the mesh. A chair cutout of the 3D mesh with material zones is shown in Figure 3-5.

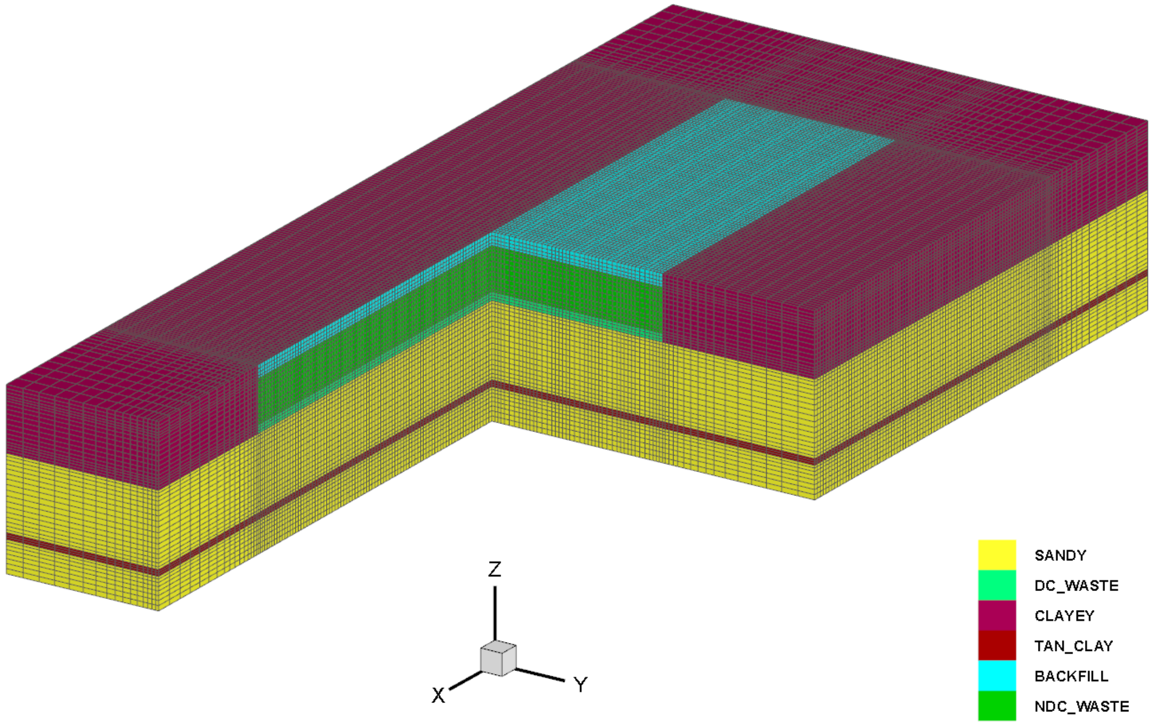

Figure 3-5. Chair cutout of the PORFLOW ET 3D mesh with material zones.

An x-slice of the PORFLOW ET 3D through the center of the trench is shown in Figure 3-6.

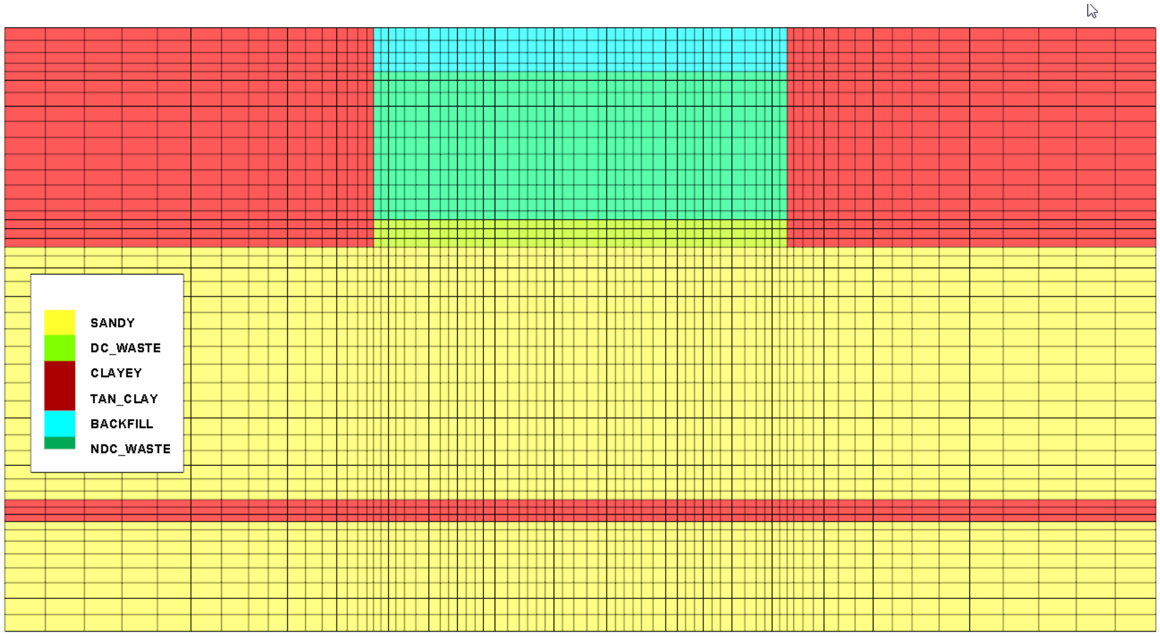

Figure 3-6. YZ cross-section of the PORFLOW ET 3D mesh with material zones.

The coordinates and lengths of the material zones within the footprint of the engineered trench are shown in Table 3-2. The SANDY soil layer is broken into two layers: SANDY2 is the region above the TAN_CLAY and SANDY1 is the region below the TAN_CLAY.

Table 3-2. Material zones within the footprint of the engineered trench.

Material Zone	Coordinates (lower-left,ft) x	y	z	Coordinates (upper-right,ft) x	y	z	Lengths (ft) dx	dy	dz
BACKFILL	140.0	140.0	51.0	796.0	297.0	55.0	656	157	4
NDC_WASTE	140.0	140.0	37.5	796.0	297.0	51.0	656	157	13.5
DC_WASTE	140.0	140.0	35.0	796.0	297.0	37.5	656	157	2.5
SANDY2	140.0	140.0	12.0	796.0	297.0	35.0	656	157	23
TAN_CLAY	140.0	140.0	10.0	796.0	297.0	12.0	656	157	2
SANDY1	140.0	140.0	0.0	796.0	297.0	10.0	656	157	10

Hydraulic and transport properties of the porous media in an engineered trench are specified prior to and after dynamic compaction for each material type. Nominal parameter values for saturated effective diffusion coefficient (De), porosity, dry bulk density (rhob) and particle density (rhop) for each material type are given in Table 3-3.

Table 3-3. Hydraulic and transport properties of porous media in an engineered trench.

ID	Material Name	De (cm^2/yr)	Porosity	rhob (g/cm^3)	rhop (g/cm^3)	Time period 0 to 171 yrs	171 to 5000 yrs
UpperVadoseZone	Upper Vadose Zone	167.25528	0.385	1.6544	2.69	CLAYEY TAN_CLAY	CLAYEY TAN_CLAY
LowerVadoseZone	Lower Vadose Zone	167.25528	0.380	1.6554	2.67	SANDY2 SANDY1	SANDY2 SANDY1
OscBefore (OSC1)	E-Area Operational Soil Cover Before Dynamic Compaction	167.25528	0.456	1.4417	2.65	BACKFILL	
OscAfter (OSC2)	E-Area Operational Soil Cover After Dynamic Compaction	126.2304	0.275	1.9222	2.65		BACKFILL NDC_WASTE
STETboxesBC	ET boxed waste before DC	167.25528	0.894	0.2821	2.65	DC_WASTE NDC_WASTE	
STETboxesAC	ET boxed waste after DC	126.2304	0.275	1.9222	2.65		DC_WASTE

3.2 PORFLOW Slit Trench Vadose Zone Model

The extent of the PORFLOW ST mesh is 201 vertices in the x-direction, 76 vertices in the y-direction and 47 vertices in the z-direction. The length of the mesh in the x, y and z directions is 936 feet, 437 feet and 55 feet, respectively. The slit trench resides within a 656-foot by 157-foot region in the interior of the mesh. A chair cutout of the 3D mesh with material zones is shown in Figure 3-7.

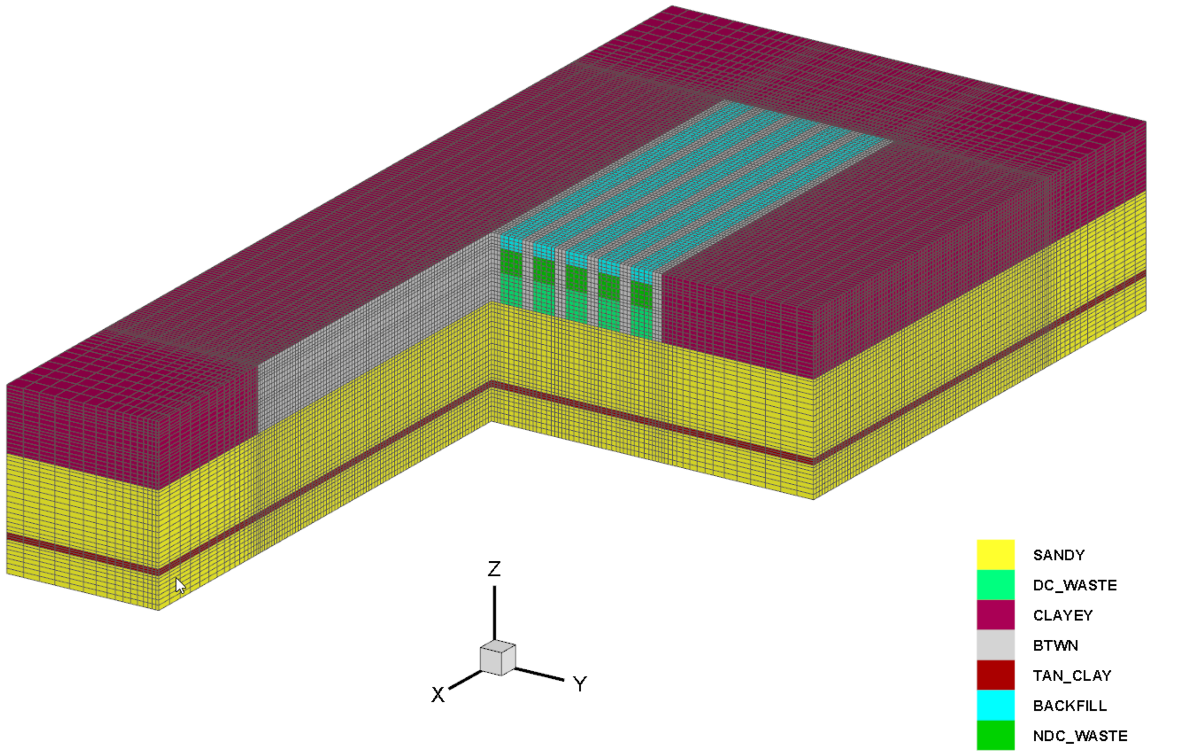

Figure 3-7. Chair cutout of the PORFLOW ST 3D mesh with material zones.

An x-slice of the PORFLOW ET 3D through the center of the trench is shown in Figure 3-8.

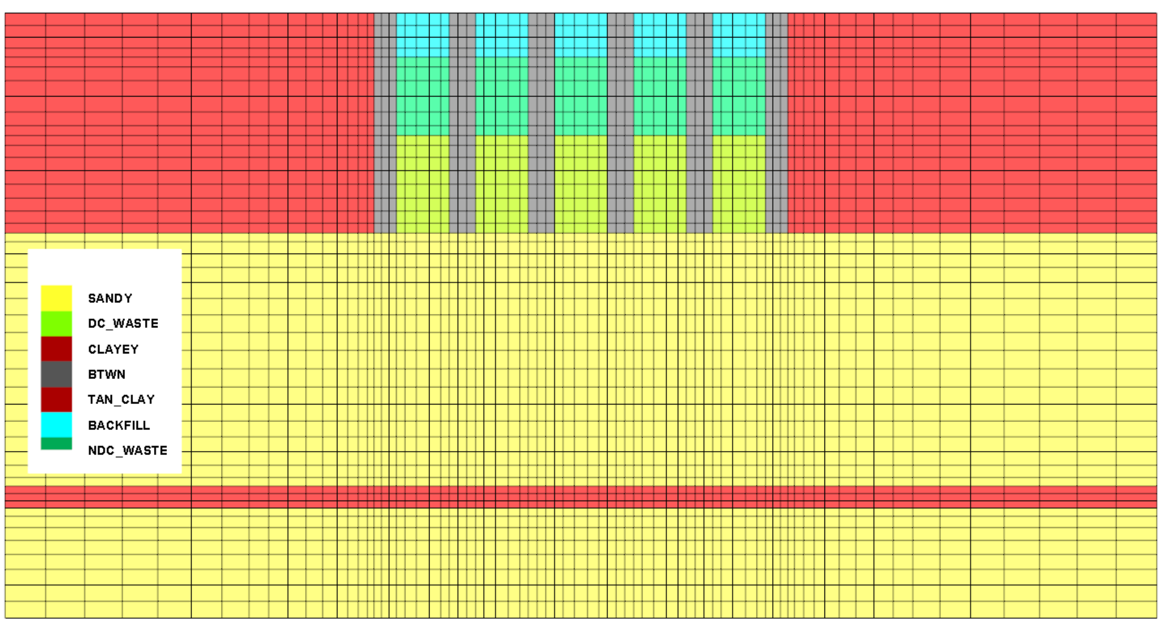

Figure 3-8. YZ cross-section of the PORFLOW ST 3D mesh with material zones.

The coordinates and lengths of the material zones within the footprint of slit trench and non-waste segments are shown in Table 3-4. The slit trench segments are numbered 1 through 5 with the material zones listed in the ascending y-direction. BTWN_STx_STy is the 10-foot wide non-waste segment between STx and STy adjacent waste segments. ST_EDGE1 is 8.5-foot wide non-waste segment below ST1. ST_EDGE2 is 8.5-foot wide non-waste segment above ST5. The SANDY soil layer is broken into two layers: SANDY2 is the region above the TAN_CLAY and SANDY1 is the region below the TAN_CLAY.

Table 3-4. Material zones within the footprint of the slit trench and non-waste segments.

Segment	Material	Coordinates (lower-left,ft)			Coordinates (upper-right,ft)			Lengths (ft)		
	Zone	x	y	z	x	y	z	dx	dy	dz
ST1	BACKFILL	140.00	148.50	51.00	796.00	168.50	55.00	656.00	20.00	4.00
ST1	NDC_WASTE	140.00	148.50	43.87	796.00	168.50	51.00	656.00	20.00	7.13
ST1	DC_WASTE	140.00	148.50	35.00	796.00	168.50	43.87	656.00	20.00	8.87
ST1	SANDY2	140.00	148.50	12.00	796.00	168.50	35.00	656.00	20.00	23.00
ST1	TAN_CLAY	140.00	148.50	10.00	796.00	168.50	12.00	656.00	20.00	2.00
ST1	SANDY1	140.00	148.50	0.00	796.00	168.50	10.00	656.00	20.00	10.00
ST2	BACKFILL	140.00	178.50	51.00	796.00	198.50	55.00	656.00	20.00	4.00
ST2	NDC_WASTE	140.00	178.50	43.87	796.00	198.50	51.00	656.00	20.00	7.13
ST2	DC_WASTE	140.00	178.50	35.00	796.00	198.50	43.87	656.00	20.00	8.87
ST2	SANDY2	140.00	178.50	12.00	796.00	198.50	35.00	656.00	20.00	23.00
ST2	TAN_CLAY	140.00	178.50	10.00	796.00	198.50	12.00	656.00	20.00	2.00
ST2	SANDY1	140.00	178.50	0.00	796.00	198.50	10.00	656.00	20.00	10.00
ST3	BACKFILL	140.00	208.50	51.00	796.00	228.50	55.00	656.00	20.00	4.00
ST3	NDC_WASTE	140.00	208.50	43.87	796.00	228.50	51.00	656.00	20.00	7.13
ST3	DC_WASTE	140.00	208.50	35.00	796.00	228.50	43.87	656.00	20.00	8.87
ST3	SANDY2	140.00	208.50	12.00	796.00	228.50	35.00	656.00	20.00	23.00
ST3	TAN_CLAY	140.00	208.50	10.00	796.00	228.50	12.00	656.00	20.00	2.00
ST3	SANDY1	140.00	208.50	0.00	796.00	228.50	10.00	656.00	20.00	10.00
ST4	BACKFILL	140.00	238.50	51.00	796.00	258.50	55.00	656.00	20.00	4.00
ST4	NDC_WASTE	140.00	238.50	43.87	796.00	258.50	51.00	656.00	20.00	7.13
ST4	DC_WASTE	140.00	238.50	35.00	796.00	258.50	43.87	656.00	20.00	8.87
ST4	SANDY2	140.00	238.50	12.00	796.00	258.50	35.00	656.00	20.00	23.00
ST4	TAN_CLAY	140.00	238.50	10.00	796.00	258.50	12.00	656.00	20.00	2.00
ST4	SANDY1	140.00	238.50	0.00	796.00	258.50	10.00	656.00	20.00	10.00
ST5	BACKFILL	140.00	268.50	51.00	796.00	288.50	55.00	656.00	20.00	4.00
ST5	NDC_WASTE	140.00	268.50	43.87	796.00	288.50	51.00	656.00	20.00	7.13
ST5	DC_WASTE	140.00	268.50	35.00	796.00	288.50	43.87	656.00	20.00	8.87
ST5	SANDY2	140.00	268.50	12.00	796.00	288.50	35.00	656.00	20.00	23.00
ST5	TAN_CLAY	140.00	268.50	10.00	796.00	288.50	12.00	656.00	20.00	2.00

Segment	Material	Coordinates (lower-left,ft)			Coordinates (upper-right,ft)			Lengths (ft)		
	Zone	x	y	z	x	y	z	dx	dy	dz
ST5	SANDY1	140.00	268.50	0.00	796.00	288.50	10.00	656.00	20.00	10.00
ST_EDGE1	BACKFILL	140.00	140.00	51.00	796.00	148.50	55.00	656.00	8.50	4.00
ST_EDGE1	NDC_WASTE	140.00	140.00	43.87	796.00	148.50	51.00	656.00	8.50	7.13
ST_EDGE1	DC_WASTE	140.00	140.00	35.00	796.00	148.50	43.87	656.00	8.50	8.87
ST_EDGE1	SANDY2	140.00	140.00	12.00	796.00	148.50	35.00	656.00	8.50	23.00
ST_EDGE1	TAN_CLAY	140.00	140.00	10.00	796.00	148.50	12.00	656.00	8.50	2.00
ST_EDGE1	SANDY1	140.00	140.00	0.00	796.00	148.50	10.00	656.00	8.50	10.00
ST_EDGE2	CLAYEY	140.00	288.50	51.00	796.00	297.00	55.00	656.00	8.50	4.00
ST_EDGE2	CLAYEY	140.00	288.50	43.87	796.00	297.00	51.00	656.00	8.50	7.13
ST_EDGE2	CLAYEY	140.00	288.50	35.00	796.00	297.00	43.87	656.00	8.50	8.87
ST_EDGE2	SANDY2	140.00	288.50	12.00	796.00	297.00	35.00	656.00	8.50	23.00
ST_EDGE2	TAN_CLAY	140.00	288.50	10.00	796.00	297.00	12.00	656.00	8.50	2.00
ST_EDGE2	SANDY1	140.00	288.50	0.00	796.00	297.00	10.00	656.00	8.50	10.00
BTWN_ST1_ST2	CLAYEY	140.00	168.50	51.00	796.00	178.50	55.00	656.00	10.00	4.00
BTWN_ST1_ST2	CLAYEY	140.00	168.50	43.87	796.00	178.50	51.00	656.00	10.00	7.13
BTWN_ST1_ST2	CLAYEY	140.00	168.50	35.00	796.00	178.50	43.87	656.00	10.00	8.87
BTWN_ST1_ST2	SANDY2	140.00	168.50	12.00	796.00	178.50	35.00	656.00	10.00	23.00
BTWN_ST1_ST2	TAN_CLAY	140.00	168.50	10.00	796.00	178.50	12.00	656.00	10.00	2.00
BTWN_ST1_ST2	SANDY1	140.00	168.50	0.00	796.00	178.50	10.00	656.00	10.00	10.00
BTWN_ST2_ST3	CLAYEY	140.00	198.50	51.00	796.00	208.50	55.00	656.00	10.00	4.00
BTWN_ST2_ST3	CLAYEY	140.00	198.50	43.87	796.00	208.50	51.00	656.00	10.00	7.13
BTWN_ST2_ST3	CLAYEY	140.00	198.50	35.00	796.00	208.50	43.87	656.00	10.00	8.87
BTWN_ST2_ST3	SANDY2	140.00	198.50	12.00	796.00	208.50	35.00	656.00	10.00	23.00
BTWN_ST2_ST3	TAN_CLAY	140.00	198.50	10.00	796.00	208.50	12.00	656.00	10.00	2.00
BTWN_ST2_ST3	SANDY1	140.00	198.50	0.00	796.00	208.50	10.00	656.00	10.00	10.00
BTWN_ST3_ST4	CLAYEY	140.00	228.50	51.00	796.00	238.50	55.00	656.00	10.00	4.00
BTWN_ST3_ST4	CLAYEY	140.00	228.50	43.87	796.00	238.50	51.00	656.00	10.00	7.13
BTWN_ST3_ST4	CLAYEY	140.00	228.50	35.00	796.00	238.50	43.87	656.00	10.00	8.87
BTWN_ST3_ST4	SANDY2	140.00	228.50	12.00	796.00	238.50	35.00	656.00	10.00	23.00
BTWN_ST3_ST4	TAN_CLAY	140.00	228.50	10.00	796.00	238.50	12.00	656.00	10.00	2.00
BTWN_ST3_ST4	SANDY1	140.00	228.50	0.00	796.00	238.50	10.00	656.00	10.00	10.00
BTWN_ST4_ST5	CLAYEY	140.00	258.50	51.00	796.00	268.50	55.00	656.00	10.00	4.00

Segment	Material Zone	Coordinates (lower-left,ft) x	y	z	Coordinates (upper-right,ft) x	y	z	Lengths (ft) dx	dy	dz
BTWN_ST4_ST5	CLAYEY	140.00	258.50	43.87	796.00	268.50	51.00	656.00	10.00	7.13
BTWN_ST4_ST5	CLAYEY	140.00	258.50	35.00	796.00	268.50	43.87	656.00	10.00	8.87
BTWN_ST4_ST5	SANDY2	140.00	258.50	12.00	796.00	268.50	35.00	656.00	10.00	23.00
BTWN_ST4_ST5	TAN_CLAY	140.00	258.50	10.00	796.00	268.50	12.00	656.00	10.00	2.00
BTWN_ST4_ST5	SANDY1	140.00	258.50	0.00	796.00	268.50	10.00	656.00	10.00	10.00

Hydraulic and transport properties of the porous media in a slit trench are specified prior to and after dynamic compaction for each material type. Nominal parameter values for saturated effective diffusion coefficient (De), porosity, dry bulk density (rhob) and particle density (rhop) for each material type are given in Table 3-5.

Table 3-5. Hydraulic and transport properties of porous media in a slit trench.

ID	Material Name	De (cm^2/yr)	Porosity	rhob (g/cm^3)	rhop (g/cm^3)	Time period 0 to 171 yrs	Time period 171 to 5000 yrs
UpperVadoseZone	Upper Vadose Zone	167.25528	0.385	1.6544	2.69	BTWN CLAYEY TAN_CLAY	BTWN CLAYEY TAN_CLAY
LowerVadoseZone	Lower Vadose Zone	167.25528	0.380	1.6554	2.67	SANDY2 SANDY1	SANDY2 SANDY1
OscBefore (OSC1)	E-Area Operational Soil Cover Before Dynamic Compaction	167.25528	0.456	1.4417	2.65	BACKFILL	
OscAfter (OSC2)	E-Area Operational Soil Cover After Dynamic Compaction	126.2304	0.275	1.9222	2.65		BACKFILL NDC_WASTE
SThybridBC	ST hybrid waste before DC	167.25528	0.600	1.0590	2.65	DC_WASTE NDC_WASTE	
SThybridAC	ST hybrid waste after DC	126.2304	0.275	1.9222	2.65		DC_WASTE

4.0 GoldSim Vadose Zone Models

ELLWF Trench GoldSim Models were built using the Contaminant Transport Module in GoldSim version 12.1.3 #192 (March 13, 2019). The GoldSim cell pathway element was used to build a column and cell network for modeling the advective and diffusive transport of radionuclides below the operational soil cover to the water table in the ST and ET. The cell pathway allows inventory transfer within the waste zone during dynamic compaction. The cell pathway accommodates back diffusion which can occur after dynamic compaction of the waste zone. The GoldSim ET trench model includes intact and subsidence cell pathway elements. The GoldSim ST trench model includes intact, between segment and subsidence cell pathway elements. Dynamic compaction of the waste zone and subsidence are assumed to occur at the end of IC.

4.1 Dashboard User Interface

The home screen of the ELLWF Trench System Model is shown in Figure 4-1. The model at this level contains 10 containers and 2 hyperlinks. The GoldSim benchmarking effort involves development and benchmarking of the vadose zone models contained within the Transport container. References to containers outside the Transport container will be described during the documentation of the vadose zone models.

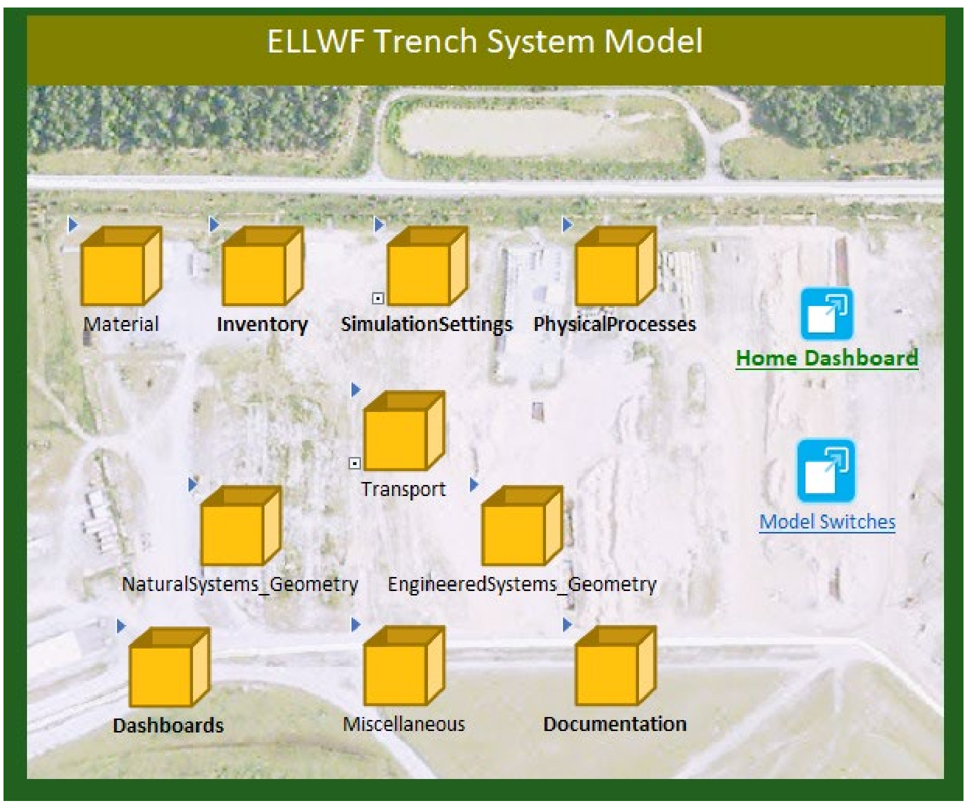

Figure 4-1. Top-Level container of the ELLWF Trench System Model.

Clicking the "Home Dashboard" hyperlink accesses the "Home Dashboard for the Slit Trench Model", Figure 4-2, where the user can move to the Model Switches and Slit Trenches dashboards. The dashboard contains the Simulation Settings and Run Model buttons. ***This dashboard will be updated to include hyperlinks to engineered and slit trench dashboards when vadose zone models are linked to new aquifer zone models.***

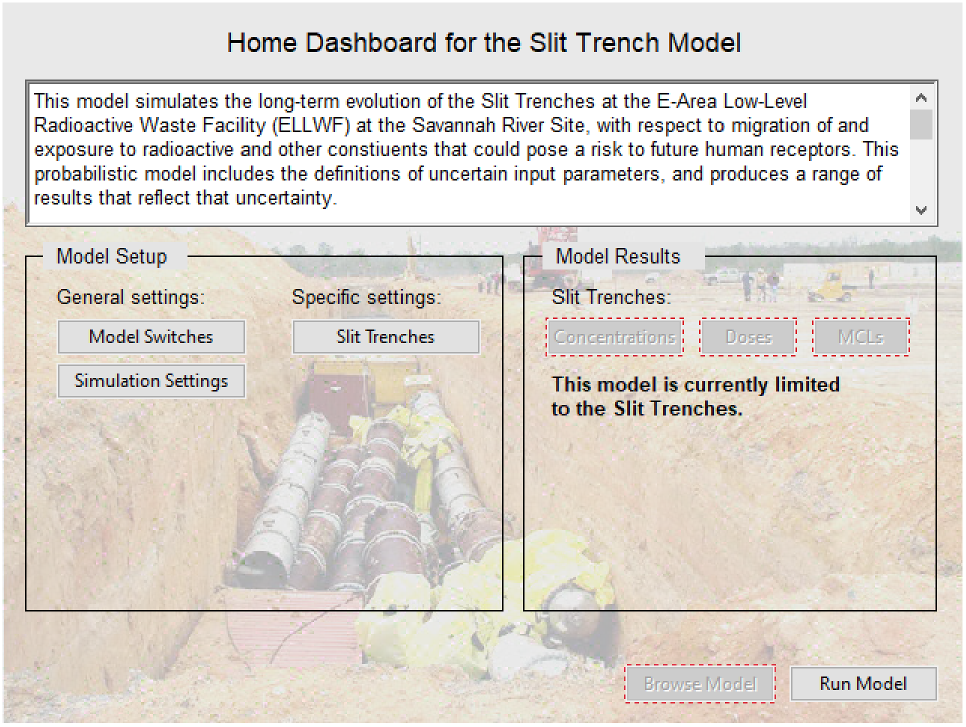

Figure 4-2. Home dashboard for the slit trench model.

Clicking the Model Switches hyperlink, Figure 4-3, accesses the "General Model Simulation Controls". The user can choose to allow diffusion in water, chemical retardation and institutional control. This dashboard also controls the subsidence parameters that are used in the engineered trench vadose zone portion of the model. Specific disposal unit controls can be selected via the Slit Trenches dashboard. The dashboard contains the Simulation Settings, Run Model and Home buttons. ***This dashboard will be updated to include hyperlinks to engineered and slit trench dashboards when vadose zone models are linked to new aquifer zone models.***

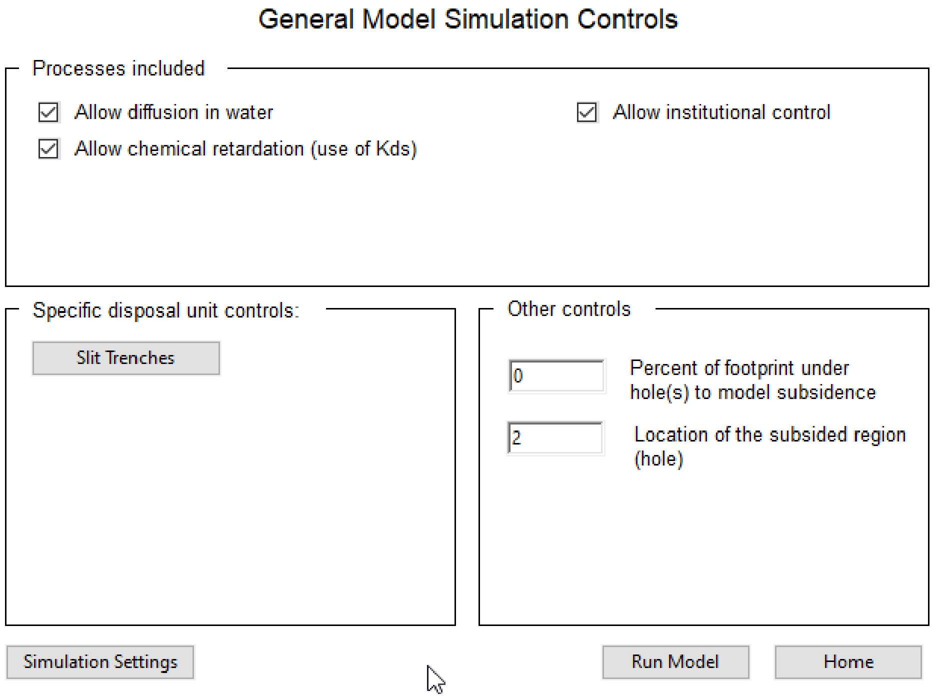

Figure 4-3. General model simulation controls.

The Slit Trenches dashboard, Figure 4-4, allows the user to select which trench to model, inventory parent(s) to run and inventory options. ***This dashboard will be updated to include settings for engineered and slit trenches when vadose zone models are linked to new aquifer zone models.***

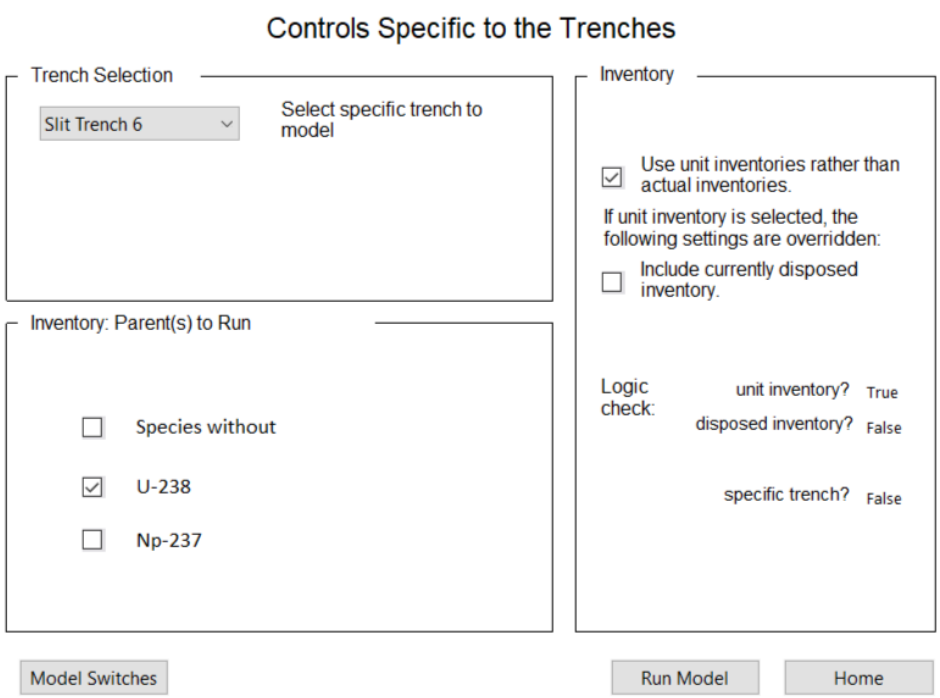

Figure 4-4. Controls specific to the slit trenches.

The Transport container in the GoldSim system model contains the vadose zone models for engineered and slit trenches as shown in Figure 4-5. The WasteZone and VadoseZone containers encapsulate the engineered trench vadose zone models. The WasteZoneST and VadoseZoneST localized containers encapsulate the slit trench vadose zone models. The ToSeep aquifer transport container is available but not used in this model as the 100-m well is the POA.

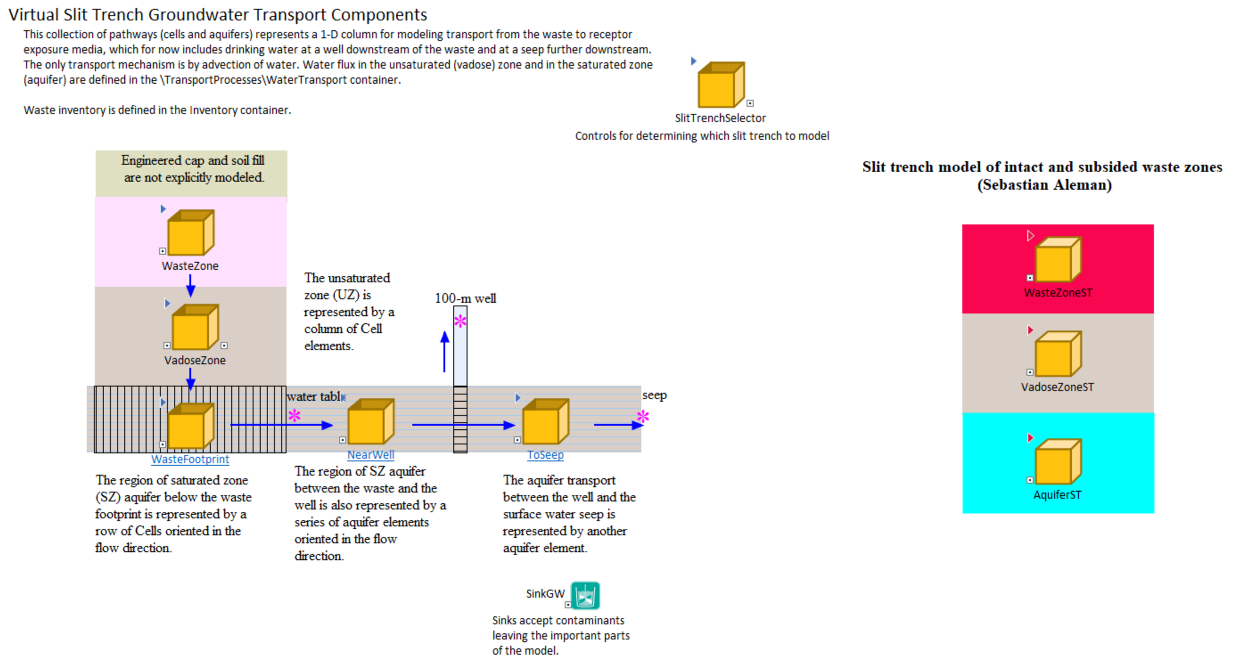

Figure 4-5. GoldSim vadose zone models for engineered and slit trenches.

The GoldSim engineered and slit trench vadose zone models will be described in Sections 4.2 and 4.3, respectively

4.2 GoldSim Engineered Trench Vadose Zone Model

The conceptual model of the engineered trench vadose zone is shown schematically in Figure 4-6. The closure cap is not explicitly modeled but accounted by utilizing volume-averaged vertical Darcy velocities and water saturations extracted from the PORFLOW ET vadose zone flow models. The vadose zone is modeled by a series of one-dimensional (1-D) Waste Zone (spanning the entire thickness of the UVZ) and LVZ (comprised of Sandy and Clayey layers) cell pathways. The cell pathways are connected via advective and diffusive fluxes. Lateral advective and diffusive fluxes to and from the overall engineered trench footprint were not modeled in the GoldSim ET VZ model. The two series represent areas within the trench that contain either crushable containers (intact cap case) or non-crushable containers (subsided cap case) as described in Section 3.1.

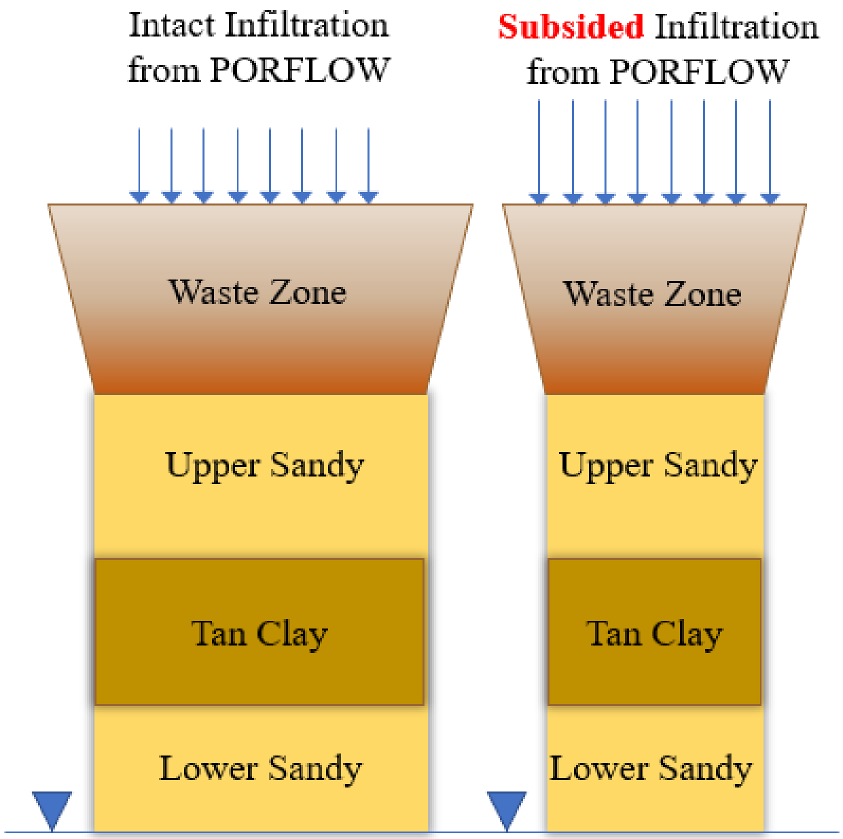

Figure 4-6. Schematic of the GoldSim engineered trench vadose zone conceptual model.

The WasteZone container includes the WasteZone_Crushed and WasteZone_Noncrushed containers as shown in Figure 4-7. These containers encapsulate the GoldSim engineered trench waste zone models.

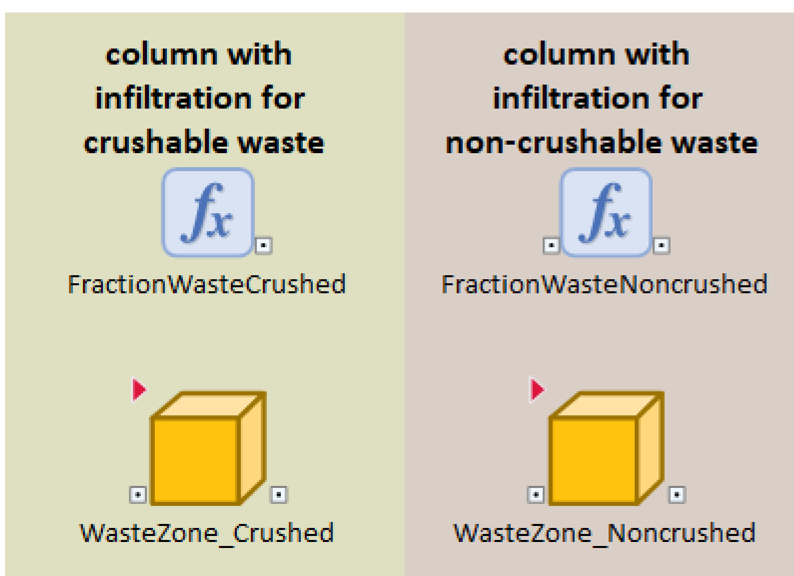

Figure 4-7. GoldSim engineered trench waste zone containers.

The VadoseZone container includes the VadoseZone_Crushed and VadoseZone_Noncrushed containers as shown in Figure 4-8. These containers encapsulate the GoldSim engineered trench lower vadose zone models.

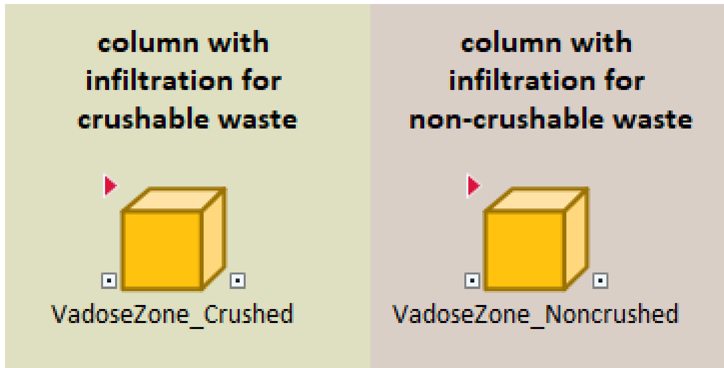

Figure 4-8. GoldSim engineered trench lower vadose zone containers.

The WasteZone_Crushed and WasteZone_Noncrushed containers have advective and diffusive flux links to the VadoseZone_Crushed and VadoseZone_Noncrushed containers, respectively.

Vertical Darcy velocities and water saturations from the PORFLOW ET vadose zone flow simulations, are extracted for each steady-state simulation (time period) and averaged within user specified material zones for the GoldSim ET VZ model. Volume-averaged vertical Darcy velocities are computed for each intact and subsided cell pathway column (WZ and LVZ) within the GoldSim ET VZ model.

The ST06/ET Case01 vertical velocities through the WZ and LVZ are shown in Figure 4-9. The AVERAGE velocities are input data into the Velocity_Intact_Case01 time series element (WaterTransport_Vadose). These velocities are used to compute volumetric flowrates in the Flowrate_Intact_Case01 expression elements (WasteZone_Crushed and VadoseZone_Crushed).

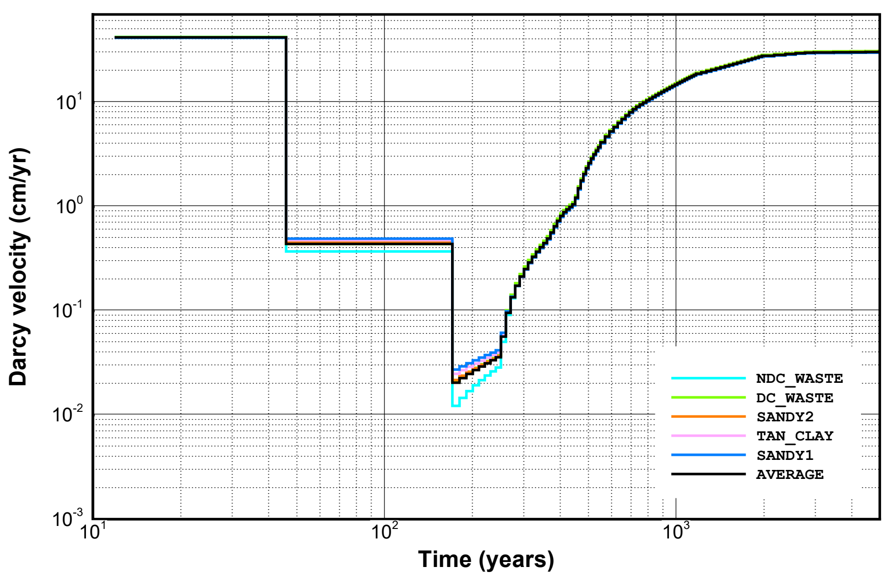

Figure 4-9. ST06/ET Case01 vertical velocities in the WZ and LVZ.

The ST06/ET Case11b vertical velocities through the WZ and LVZ in Hole 2 are shown in Figure 4-10. The AVERAGE velocities are data input to the Velocity_Hole2 time series element (WaterTransport_Vadose). These velocities are used to compute volumetric flowrates in the Flowrate_H2 expression elements (WasteZone_Noncrushed and VadoseZone_Noncrushed).

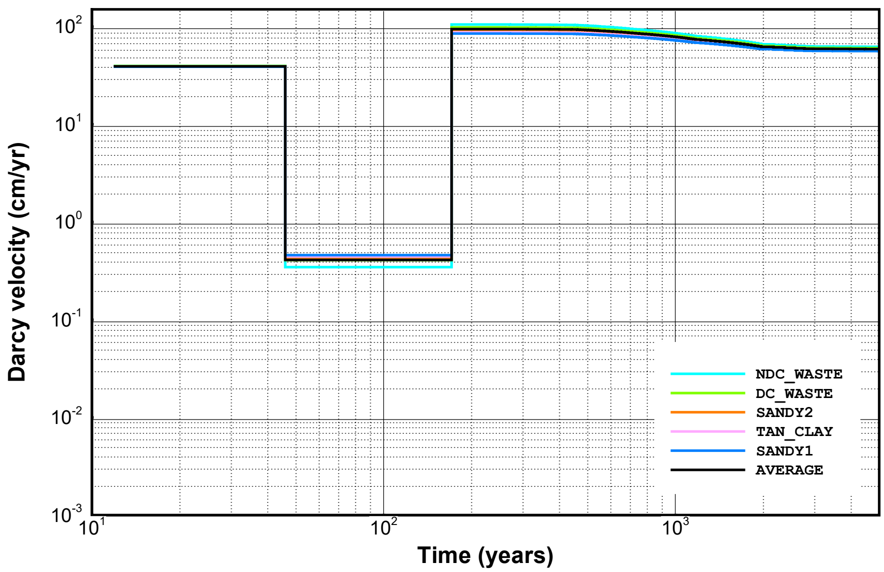

Figure 4-10. ST06/ET Case11b vertical velocities through the WZ and LVZ in Hole 2.

4.2.1 Intact and Subsided Waste Zone Models

The waste zone is represented by a series of cell pathways. The flow area is the product of the trench width (157 ft) and the length (656 ft). The area is also multiplied by the fraction of the waste that is either crushable or non-crushable depending which series the cells represent. The fraction of non-crushable waste (Hole 2 area) is set to 2% of engineered trench waste area. To model dynamic compaction at the end of IC, the waste zone is separated into two sections: 22 cells in the upper waste zone (NDC_WASTE) and 6 cells in the lower waste zone (DC_WASTE) as shown in Figure 4-11. The height of the NDC_WASTE and DC_WASTE cells are 13.5 ft/22 (0.6136 ft) and 2.5 ft/6 (0.4167 ft), respectively.

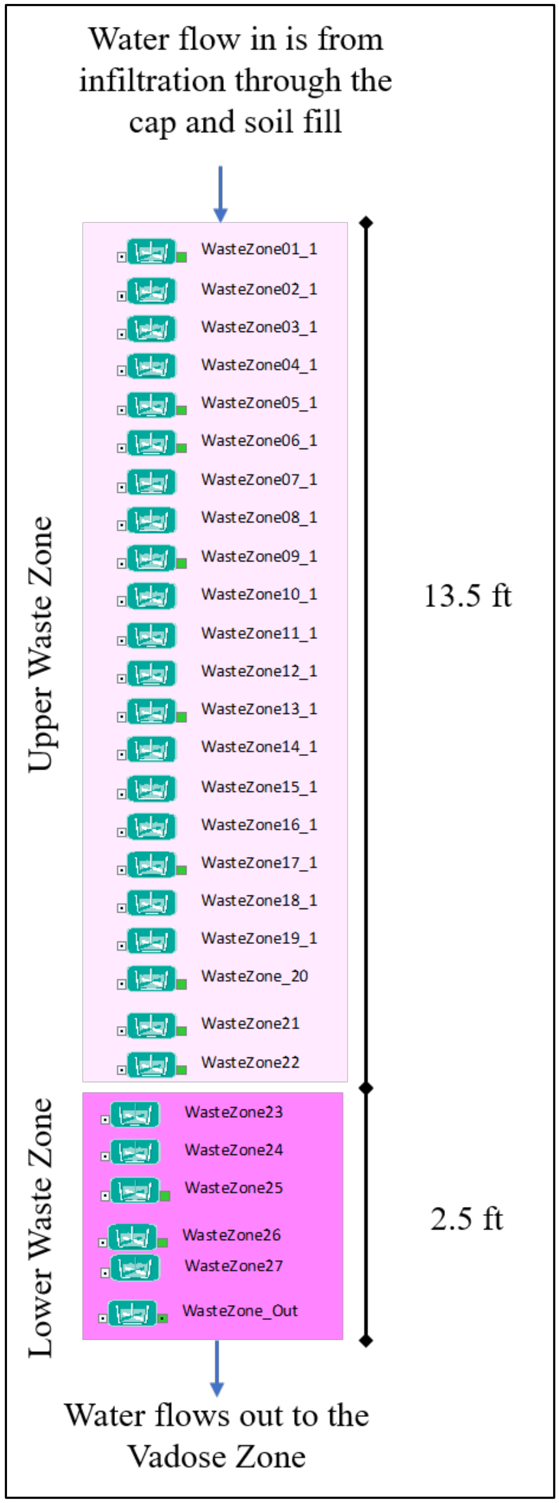

Figure 4-11. GoldSim engineered trench waste zone cell pathways.

The cell pathway properties for WasteZone_02_1 are shown in Figure 4-12 and Figure 4-13. The data requirements of the waste zone cell pathways are described in this section.

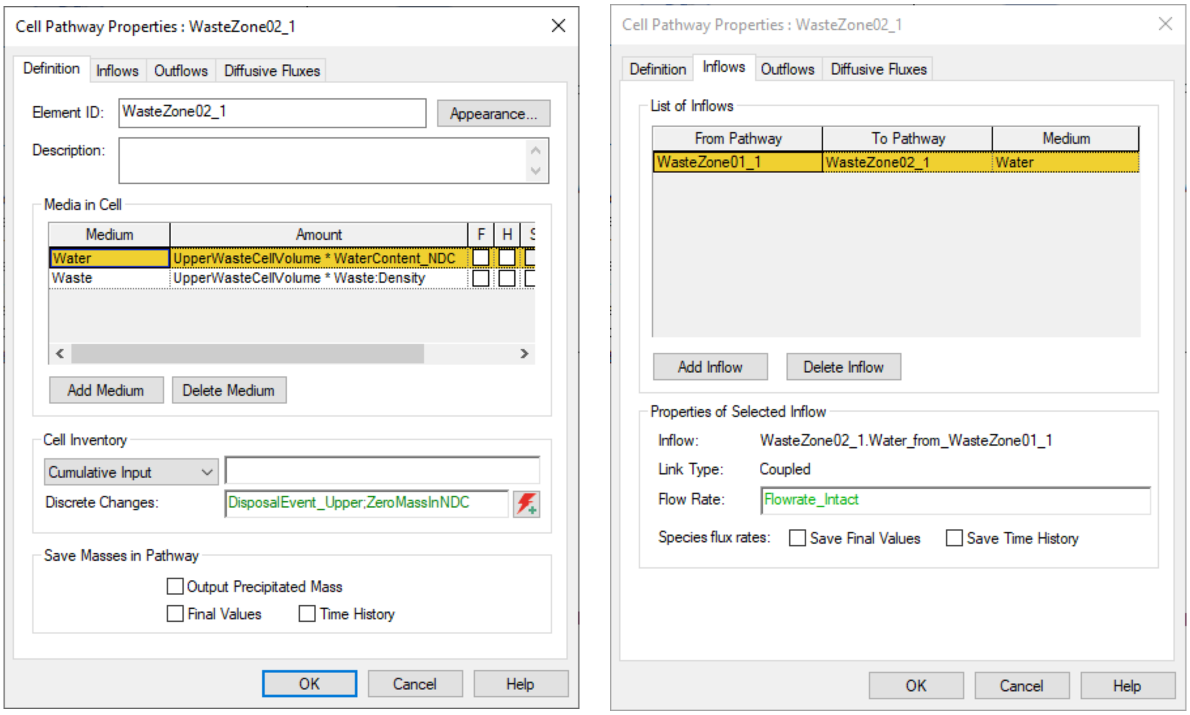

Figure 4-12. WasteZone_02_1 cell pathway properties: Definition and Inflows.

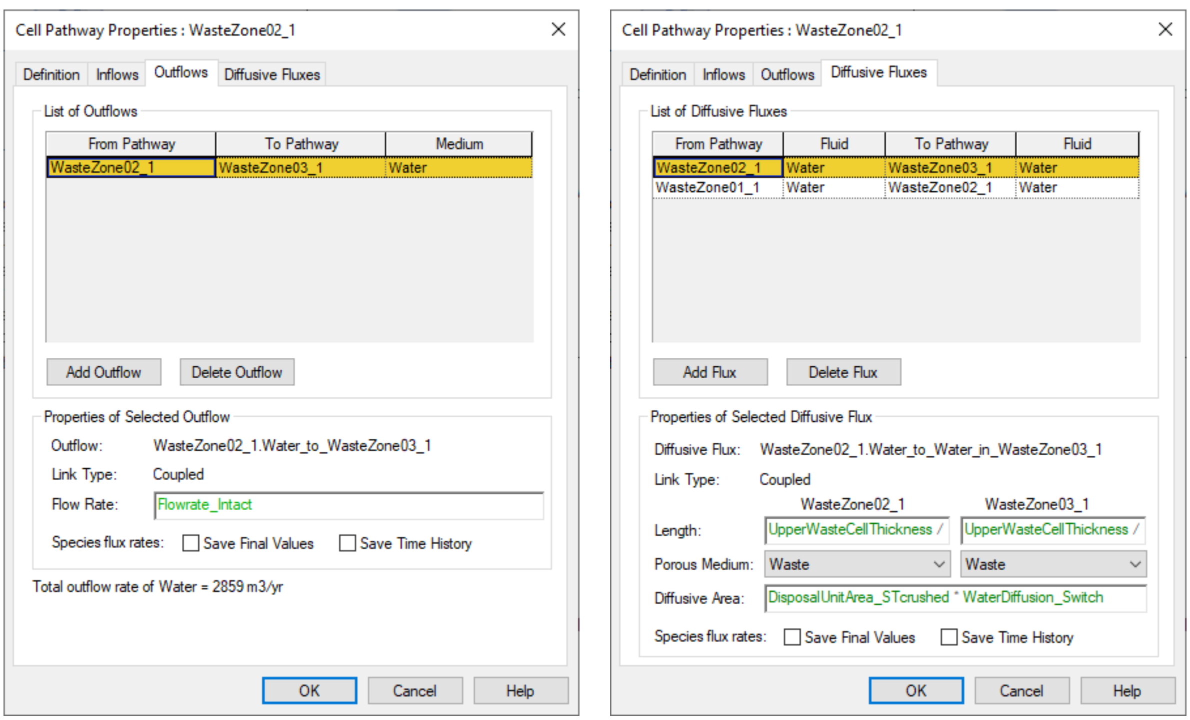

Figure 4-13. WasteZone_02_1 cell pathway properties: Outflows and Diffusive Fluxes.

An initial inventory of 1 mol is assigned to each parent radionuclide and tracer. The parent radionuclide inventories are converted to grams internally for use throughout the waste and vadose zone models. For the ST06/ET footprint, the initial inventory is distributed between crushable and non-crushable waste zones 12 years after the start of ELLWF operations. Within each crushable and non-crushable waste zone, species inventories are further distributed between upper and lower waste zones. Discrete change elements DisposalEvent_Upper and DisposalEvent_Lower trigger the placement of species inventories in upper and lower waste zone cells, respectively. The species inventories distributed to each crushable upper and lower waste zone cell are computed in Eqs 4-1 and 4-2, respectively.

$$I_{NDC\_cell,crushed} = I_p f_{crushed} \frac{H_{NDC\_cell}}{H_{WZ}} \tag{4-1}$$

$$I_{DC\_cell\_crushed} = I_p f_{crushed} \frac{H_{DC\_cell}}{H_{WZ}} \tag{4-2}$$

where

$I_{NDC\_cell,crushed}$ .... species inventory of NDC cell crushed, g

$I_{DC\_cell,crushed}$ .... species inventory of DC cell crushed, g

I_p .... inventory of parent radionuclide, g

$f_{crushed}$ .... fraction of crushable waste, 0.98

H_{NDC_cell} .... height of NDC waste cell, 13.5 ft/22

H_{DC_cell} .... height of DC waste cell, 2.5 ft/6

H_{WZ} .... height of waste zone, 16 ft

The species inventories distributed to each non-crushable upper and lower waste zone cell are computed in Eqs. 4-3 and 4-4, respectively.

$$I_{NDC\_cell,noncrushed} = I_p f_{noncrushed} \frac{H_{NDC\_cell}}{H_{WZ}} \tag{4-3}$$

$$I_{DC\_cell\_noncrushed} = I_p f_{noncrushed} \frac{H_{DC\_cell}}{H_{WZ}} \tag{4-4}$$

where

$I_{NDC\_cell,noncrushed}$ .... species inventory of NDC cell noncrushed, g

$I_{DC\_cell,noncrushed}$ .... species inventory of DC cell noncrushed, g

$f_{noncrushed}$ .... fraction of non-crushable waste, 0.02

When the final cap is emplaced at end of IC, the species inventories (Mass_In_Pathway) within the upper waste zone are transferred to the lower waste zone using a series of discrete change elements (AddMassFromNDC, ZeroMassinNDC and AddMasstoDC) as well as a mass collector cell pathway (MassCollector). The AddMassFromNDC element sums the Mass_In_Pathway from WasteZone01_1 to WasteZone22 cell pathways and makes them available in the MassCollector. The ZeroMassinNDC element replaces the species inventories in the upper waste zone with zero values. The AddMassToDC element adds and distributes the species inventories from the upper waste zone evenly among the lower waste zone cell pathways.

The ST06/ET Case01 water saturations in the WZ are shown in Figure 4-14. The NDC_WASTE and DC_WASTE water saturations are data inputs to the Saturation_NDC_Case01 and Saturation_DC_Case01 expression elements, respectively. These water saturations are used to compute water contents in the WaterContent_NDC_Case01 and WaterContent_DC_Case01 expression elements (WasteZone_Crushed).

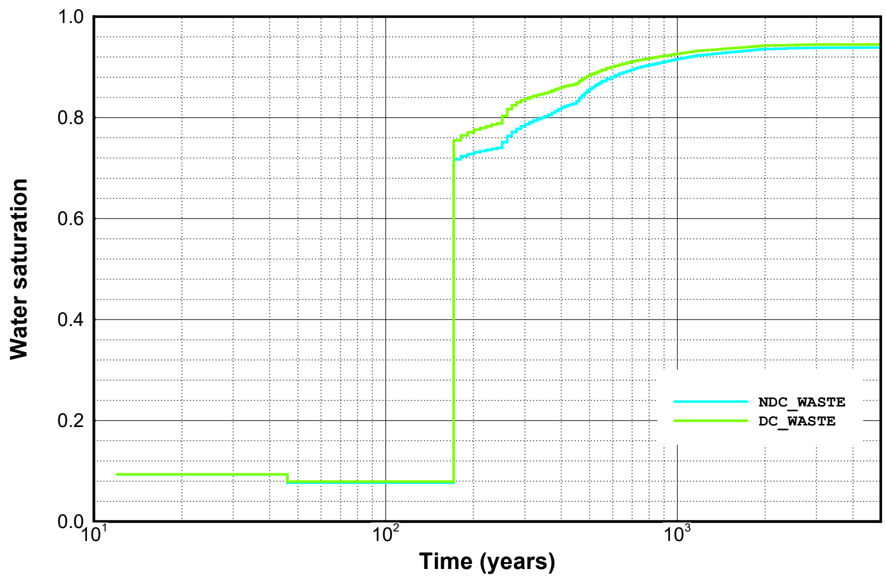

Figure 4-14. ST06/ET Case01 water saturations in the WZ.

The ST06/ET Case11b water saturations in the WZ of Hole 2 are shown in Figure 4-15. The NDC_WASTE and DC_WASTE water saturations are data inputs to the Saturation_NDC and Saturation_DC time series elements, respectively. These water saturations are used to compute water contents in the WaterContent_NDC and WaterContent_DC expression elements (WasteZone_Noncrushed).

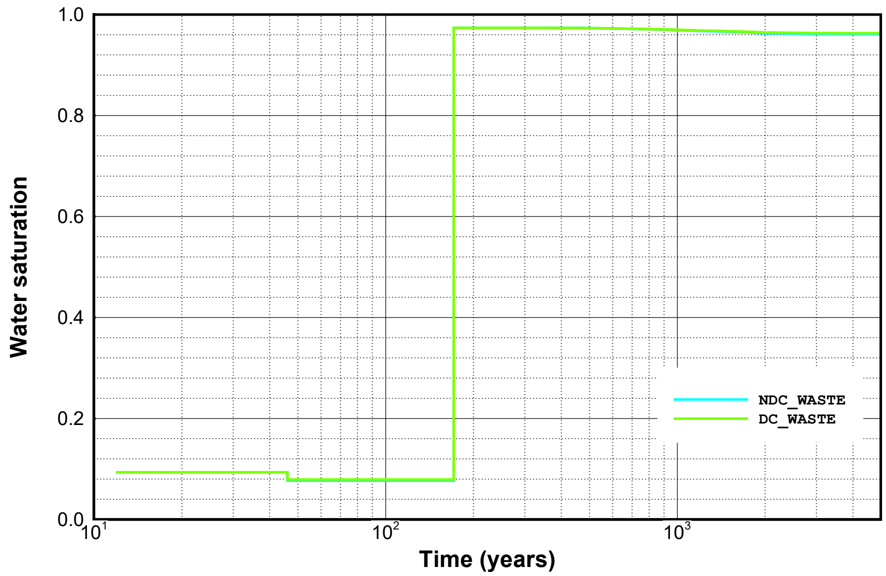

Figure 4-15. ST06/ET Case11b water saturations in the WZ of Hole 2.

4.2.2 Lower Vadose Zone Models

Advective and diffusive species mass flow rates leave the waste zone and enter the upper sandy layer (SANDY2) of each intact and subsided lower vadose zone. Each section is modeled by a series of 30 cell pathways. After leaving the upper sandy layer, species mass flow rates go through 5 cell pathways in the clayey layer (TAN_CLAY) and then 8 cell pathways in the lower sandy layer (SANDY1). Although many DUs have two layers of clayey soil separated by sandy layers, the clayey layers are combined in the system model. This is consistent with the PORFLOW vadose zone model and produces only a ~1% difference in flux to the water table (Danielson 2019). The representation of the lower vadose zone is given in Figure 4-16. The height of the SANDY2, TAN_CLAY and SANDY1 cells are 23 ft/30 (0.7667 ft), 2 ft/5 (0.4 ft) and 10 ft/8 (1.25 ft), respectively.

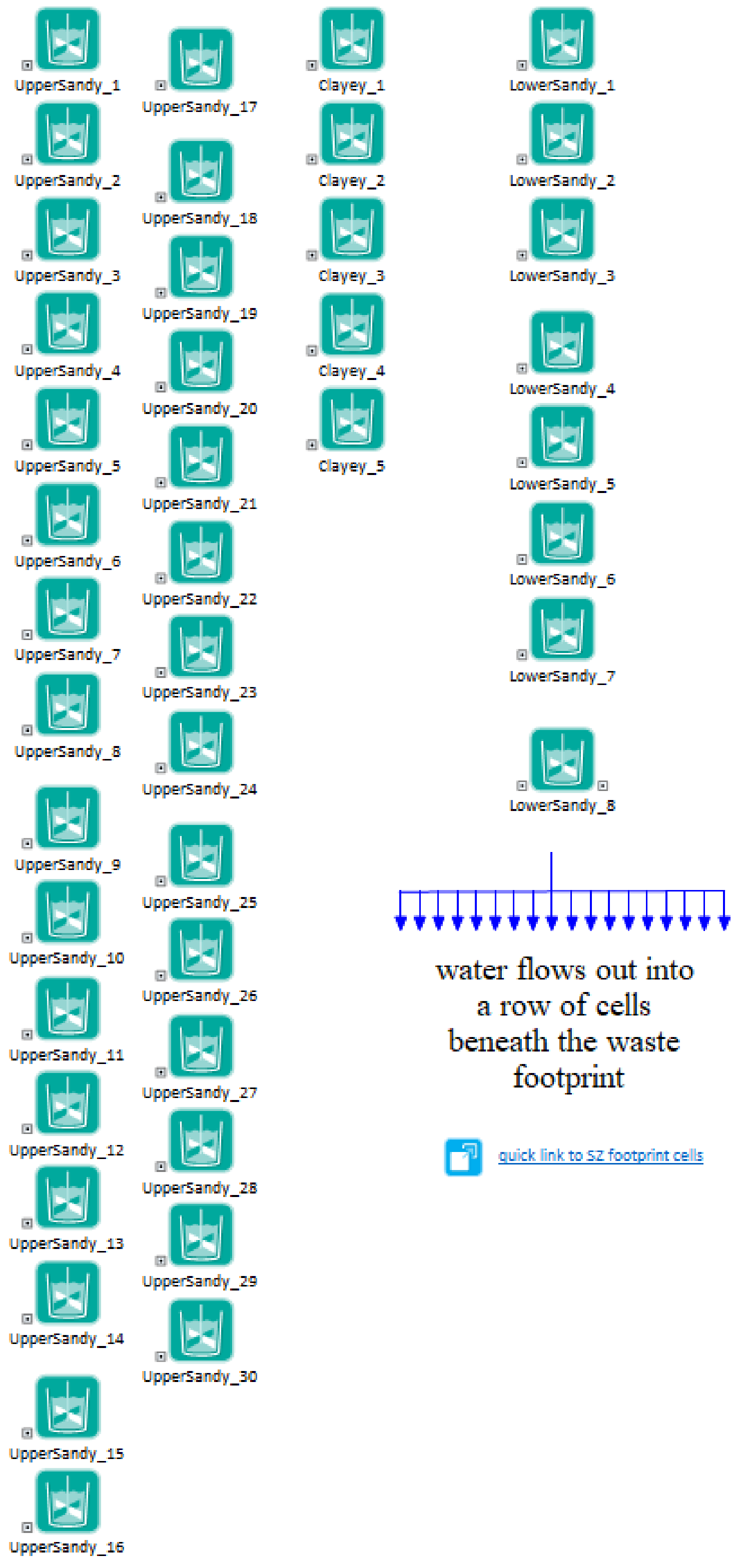

Figure 4-16. GoldSim engineered trench lower vadose zone cell pathways.

The cell pathway properties for Clayey_1 are shown in Figure 4-17 and Figure 4-18. The data requirements of the lower vadose zone cell pathways are described in this section.

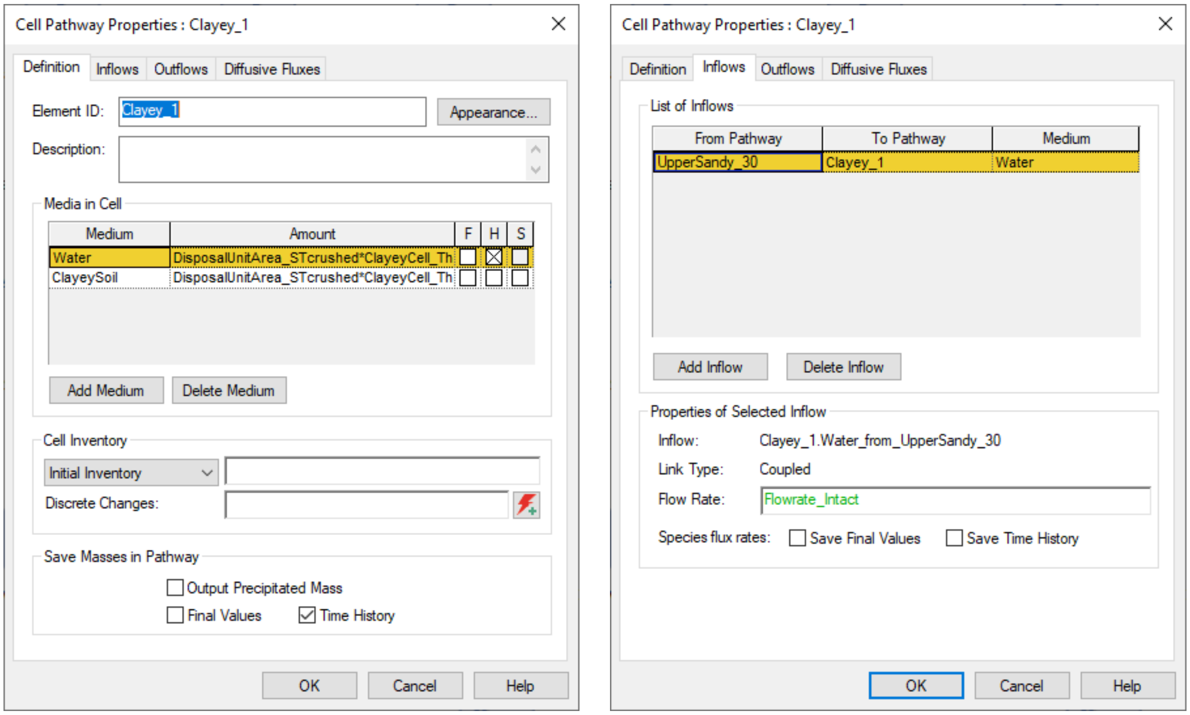

Figure 4-17. Clayey_1 cell pathway properties: Definition and Inflows.

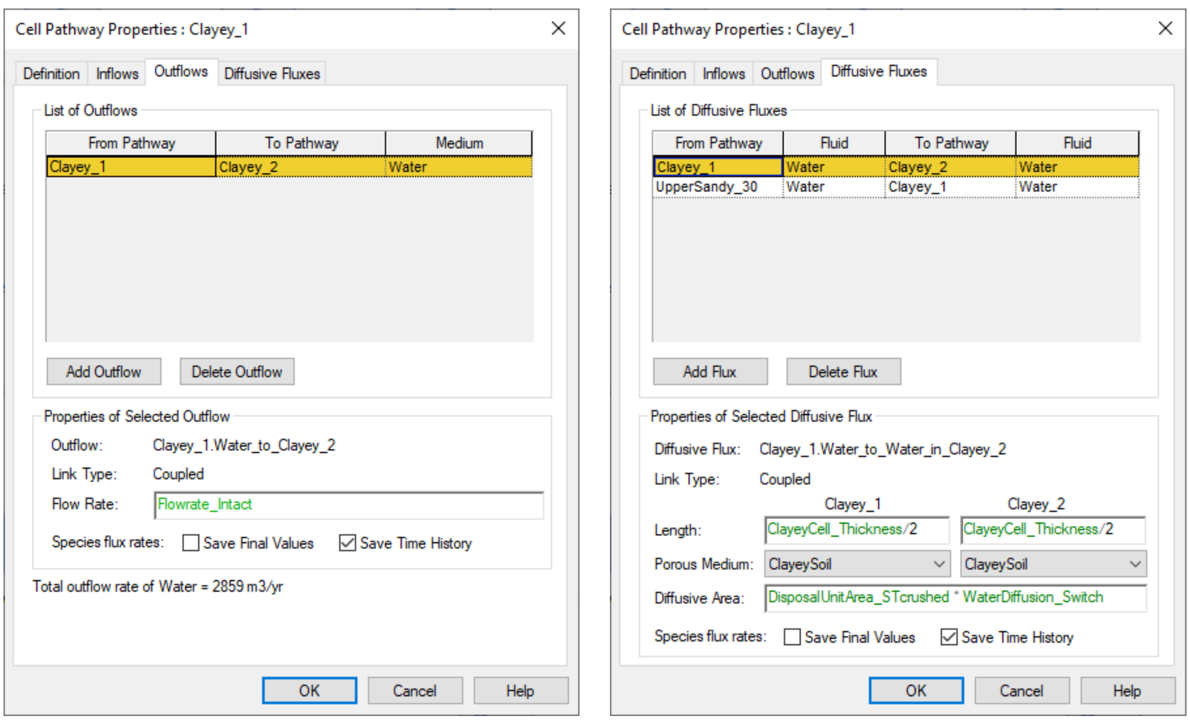

Figure 4-18. Clayey_1 cell pathway properties: Outflows and Diffusive Fluxes.

The ST06/ET Case01 water saturations in the LVZ are shown in Figure 4-19. The SANDY2, TAN_CLAY, and SANDY1 water saturations are data inputs to the Saturation_Sandy1_Intact, Saturation_Clay_Intact and Saturation_Sandy2_Intact expression elements, respectively (within the /Transport/VadoseZone/VadoseZone_Crushed/VZ_Nominal_Flow container).

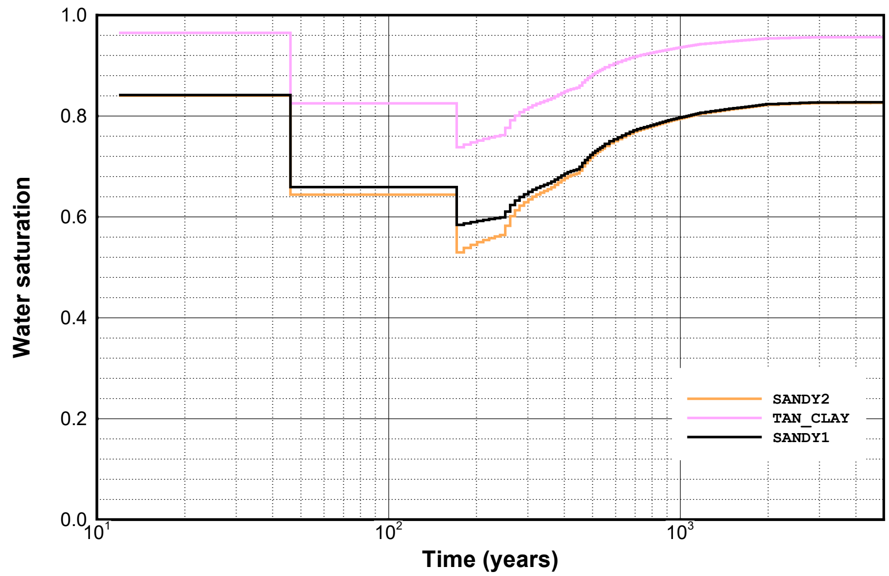

Figure 4-19. ST06/ET Case01 water saturations in the LVZ.

The ST06/ET Case11b water saturations in the LVZ of Hole 2 are shown in Figure 4-20. The SANDY2, TAN_CLAY and SANDY1 water saturations are data inputs to the Saturation_Sandy1_Hole2, Saturation_Clay_Hole2 and Saturation_Sandy2_Hole2 expression elements, respectively (within the /Transport/VadoseZone_Noncrushed/VZ_Nominal_Flow container).

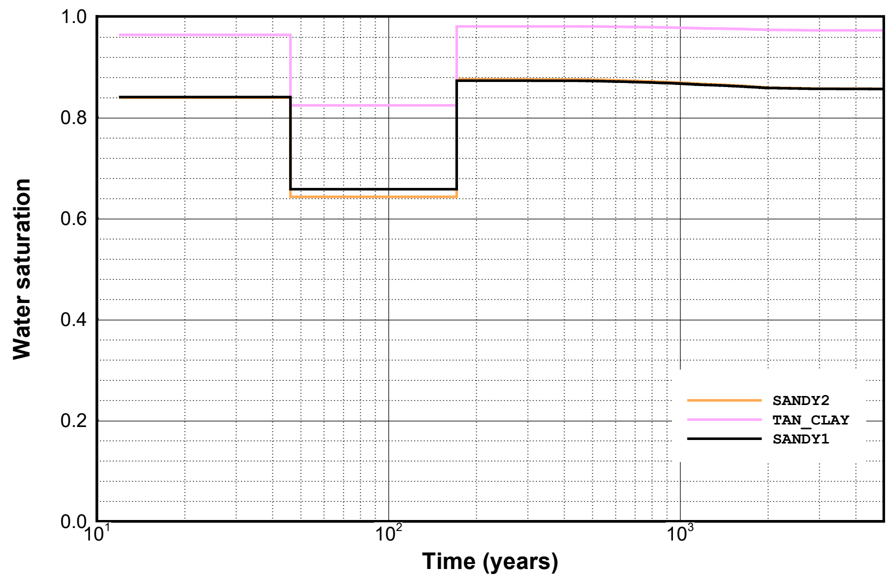

Figure 4-20. ST06/ET Case11b water saturations in the LVZ of Hole 2.

4.3 GoldSim Slit Trench Vadose Zone Model

The initial conceptual model of the GoldSim slit trench vadose zone is shown schematically in Figure 4-21. This model includes the five individual slit trench segments (ST1 to ST5) separated by 10-foot wide non-waste segments with 8.5-foot wide non-waste segments outside ST1 and ST5 segments. A single intact slit trench segment advects and diffuses into non-waste segments on either side of the segment. The subsided slit trench segment advects and diffuses from the hole to the intact portion of the slit segment and into non-waste segments on either side of the subsided segment. The advective fluxes from the slit segment to the non-waste segment were not modelled due to the lack of detailed water budget information within the ST layout. Advective and diffusive fluxes to and from the overall ST06/ST footprint were not modeled in the GoldSim ST VZ model.

To reduce the development effort of the GoldSim ST vadose zone model, symmetry of the ST layout was utilized to separately model a single intact and subsided ST segment as shown in Figure 4-22 and Figure 4-23, respectively. The intact and subsided slit trench segments are further simplified as shown in the right-hand side of the figures. The subsided case evaluated is Hole 2 located in the ST5 trench segment as shown in Figure 3-2. In Figure 4-23, the black downward arrows represent the change in infiltration due to subsidence.

The closure cap is not explicitly modeled but accounted for by utilizing volume-averaged vertical Darcy velocities and water saturations extracted from the PORFLOW ST vadose zone flow models. The vadose zone is modeled by a series of Waste Zone and non-waste zone (spanning the entire thickness of the UVZ), and LVZ (comprised of Sandy and Clayey layers) cell networks. The cell networks are connected via advective and diffusive fluxes. The intact and subsided series represent areas within the trench that contain either crushable containers (intact cap case), non-waste, or non-crushable containers (subsided cap case) as described in Section 3.2.

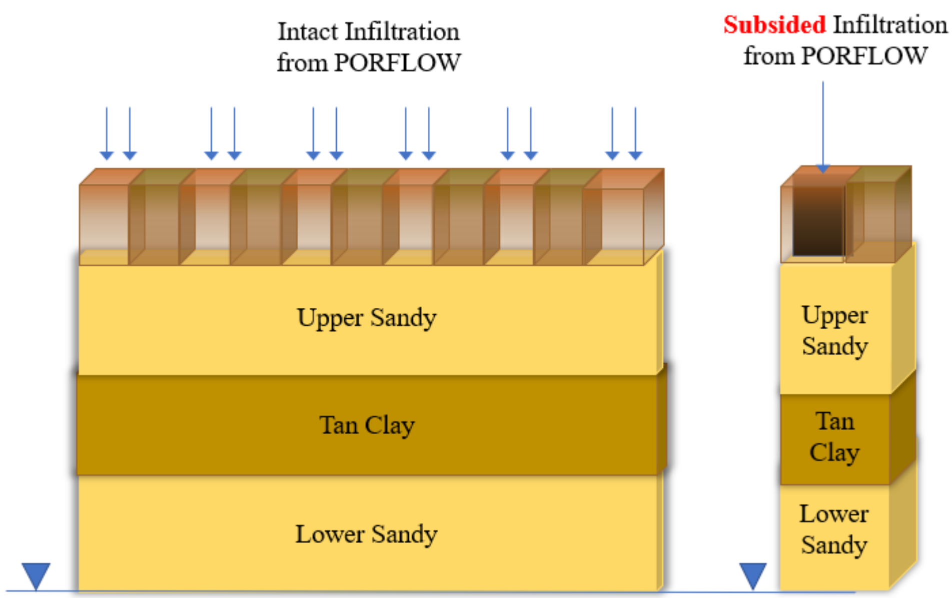

Figure 4-21. Schematic of the GoldSim slit trench five segment VZ model.

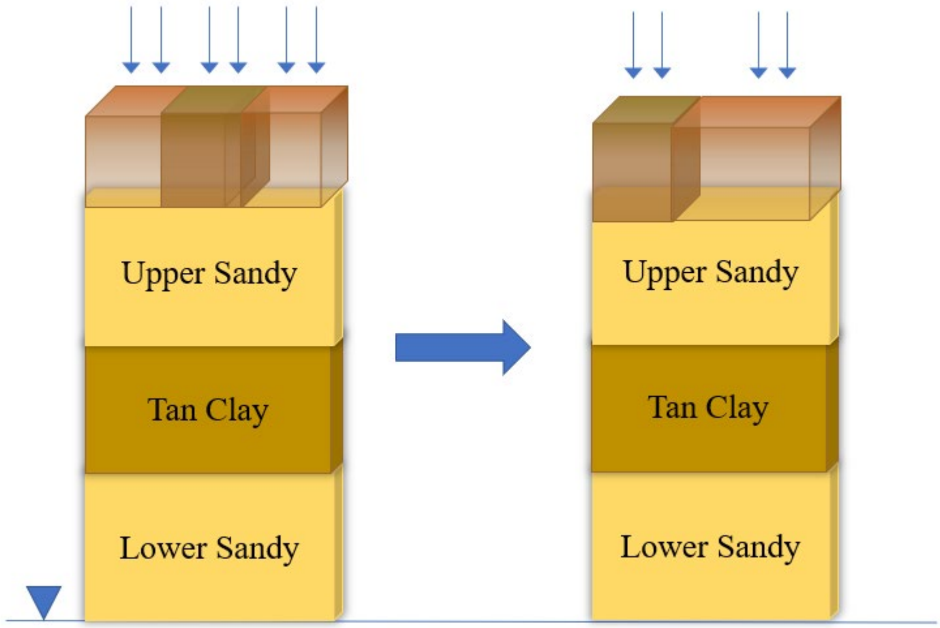

Figure 4-22. Schematic of the GoldSim slit trench intact segment (S1 to S4) VZ model.

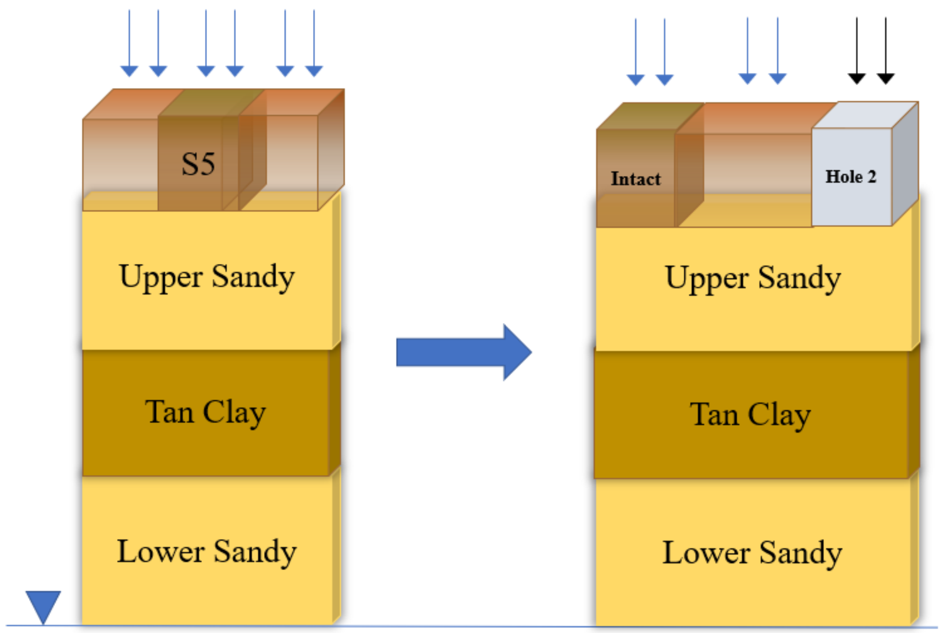

Figure 4-23. Schematic of the GoldSim slit trench subsided segment (S5) VZ model.

The WasteZoneST container in Figure 4-5 includes the WasteZone_Intact and WasteZone_Subsided containers as shown in Figure 4-24. These localized containers encapsulate the GoldSim slit trench waste zone models.

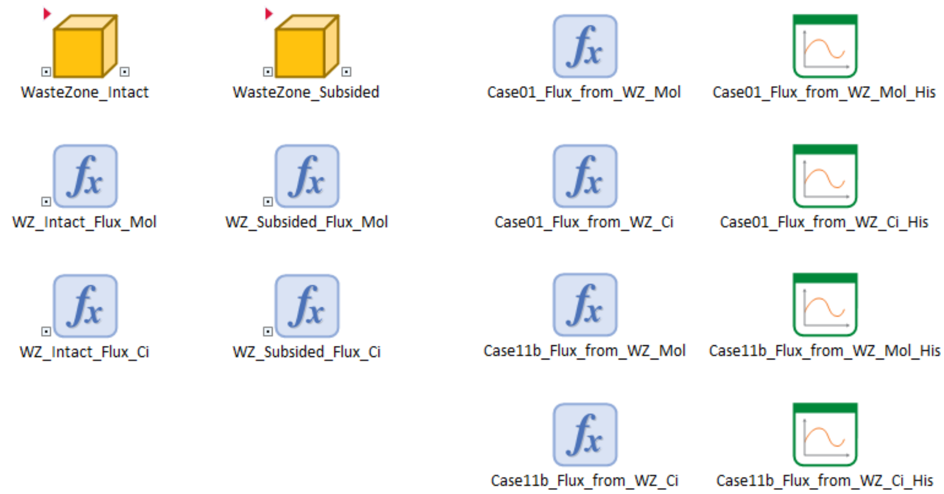

Figure 4-24. GoldSim slit trench waste zone containers.

The VadoseZoneST container in Figure 4-5 includes the VadoseZone_Intact and VadoseZone_Subsided containers as shown in Figure 4-25. These localized containers encapsulate the GoldSim slit trench lower vadose zone models.

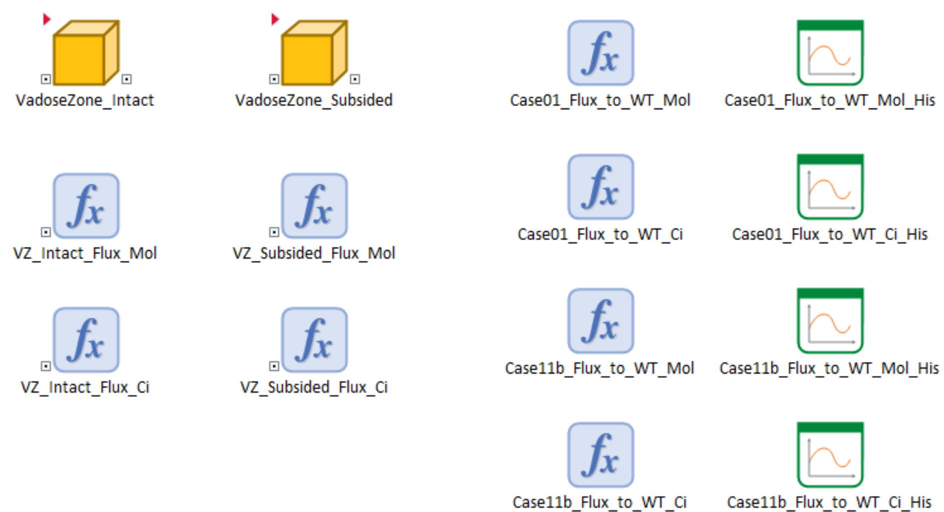

Figure 4-25. GoldSim slit trench lower vadose zone containers.

The WasteZone_Intact and WasteZone_Subsided containers have advective and diffusive flux links to the VadoseZone_Intact and VadoseZone_Subsided containers, respectively.

Vertical Darcy velocities and water saturations from the PORFLOW ST vadose zone flow simulations, are extracted for each steady-state simulation (time period) and averaged within user specified material zones for the GoldSim ST VZ model. Volume-averaged vertical Darcy velocities are computed for each intact and subsided cell network (WZ, UVZ and LVZ) within the GoldSim ST VZ model.

The ST06/ST Case01 average vertical velocities in slit segments 1 through 5 (WZ and LVZ) are shown in Figure 4-26. The AVERAGE velocities are input data into the Velocity_NDC_ST and Velocity_DC_ST time series elements (within the /Transport/WasteZoneST/WasteZone_Intact container). These velocities are used to compute volumetric flowrates in the Flowrate_NDC_ST and Flowrate_DC_ST expression elements. The AVERAGE velocities are input data into the Velocity_US_ST, Velocity_TC_ST and Velocity_LS_ST time series elements (within /Transport/VadoseZoneST/VadoseZone_Intact container). These velocities are used to compute volumetric flowrates in the Flowrate_US_ST, Flowrate_TC_ST and Flowrate_LS_ST expression elements.

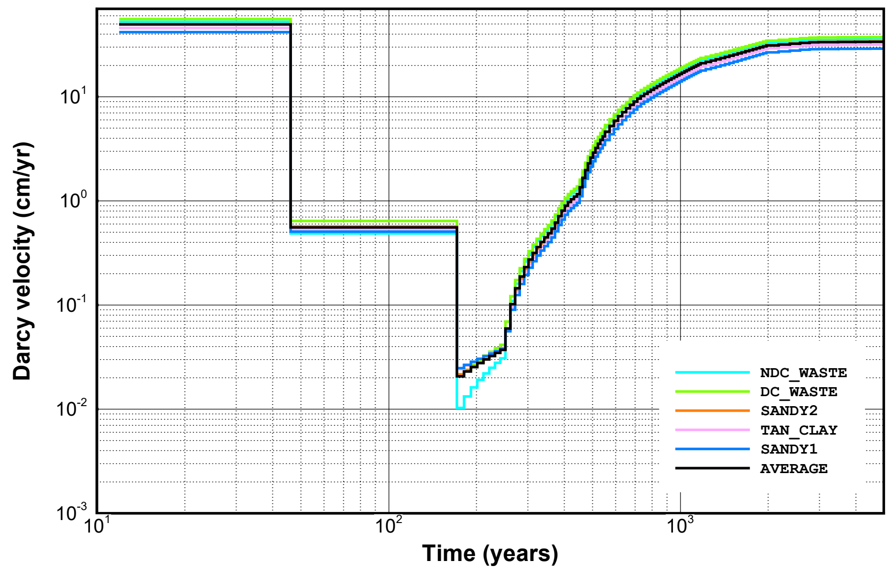

Figure 4-26. ST06/ST Case01 average vertical velocities in slit segements 1 through 5 (WZ and LVZ).

The ST06/ST Case01 average vertical velocities between slit segments (BS) in the UVZ and LVZ are shown in Figure 4-27. The AVERAGE velocities are input data into the Velocity_NDC_BS and Velocity_DC_BS time series elements (within /Transport/WasteZoneST/WasteZone_Intact container). These velocities are used to compute volumetric flowrates in the Flowrate_NDC_BS and Flowrate_DC_BS expression elements. The AVERAGE velocities are input data into the Velocity_US_BS, Velocity_TC_BS and Velocity_LS_BS time series elements (within the /Transport/VadoseZoneST/VadoseZone_Intact container). These velocities are used to compute volumetric flowrates in the Flowrate_US_BS, Flowrate_TC_BS and Flowrate_LS_BS expression elements.

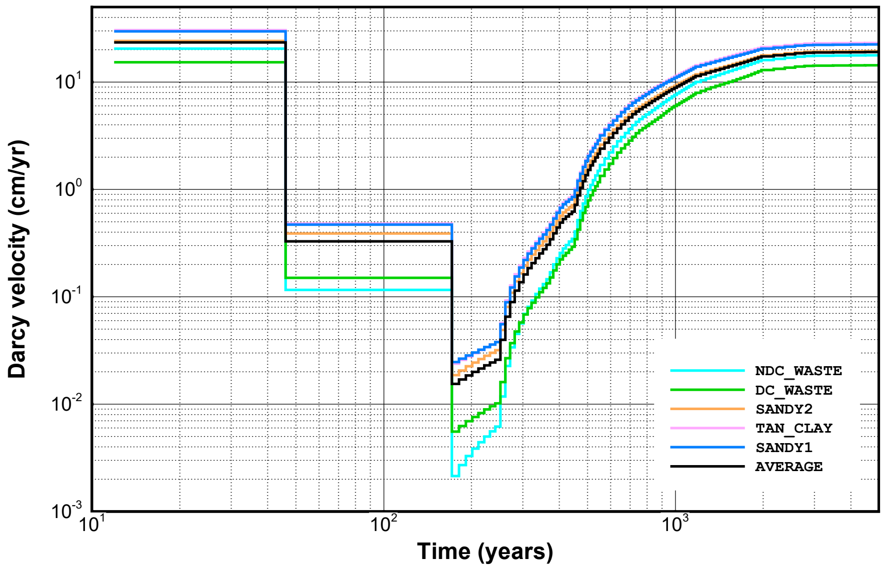

Figure 4-27. ST06/ST Case01 average vertical velocities between slit segments (UVZ and LVZ).

The ST06/ET Case11b vertical velocities through slit segment 5 (WZ and LVZ) are shown in Figure 4-28. The AVERAGE velocities are input data into the Velocity_NDC_ST and Velocity_DC_ST time series elements (within /Transport/WasteZoneST/WasteZone_Subsided container). These velocities are used to compute volumetric flowrates in the Flowrate_NDC_ST and Flowrate_DC_ST expression elements. The AVERAGE velocities are also input data into the Velocity_US_ST, Velocity_TC_ST and Velocity_LS_ST time series elements (within the /Transport/VadoseZoneST /VadoseZone_Subsided container). These velocities are used to compute volumetric flowrates in the Flowrate_US_ST, Flowrate_TC_ST and Flowrate_LS_ST expression elements.

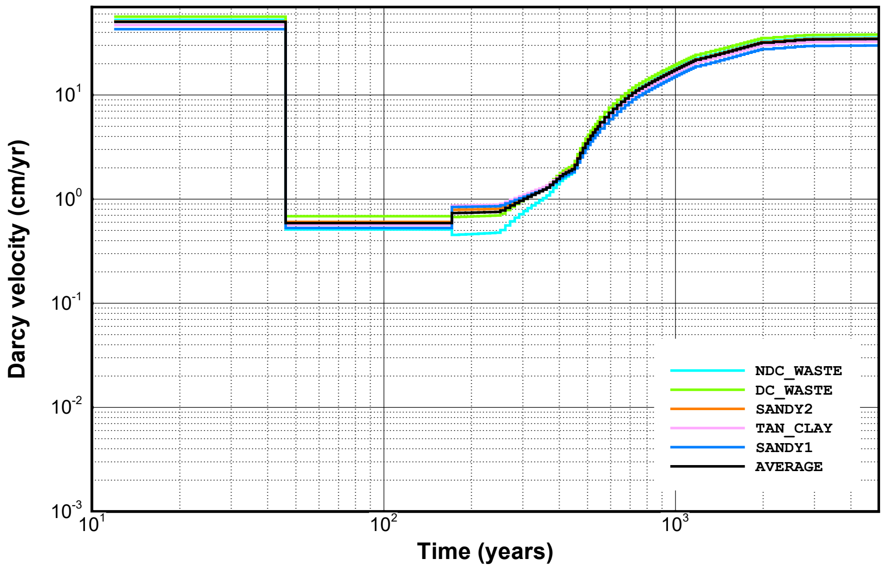

Figure 4-28. ST06/ST Case11b vertical velocities through slit segment 5 (WZ and LVZ).

The ST06/ST Case11b vertical velocities between slit segments 4 and 5 (UVZ and LVZ) are shown in Figure 4-29. The AVERAGE velocities are input data into the Velocity_NDC_BS and Velocity_DC_BS time series elements (within /Transport/WasteZoneST/WasteZone_Subsided container). These velocities are used to compute volumetric flowrates in the Flowrate_NDC_BS and Flowrate_DC_BS expression elements. The AVERAGE velocities are input data into the Velocity_US_BS, Velocity_TC_BS and Velocity_LS_BS time series elements (within /Transport/VadoseZoneST /VadoseZone_Subsided container). These velocities are used to compute volumetric flowrates in the Flowrate_US_BS, Flowrate_TC_BS and Flowrate_LS_BS expression elements.

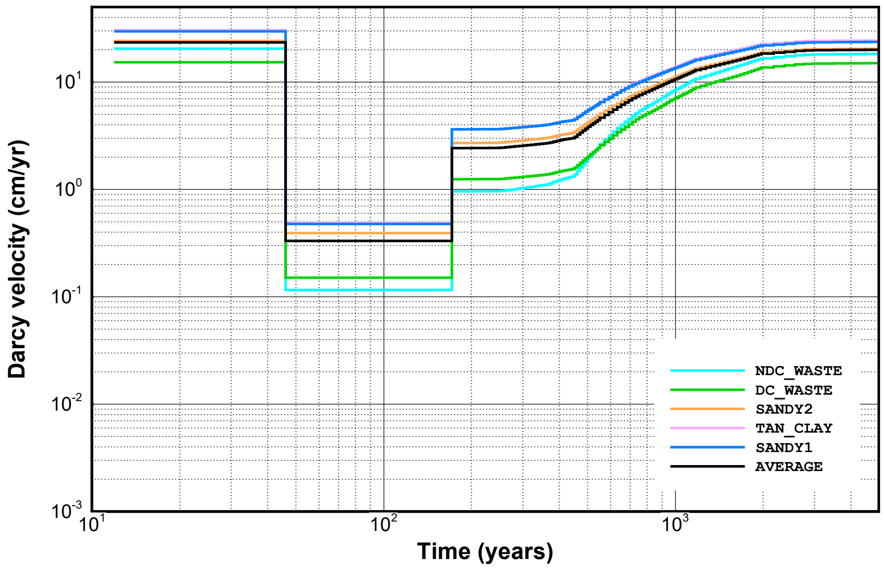

Figure 4-29. ST06/ST Case11b vertical velocities between slit segments 4 and 5 (UVZ and LVZ).

The ST06/ET Case11b vertical velocities through hole 2 (H2) in slit segment 5 (WZ and LVZ) are shown in Figure 4-30. The AVERAGE velocities are input data into the Velocity_NDC_H2 and Velocity_DC_H2 time series elements (within /Transport/WasteZoneST/WasteZone_Subsided container). These velocities are used to compute volumetric flowrates in the Flowrate_NDC_H2 and Flowrate_DC_H2 expression elements. The AVERAGE velocities are also input data into the Velocity_US_H2, Velocity_TC_H2 and Velocity_LS_H2 time series elements (in /Transport/VadoseZoneST /VadoseZone_Subsided container). These velocities are used to compute volumetric flowrates in the Flowrate_US_H2, Flowrate_TC_H2 and Flowrate_LS_H2 expression elements.

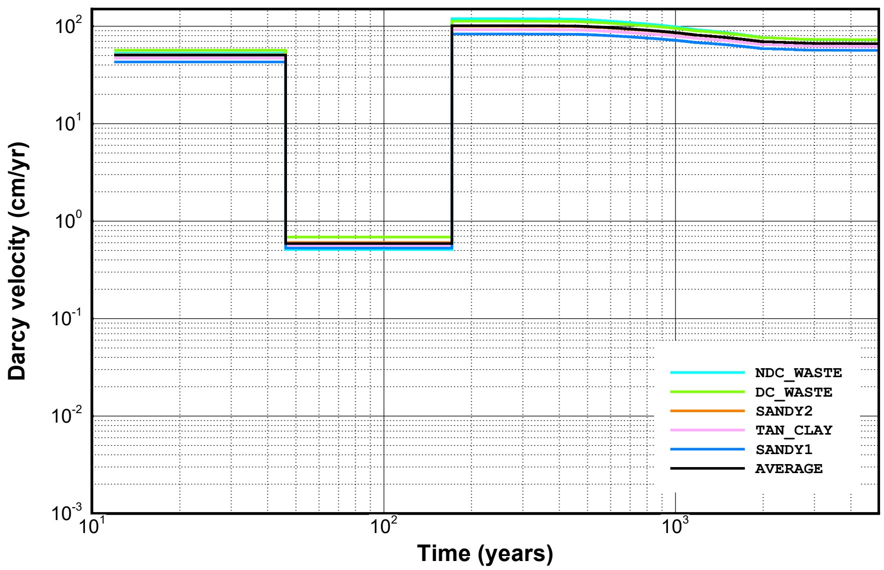

Figure 4-30. ST06/ST Case11b vertical velocities through H2 in slit segment 5 (WZ and LVZ).

4.3.1 Intact Waste Zone Model

The intact waste zone model is represented by a cell network consisting of a slit trench segment (ST) and clayey between segment (BS). Each column of ST and BS cell pathways are connected through advective and diffusive flux links. There are only diffusive flux links between the ST and BS as explained in an earlier section. The widths of the ST and BS are 20 ft and 10 ft, respectively. The length of the ST and BS is 656 ft. To model dynamic compaction at the end of IC, the waste zone is separated into two sections: 12 cell pathways in NDC_WASTE (NDC_ST) and 16 cell pathways in DC_WASTE (DC_ST). The adjacent cell pathways are designated NDC_BS and DC_BS, respectively. The GoldSim intact slit trench segment waste zone cell network is shown in Figure 4-31. The height of the NDC_(ST/BS) and DC_(ST/BS) cell pathways are 7.13 ft/12 (0.5942 ft) and 8.87 ft/16 (0.5544 ft), respectively.

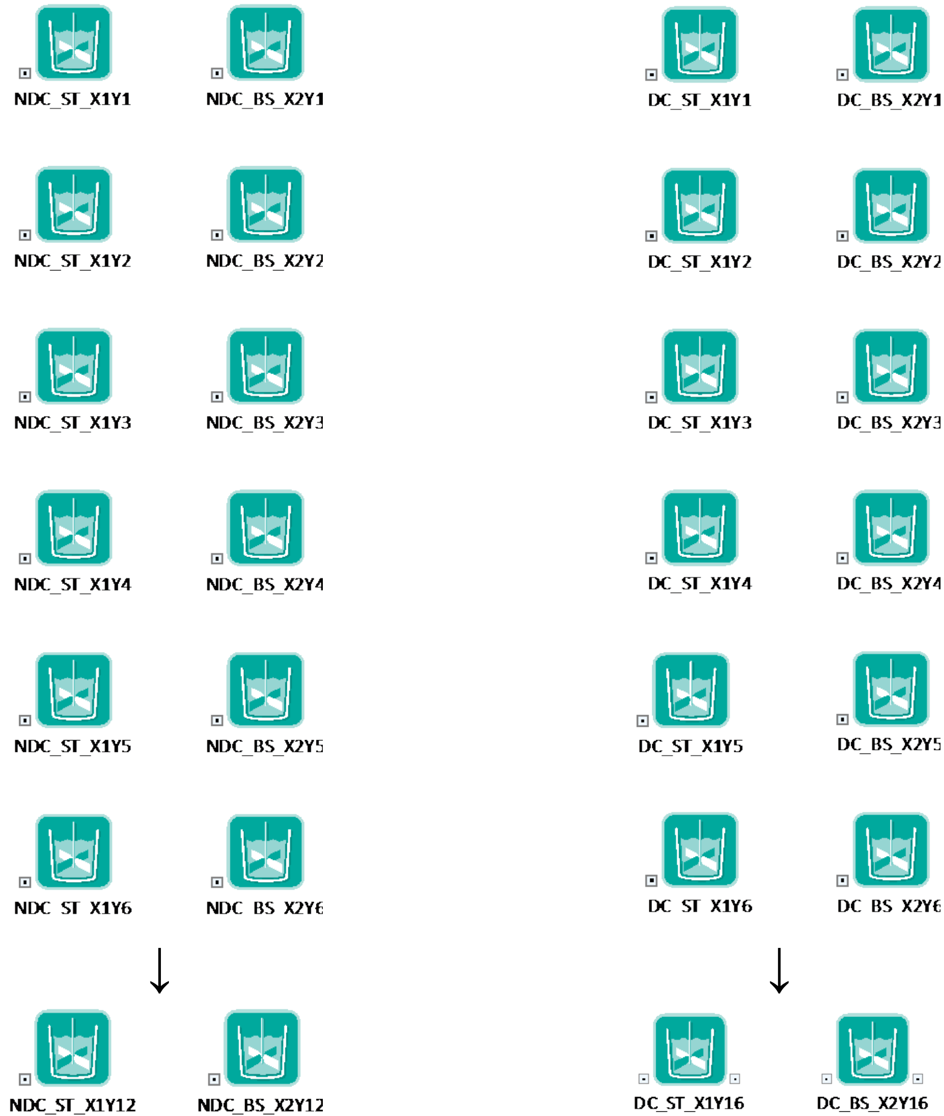

Figure 4-31. GoldSim intact slit trench segment waste zone cell network.

The cell pathway properties for NDC_ST_X1Y1 are shown in Figure 4-32 and Figure 4-33. The data requirements of the intact waste zone cell network are described in this section.

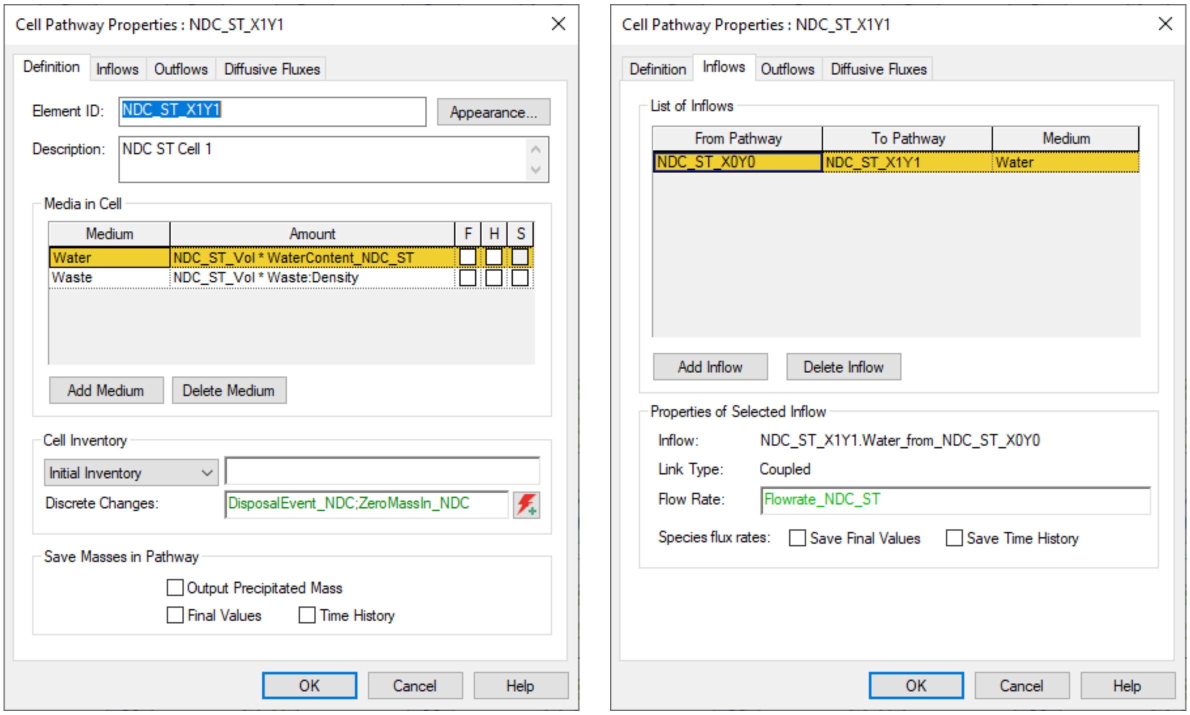

Figure 4-32. NDC_ST_X1Y1 cell pathway properties: Definition and Inflows.

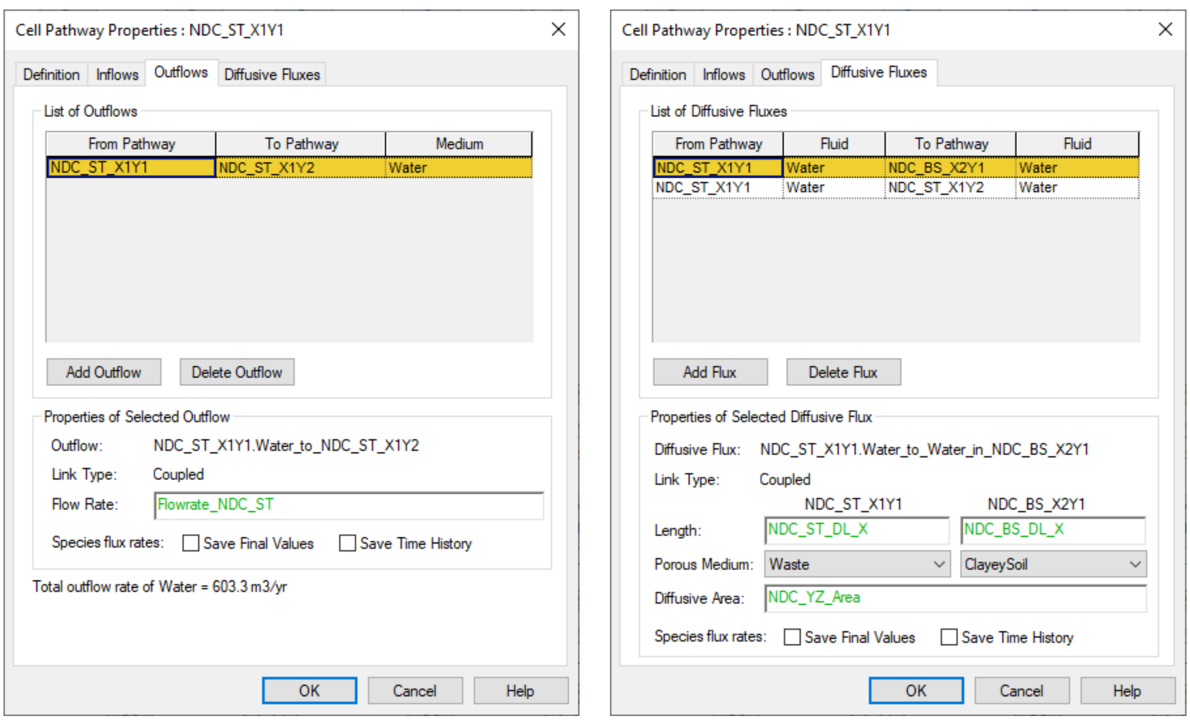

Figure 4-33. NDC_ST_X1Y1 cell pathway properties: Outflows and Diffusive Fluxes.

An initial inventory of 1/5 mol is assigned to each parent radionuclide and tracer. The parent radionuclide inventories are converted to grams internally for use throughout the waste and vadose zone models. For ST06/ST, the species inventories are distributed between NDC and DC waste zones 12 years after the start of ELLWF operations. Discrete change elements DisposalEvent_NDC and DisposalEvent_DC trigger the placement of species inventories in NDC_ST and DC_ST cell pathways, respectively. The species inventories distributed to each NDC_ST and DC_ST cell pathways are computed in Eqs 4-5 and 4-6, respectively.

$$I_{NDC\_ST} = I_p \frac{H_{NDC\_ST}}{H_{WZ}} \tag{4-5}$$

$$I_{DC\_ST} = I_p \frac{H_{DC\_ST}}{H_{WZ}} \tag{4-6}$$

where

I_{NDC_ST} .... species inventory of NDC_ST cell, g

I_{DC_ST} .... species inventory of DC_ST cell, g

I_p .... inventory of parent radionuclide, g

H_{NDC_ST} .... height of NDC_ST cell, 7.13 ft/12

H_{DC_ST} .... height of DC_ST cell, 8.87 ft/16

H_{WZ} .... height of waste zone, 16 ft

When the final cap is emplaced at end of IC, the species inventories (Mass_In_Pathway) within NDC_ST cell pathways are transferred to the DC_ST cell pathways. A series of discrete change elements (AddMassFrom_NDC, ZeroMassin_NDC and AddMassto_DC) and a cell pathway (MassCollector_NDC) were used to transfer the species inventories. The AddMassFrom_NDC element sums the Mass_In_Pathway from NDC_ST cell pathways and makes them available in the MassCollector. The ZeroMassin_NDC element replaces the species inventories in the NDC_ST cell pathways with zero values. The AddMassTo_DC element adds and distributes the species inventories from the NDC_ST cell pathways evenly among the DC_ST cell pathways.

The ST06/ST Case01 average water saturations in slit segments 1 through 5 (WZ) are shown in Figure 4-34. The NDC_WASTE and DC_WASTE water saturations are data inputs to the Saturation_NDC_ST and Saturation_DC_ST expression elements, respectively. These water saturations are used to compute water contents in the WaterContent_NDC_ST and WaterContent_DC_ST expression elements (within /Transport/WasteZoneST/WasteZone_Intact container).

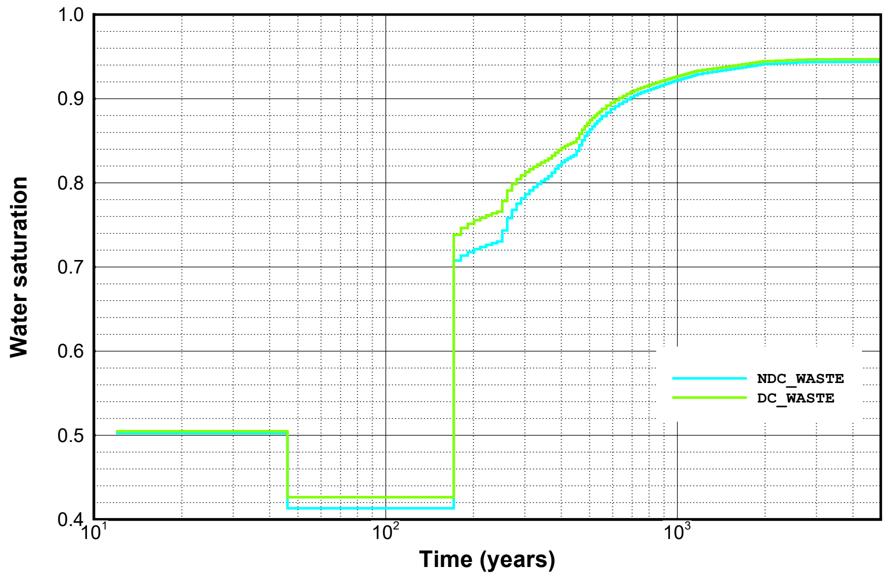

Figure 4-34. ST06/ST Case01 average water saturations in slit segments 1 through 5 (WZ).

The ST06/ST Case01 average water saturations between slit segments (UVZ) are shown in Figure 4-35. The water saturations in the NDC_WASTE and DC_WASTE regions are data inputs to the Saturation_NDC_BS and Saturation_DC_BS expression elements, respectively. These water saturations are used to compute water contents in the WaterContent_NDC_BS and WaterContent_DC_BS expression elements (within /Transport/WasteZoneST/WasteZone_Intact container).

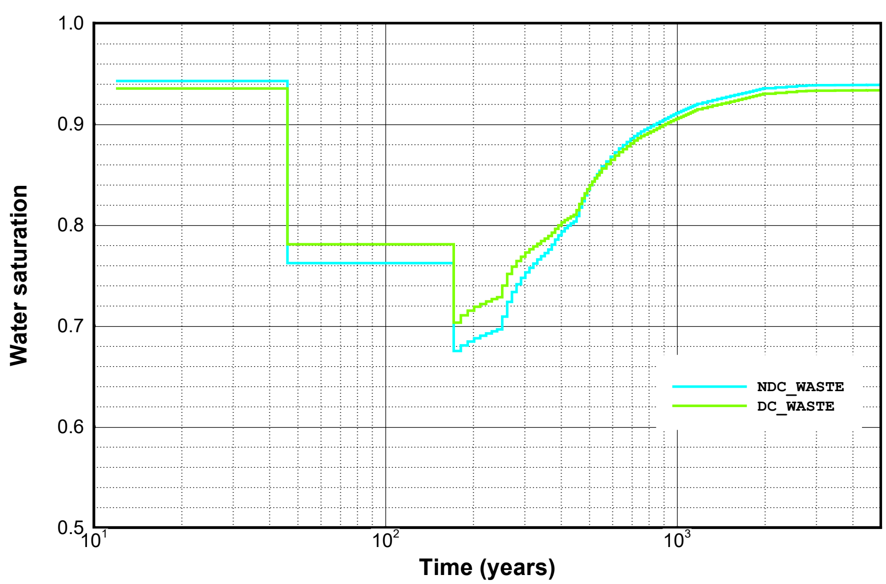

Figure 4-35. ST06/ST Case01 average water saturations between slit segments (UVZ).

4.3.2 Subsided Waste Zone Model

The subsided waste zone model is represented by a cell network consisting of a slit trench segment (ST), clayey between segment (BS) and subsided hole (H2). Each column of ST, BS and H2 cell pathways are connected through advective and diffusive flux links. There are only diffusive flux links between the ST to BS and H2 to BS pairs as explained in an earlier section. The width of the ST/H2 and BS are 20 ft and 10 ft, respectively. The length of the ST, BS and H2 are 556 ft, 656 ft and 100 ft, respectively. To model dynamic compaction at the end of IC, the waste zone is separated into two sections: 12 cell pathways in NDC_WASTE (NDC_ST and NDC_H2) and 16 cell pathways in DC_WASTE (DC_ST and DC_H2). The adjacent cell pathways are designated NDC_BS and DC_BS, respectively. The GoldSim subsided slit trench segment waste zone cell network is shown in Figure 4-36. The height of the NDC_(ST/BS/H2) and DC_(ST/BS/H2) cell pathways are 7.13 ft/12 (0.5942 ft) and 8.87 ft/16 (0.5544 ft), respectively.

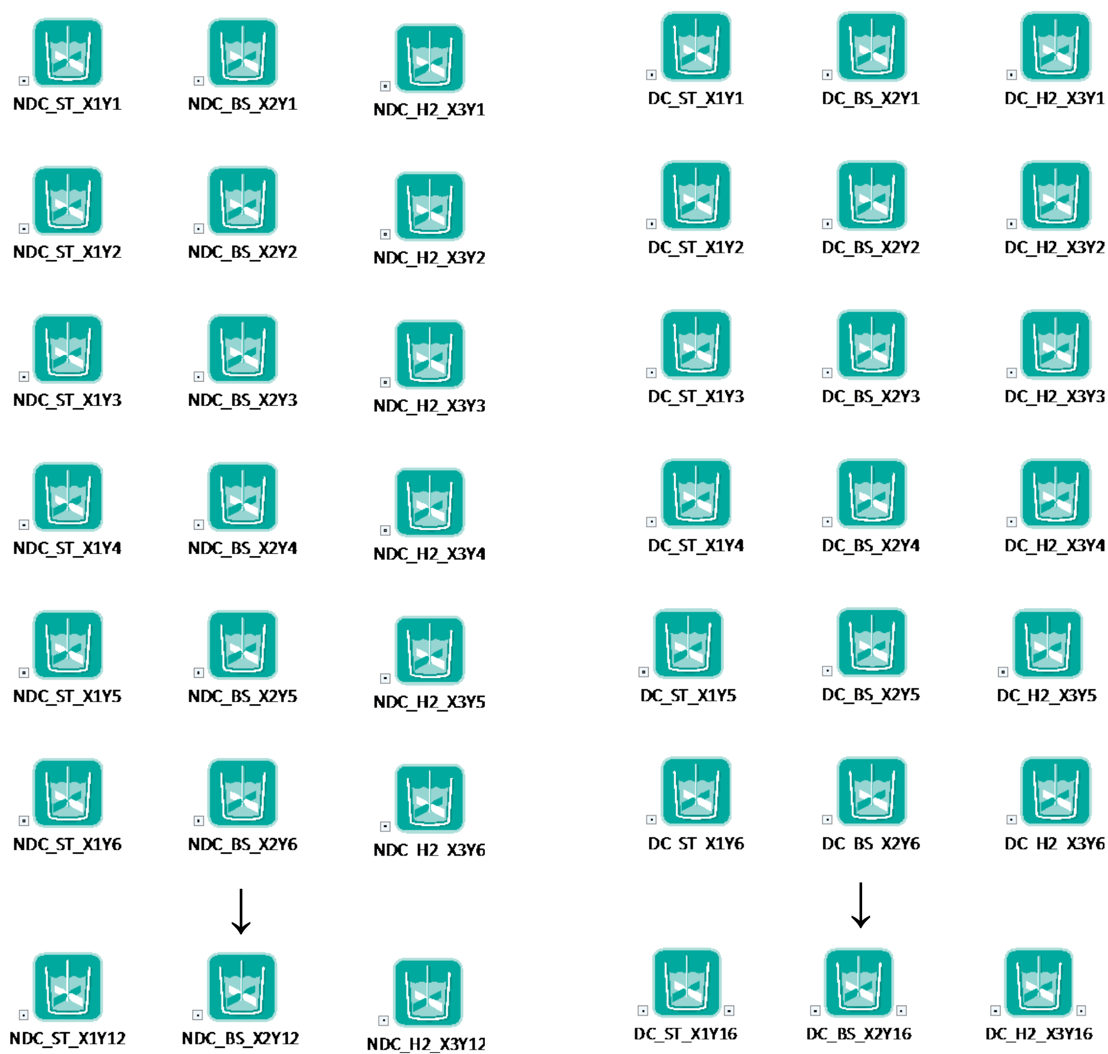

Figure 4-36. GoldSim subsided slit trench segment waste zone cell network.

The cell pathway properties for NDC_H2_X3Y1 are shown in Figure 4-37 and Figure 4-38. The data requirements of the subsided waste zone cell network are described in this section.

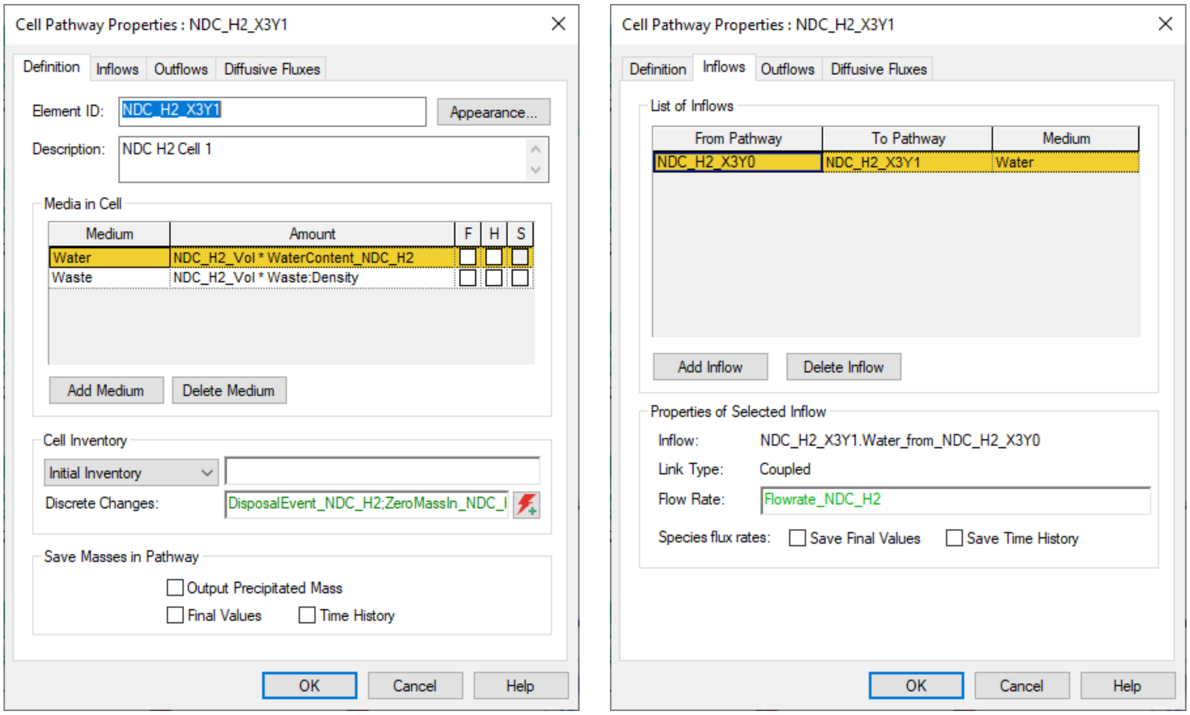

Figure 4-37. NDC_H2_X3Y1 cell pathway properties: Definition and Inflows.

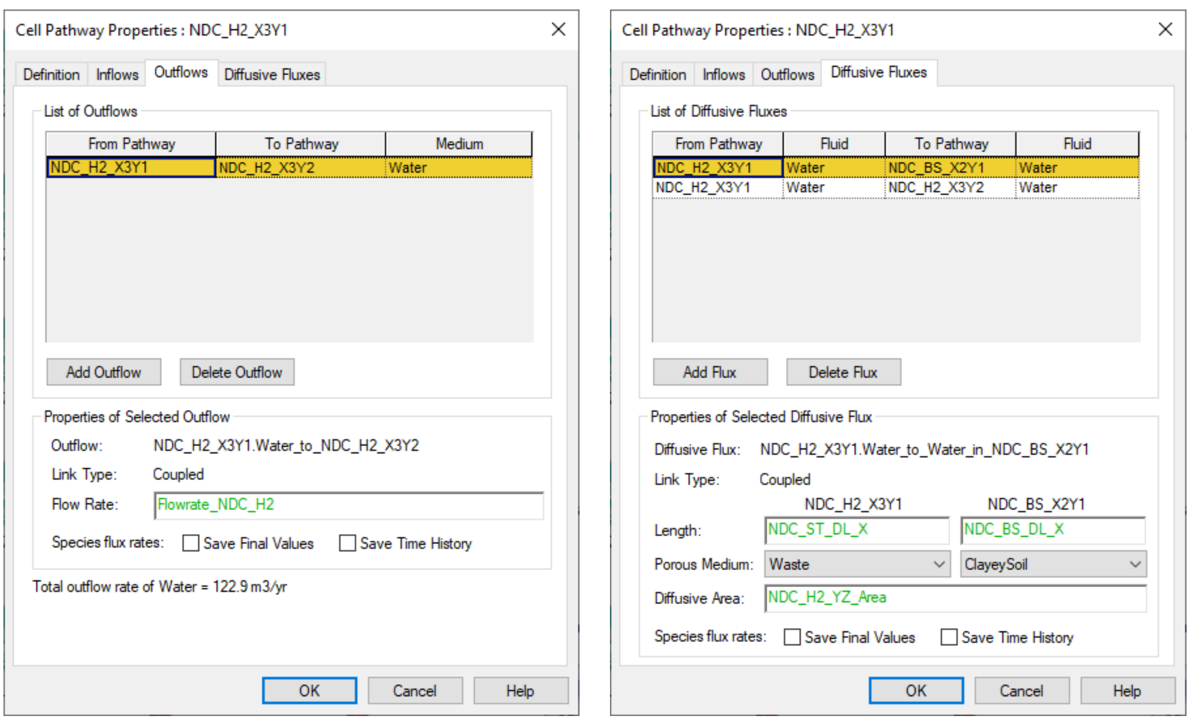

Figure 4-38. NDC_H2_X3Y1 cell pathway properties: Outflows and Diffusive Fluxes.

An initial inventory of 1/5 mol is assigned to each parent radionuclide and tracer. The parent radionuclide inventories are converted to grams internally for use throughout the waste and vadose zone models. For ST06/ST, the species inventories are distributed between NDC and DC waste zones 12 years after the start of ELLWF operations. Discrete change elements DisposalEvent_NDC_ST, DisposalEvent_NDC_H2, DisposalEvent_DC_ST and DisposalEvent_DC_H2 trigger the placement of species inventories in NDC_ST, NDC_H2, DC_ST and DC_H2 cell pathways, respectively. The species inventories distributed to each NDC_ST and DC_ST cell pathways are computed in Eqs 4-7 and 4-8, respectively.

$$I_{NDC\_ST} = I_p f_{ST} \frac{H_{NDC\_ST}}{H_{WZ}} \quad (4\text{-}7)$$

$$I_{DC\_ST} = I_p f_{ST} \frac{H_{DC\_ST}}{H_{WZ}} \quad (4\text{-}8)$$

where

I_{NDC_ST} .... species inventory of NDC_ST cell, g

I_{DC_ST} .... species inventory of DC_ST cell, g

I_p .... inventory of parent radionuclide, g

f_{ST} .... area fraction of intact segment, 0.8476

H_{NDC_ST} .... height of NDC_ST cell, 7.13 ft/12

H_{DC_ST} .... height of DC_STcell, 8.87 ft/16

H_{WZ} .... height of waste zone, 16 ft

The species inventories distributed to each NDC_H2 and DC_H2 cell pathways are computed in Eqs 4-9 and 4-10, respectively.

$$I_{NDC\_H2} = I_p f_{H2} \frac{H_{NDC\_H2}}{H_{WZ}} \quad (4\text{-}9)$$

$$I_{DC\_H2} = I_p f_{H2} \frac{H_{DC\_H2}}{H_{WZ}} \quad (4\text{-}10)$$

where

I_{NDC_H2} .... species inventory of NDC_H2 cell, g

I_{DC_H2} .... species inventory of DC_H2 cell, g

I_p .... inventory of parent radionuclide, g

f_{H2} .... area fraction of H2 segment, 0.1524

H_{NDC_H2} .... height of NDC_H2 cell, 7.13 ft/12

H_{DC_H2} .... height of DC_H2 cell, 8.87 ft/16

When the final cap is emplaced at end of IC, the species inventories (Mass_In_Pathway) within NDC_ST and NDC_H2 cell pathways are transferred to the DC_ST and DC_H2 cell pathways, respectively. A series of discrete change elements (AddMassFrom_NDC_ST, AddMassFrom_NDC_H2, ZeroMassin_NDC_ST, ZeroMassin_NDC_H2, AddMassto_DC_ST and AddMassto_DC_H2) and cell pathways (MassCollector_NDC_ST and MassCollector_NDC_H2) were used to transfer the species inventories. The AddMassFrom_NDC_ST and AddMassFrom_NDC_H2 elements sum the Mass_In_Pathway from NDC_ST and NDC_H2 cell pathways, respectively and makes them available in the MassCollectors. The ZeroMassin_NDC_ST and ZeroMassin_NDC_H2 elements replace the species inventories in the NDC_ST and NDC_H2 cell pathways, respectively with zero values. The AddMassTo_DC_ST and AddMassTo_DC_H2 elements add and distribute the species inventories from the NDC_ST and NDC_H2 cell pathways evenly among the DC_ST and DC_H2 cell pathways, respectively.

The ST06/ST Case11b water saturations in slit segment 5 (WZ) are shown in Figure 4-39. The NDC_WASTE and DC_WASTE water saturations are data inputs to the Saturation_NDC_ST and Saturation_DC_ST expression elements, respectively. These water saturations are used to compute water contents in the WaterContent_NDC_ST and WaterContent_DC_ST expression elements (within the /Transport/WasteZoneST/WasteZone_Subsided container).

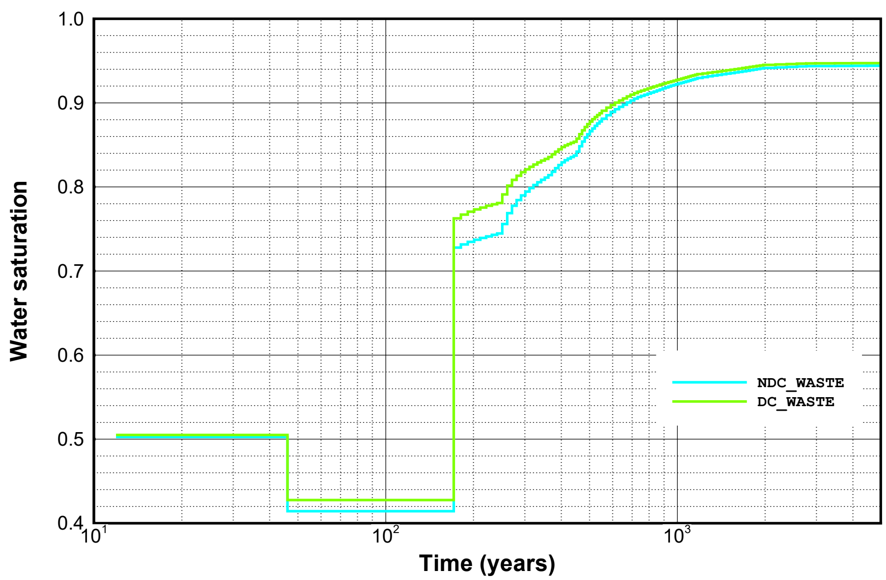

Figure 4-39. ST06/ST Case11b water saturations in slit segment 5 (WZ).

The ST06/ST Case11b water saturations between slit segments 4 and 5 (UVZ) are shown in Figure 4-40. The water saturations in the NDC_WASTE and DC_WASTE regions are data inputs to the Saturation_NDC_BS and Saturation_DC_BS expression elements, respectively. These water saturations are used to compute water contents in the WaterContent_NDC_BS and WaterContent_DC_BS expression elements (within /Transport/WasteZoneST/WasteZone_Subsided container).

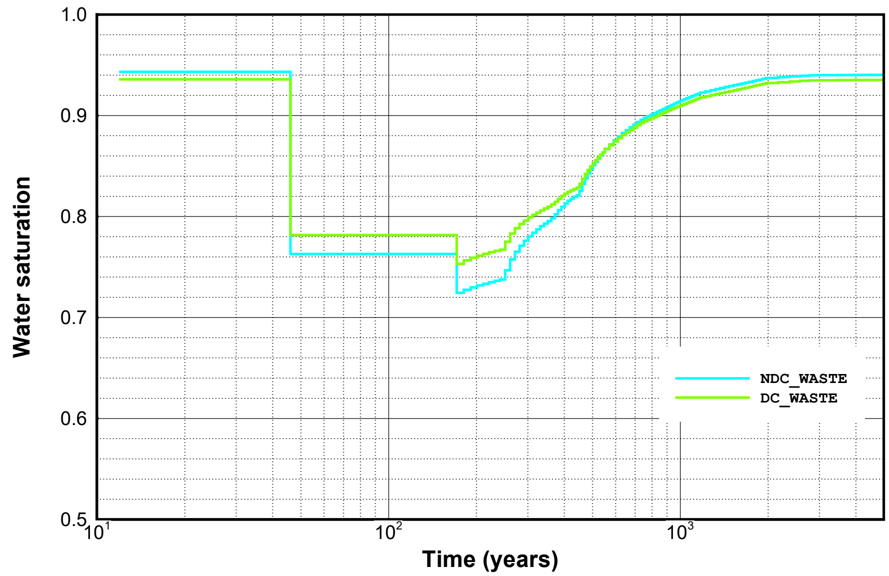

Figure 4-40. ST06/ST Case11b water saturations between slit segment 4 and 5 (UVZ).

The ST06/ST Case11b water saturations in H2 of slit segment 5 (WZ) are shown in Figure 4-41. The NDC_WASTE and DC_WASTE water saturations are data inputs to the Saturation_NDC_H2 and Saturation_DC_H2 expression elements, respectively. These water saturations are used to compute water contents in the WaterContent_NDC_H2 and WaterContent_DC_H2 expression elements (within the /Transport/WasteZoneST/WasteZone_Subsided container).

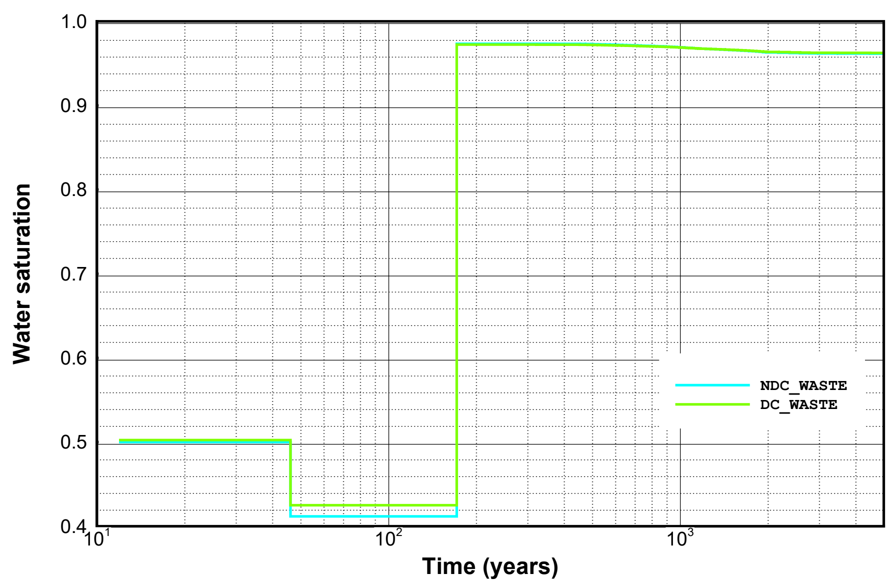

Figure 4-41. ST06/ST Case11b water saturations in H2 of slit segment 5 (WZ).

4.3.3 Lower Vadose Zone Model (Intact Waste Zone)

Advective and diffusive species fluxes leave the DC_ST and DC_BS cell pathways from WasteZone_Intact and enter the upper sandy (US) layer (SANDY2) of the lower vadose zone. The SANDY2 soil layer is represented by a cell network consisting of a column of 40 US_ST and US_BS cell pathways. The advective and diffusive species fluxes leave the SANDY2 cell network and enter the TAN_CLAY (TC) soil layer. The TAN_CLAY soil layer is represented by a cell network consisting of a column of 6 TC_ST and TC_BS cell pathways. The advective and diffusive species fluxes leave the TAN_CLAY cell network and enter the lower sandy (LS) layer (SANDY1). The SANDY1 soil layer is represented by a cell network consisting of a column of 16 LS_ST and LS_BS cell pathways. The GoldSim slit trench lower vadose zone (Intact WZ) cell network is shown in Figure 4-42.

Each column of lower vadose zone cell pathways is connected through advective and diffusive flux links. There are only diffusive flux links between the ST and BS cell pathways as explained in an earlier section. The widths of the ST and BS cell pathways are 20 ft and 10 ft, respectively. The length of the ST and BS cell pathways are 656 ft. The height of the US_ST and US_BS cell pathways are 23 ft/40 (0.575 ft). The height of the TC_ST and TC_BS cell pathways are 2 ft/6 (0.3333 ft). The height of the LS_ST and LS_BS cell pathways are 10 ft/16 (0.625 ft).

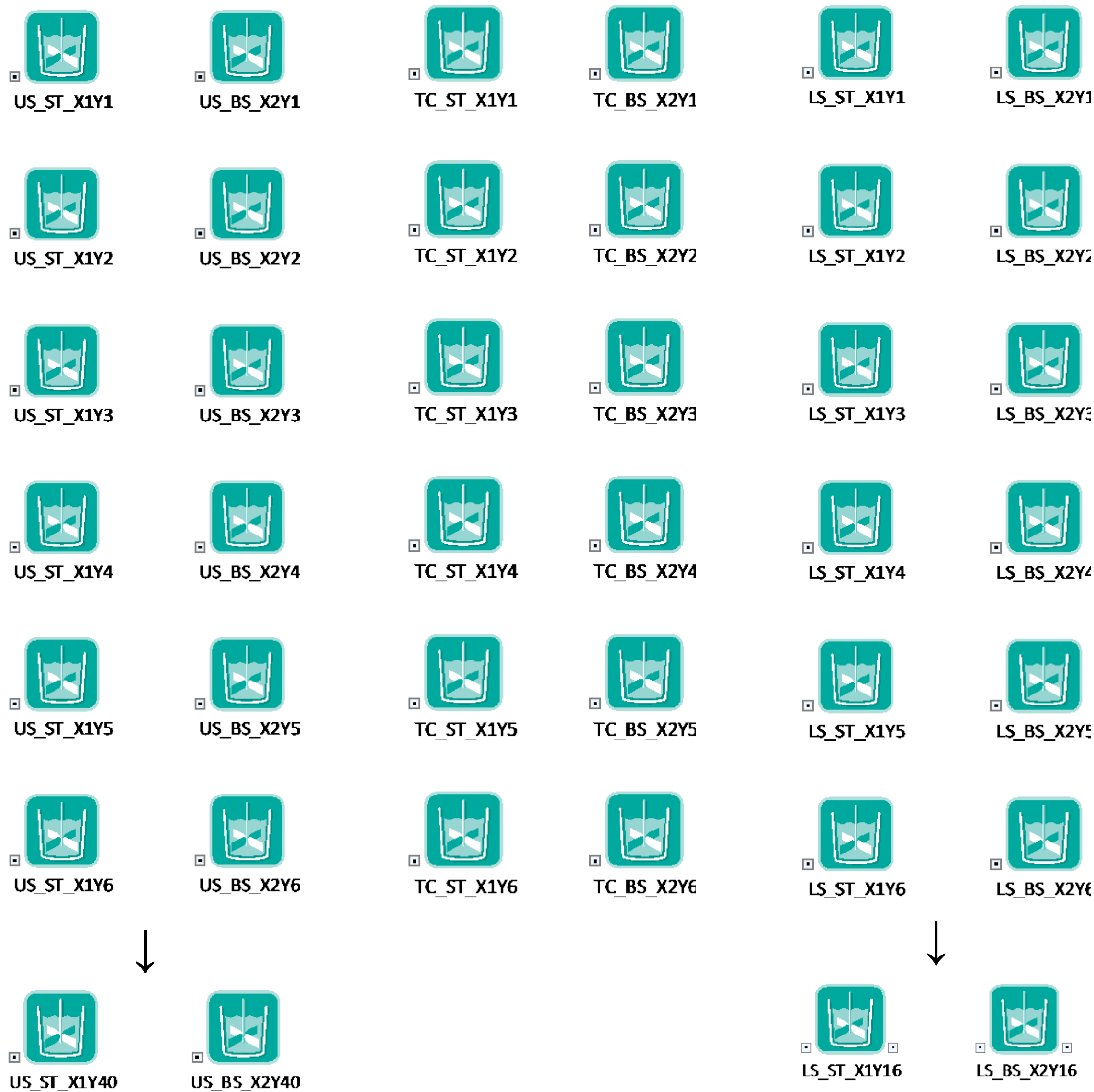

Figure 4-42. GoldSim slit trench lower vadose zone cell network (Intact WZ).

The cell pathway properties for US_ST_X1Y1 are shown in Figure 4-43 and Figure 4-44. The data requirements of the lower vadose zone cell pathways are described in this section.

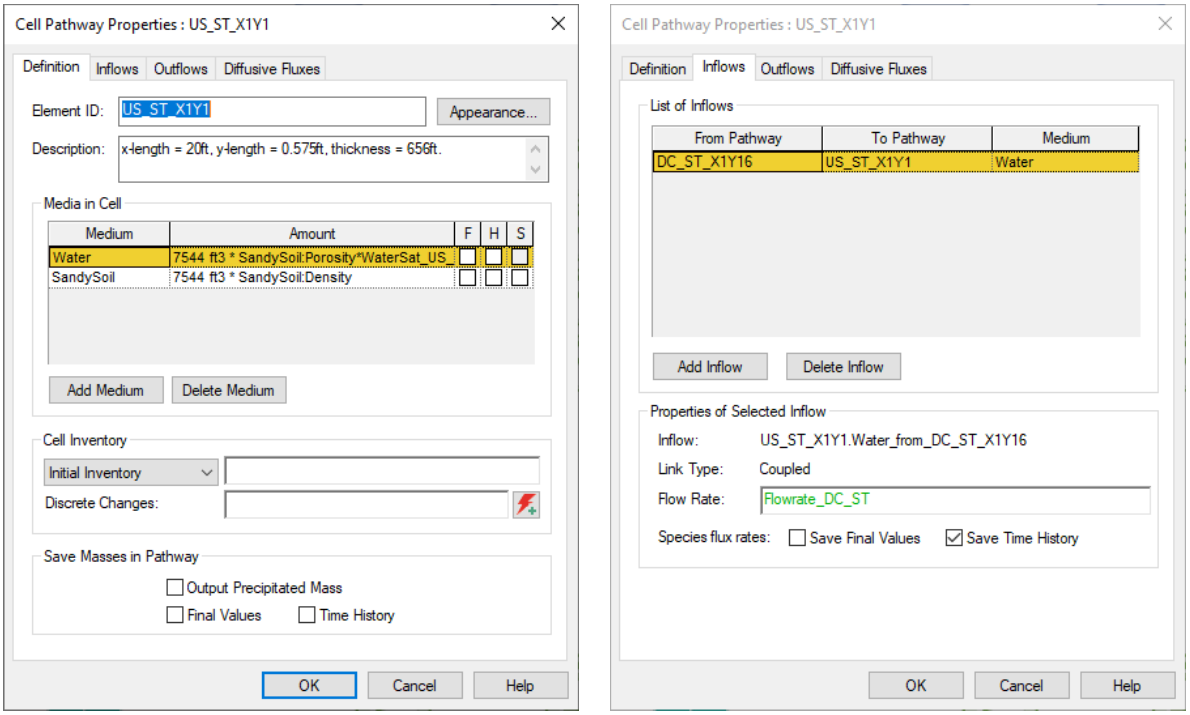

Figure 4-43. US_ST_X1Y1 cell pathway properties: Definition and Inflows.

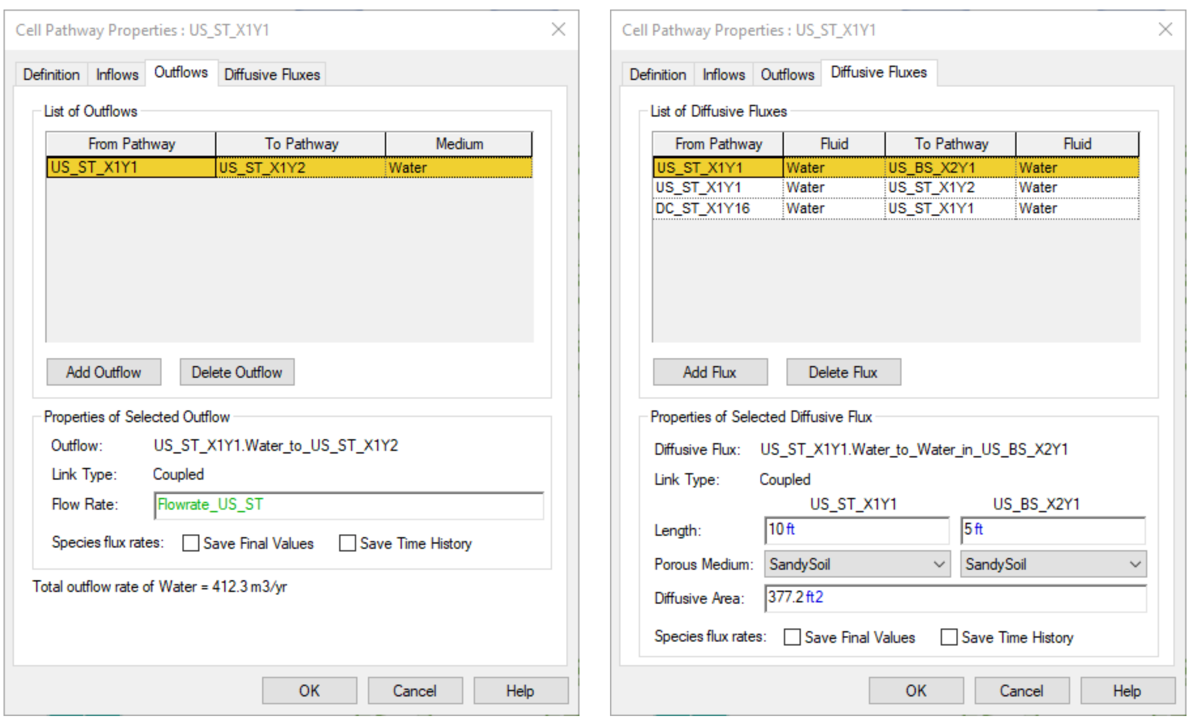

Figure 4-44. US_ST_X1Y1 cell pathway properties: Outflows and Diffusive Fluxes.

The ST06/ST Case01 average water saturations in slit segments 1 through 5 (LVZ) are shown in Figure 4-45. The SANDY2, TAN_CLAY and SANDY1 water saturations are data inputs to the

Saturation_US_ST, Saturation_TC_ST and Saturation_LS_ST expression elements, respectively (within the /Transport/VadoseZoneST/VadoseZone_Intact container).

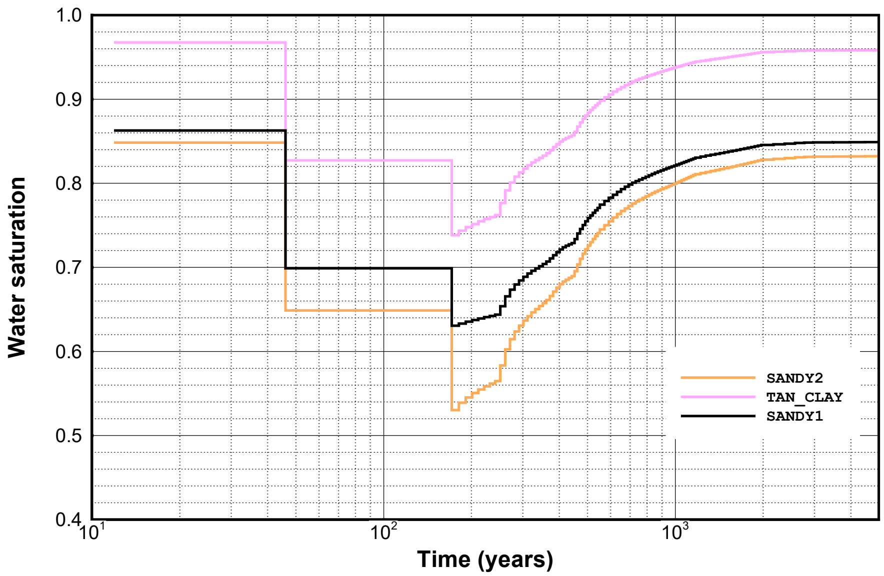

Figure 4-45. ST06/ST Case01 average water saturations in slit segments 1 through 5 (LVZ).

The ST06/ST Case01 average water saturations between slit segments (LVZ) are shown in Figure 4-46. The SANDY2, TAN_CLAY and SANDY1 water saturations are data inputs to the Saturation_US_BS, Saturation_TC_BS and Saturation_LS_BS expression elements, respectively. (VadoseZoneST /VadoseZone_Intact).

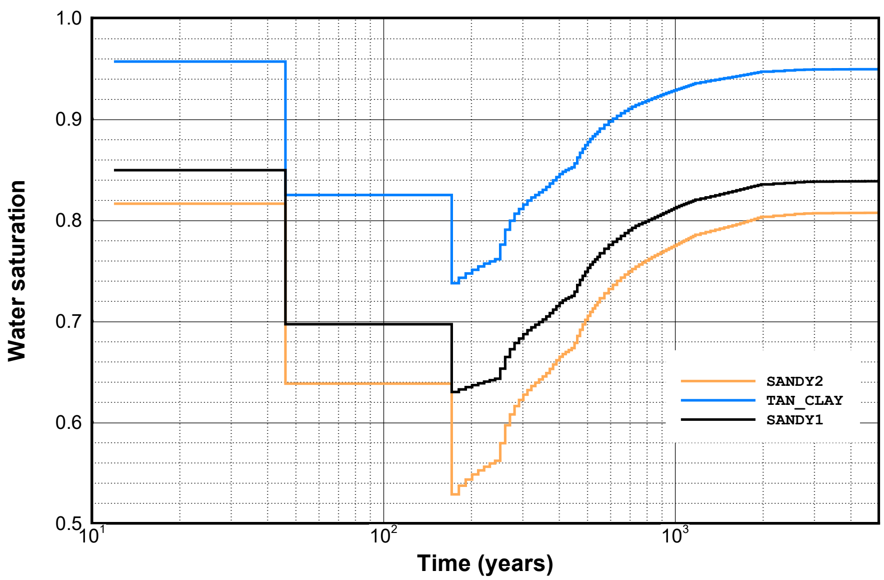

Figure 4-46. ST06/ST Case01 average water saturations between slit segments (LVZ).

4.3.4 Lower Vadose Zone Model (Subsided Waste Zone)

The VadoseZone_Subsided container is split into three localized containers for the UpperSandyLayer, TanClayLayer and LowerSandyLayer models as shown in Figure 4-47. With the additional subsided columns, US/TC/LS_H2, there was a need to split the models for ease of development. The remainder of this section describes the models within these containers.

Figure 4-47. GoldSim slit trench lower vadose zone containers (Subsided WZ).

Advective and diffusive species fluxes leave the DC_ST, DC_BS and DC_H2 cell pathways from WasteZone_Subsided and enter the upper sandy layer (SANDY2) of the lower vadose zone. The SANDY2 soil layer is represented by a cell network consisting of a column of 40 US_ST, US_BS and US_H2 cell pathways. Each column of upper sandy layer cell pathways is connected through advective and diffusive flux links. There are only diffusive flux links between the US_ST to US_BS and US_H2 to US_BS pairs as explained in an earlier section. The widths of the US_ST/H2 and US_BS cell pathways are 20 ft and 10 ft, respectively. The length of the US_ST, US_BS and US_H2 are 556 ft, 656 ft and 100 ft, respectively. The height of the US_ST, US_H2 and US_BS cell pathways are 23 ft/40 (0.575 ft). The GoldSim slit trench upper sandy layer cell network (Subsided WZ) is shown in Figure 4-48.

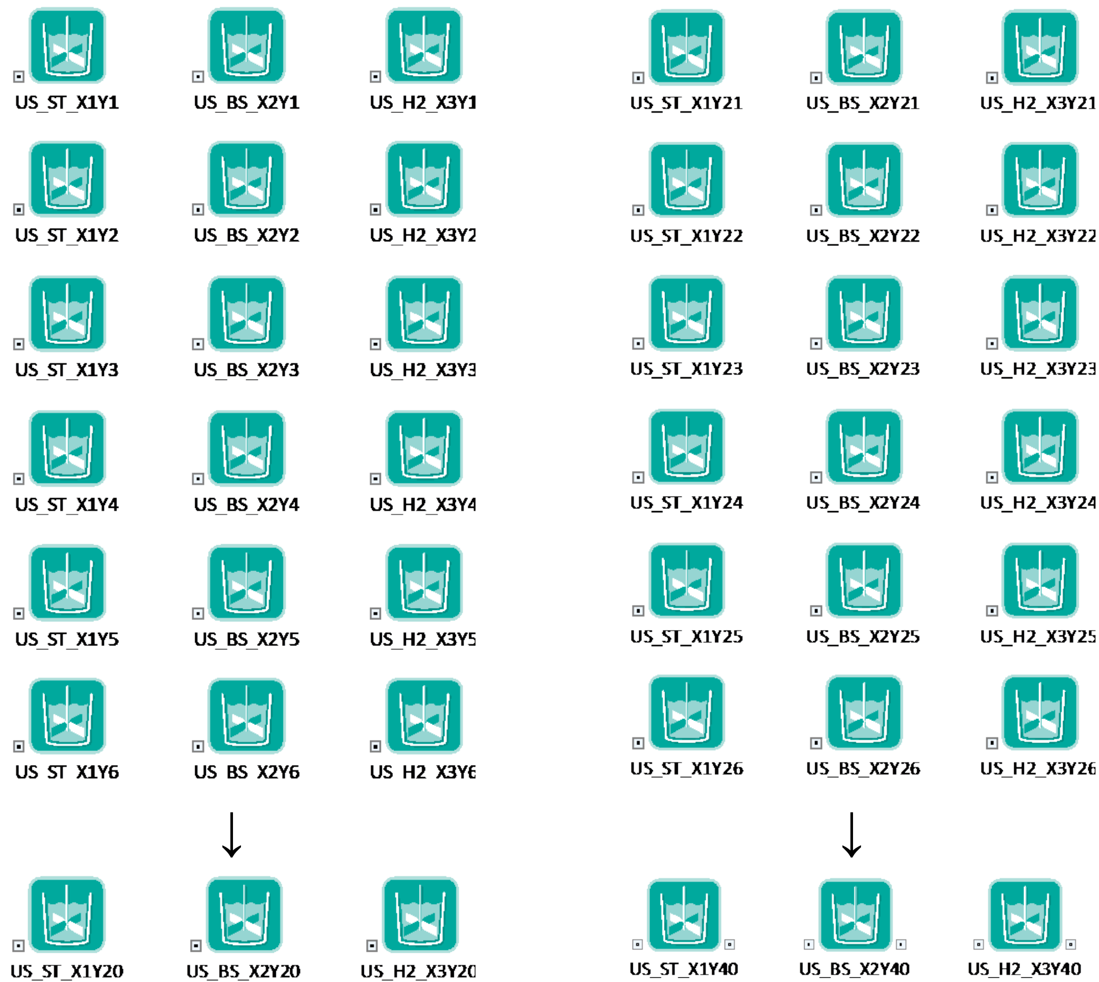

Figure 4-48. GoldSim slit trench upper sandy layer cell network (Subsided WZ).

The advective and diffusive species fluxes leave the SANDY2 cell network and enter the TAN_CLAY soil layer. The TAN_CLAY soil layer is represented by a cell network consisting of a column of 6 TC_ST, TC_BS and TC_H2 cell pathways. Each column of the TAN_CLAY layer cell pathways is connected through advective and diffusive flux links. There are only diffusive flux links between the TC_ST to TC_BS and TC_H2 to TC_BS pairs as explained in an earlier section. The widths of the TC_ST/H2 and TC_BS cell pathways are 20 ft and 10 ft, respectively. The length of the US_ST, US_BS and US_H2 are 556 ft, 656 ft and 100 ft, respectively. The height of the TC_ST, TC_H2 and TC_BS cell pathways are 2 ft/6 (0.3333 ft). The GoldSim slit trench tan clay layer cell network (Subsided WZ) is shown in Figure 4-49.

Figure 4-49. GoldSim slit trench tan clay layer cell network (Subsided WZ).

The advective and diffusive species fluxes leave the TAN_CLAY cell network and enter lower sandy layer (SANDY1). The SANDY1 soil layer is represented by a cell network consisting of a column of 16 LS_ST, LS_BS and LS_H2 cell pathways. Each column of the SANDY1 soil layer cell pathways is connected through advective and diffusive flux links. There are only diffusive flux links between the LS_ST to LS_BS and LS_H2 to LS_BS pairs as explained in an earlier section. The widths of the LS_ST/H2 and LS_BS cell pathways are 20 ft and 10 ft, respectively. The length of the LS_ST, LS_BS and LS_H2 are 556 ft, 656 ft and 100 ft, respectively. The height of the LS_ST, LS_H2 and LS_BS cell pathways are 10 ft/16 (0.625 ft). The GoldSim slit trench lower sandy layer cell network (Subsided WZ) is shown in Figure 4-50.

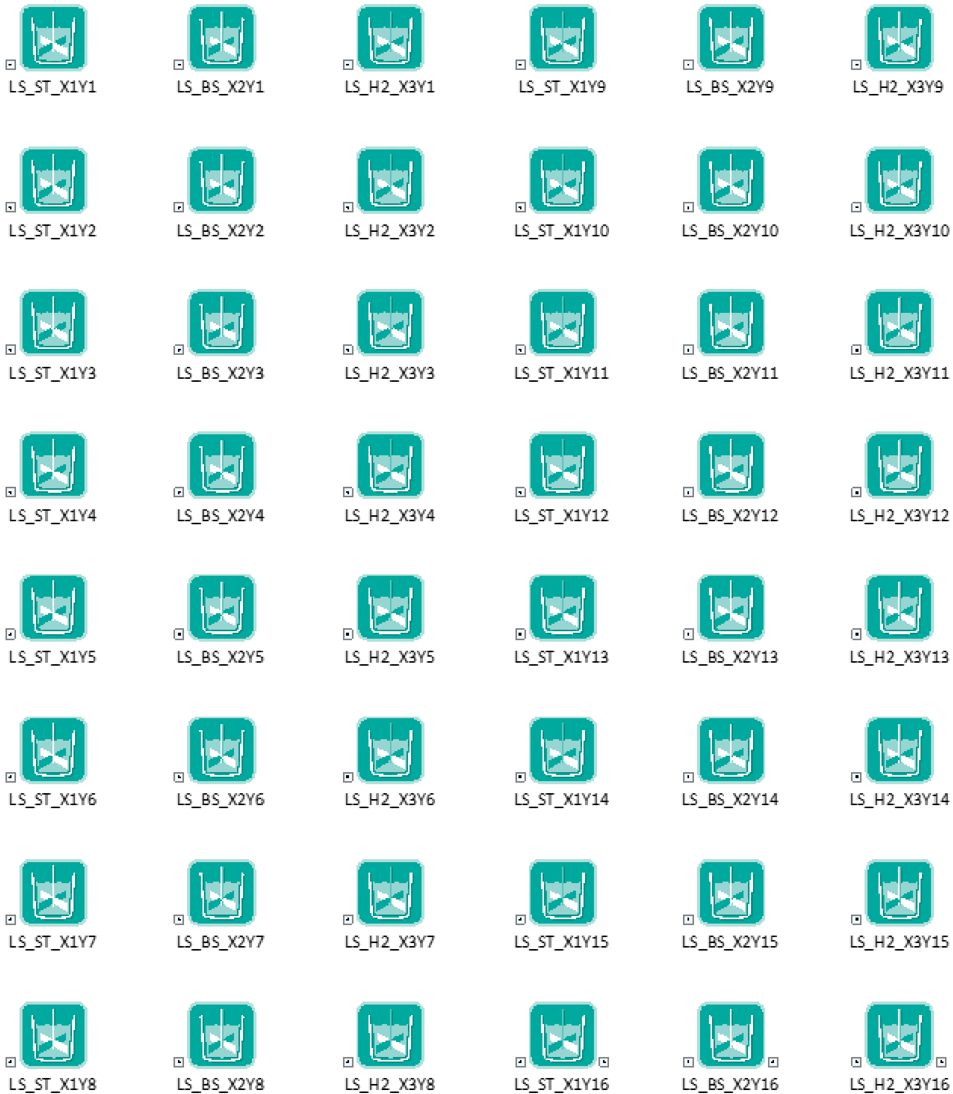

Figure 4-50. GoldSim slit trench lower sandy layer cell network (Subsided WZ).

The cell pathway properties for US_H2_X3Y1 are shown in Figure 4-51 and Figure 4-52. The data requirements of the lower vadose zone cell pathways are described in this section.

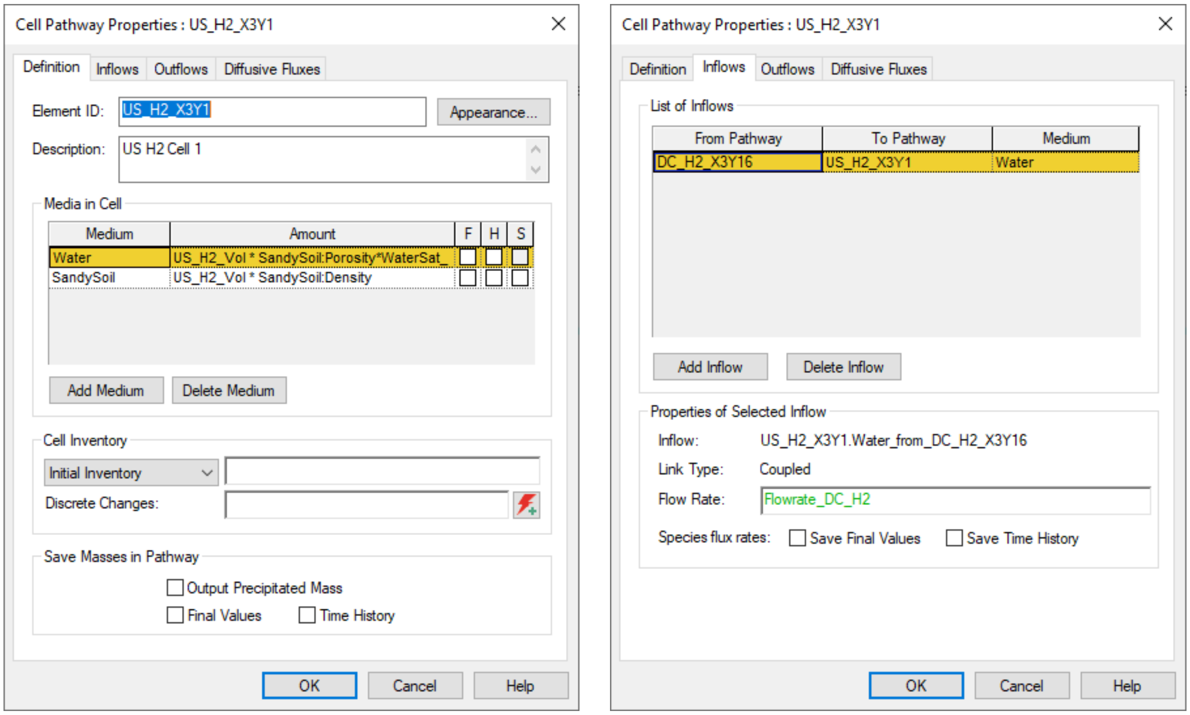

Figure 4-51. US_H2_X3Y1 cell pathway properties: Definition and Inflows.

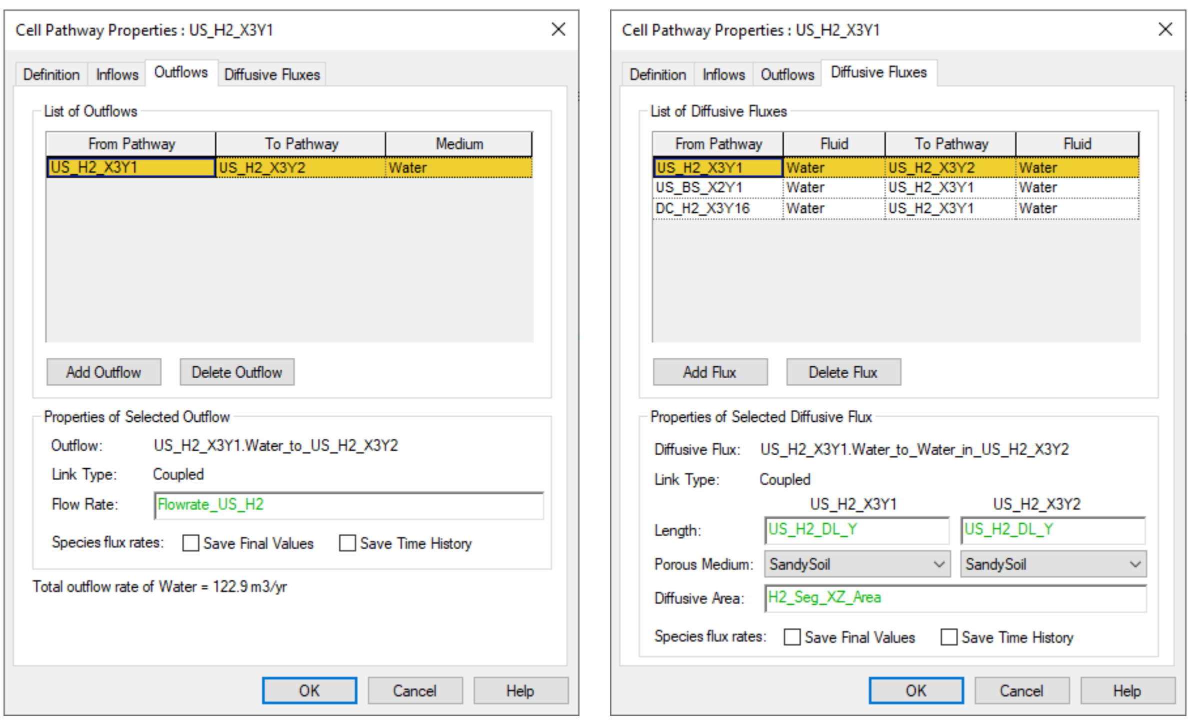

Figure 4-52. US_H2_X3Y1 cell pathway properties: Outflows and Diffusive Fluxes.

The ST06/ST Case11b water saturations in slit segment 5 (LVZ) are shown in Figure 4-53. The SANDY2, TAN_CLAY and SANDY1 water saturations are data inputs to the Saturation_US_ST (UpperSandyLayer), Saturation_TC_ST (TanClayLayer) and Saturation_LS_ST

(LowerSandyLayer) expression elements, respectively in the /Transport/VadoseZoneST/VadoseZone_Subsided container.

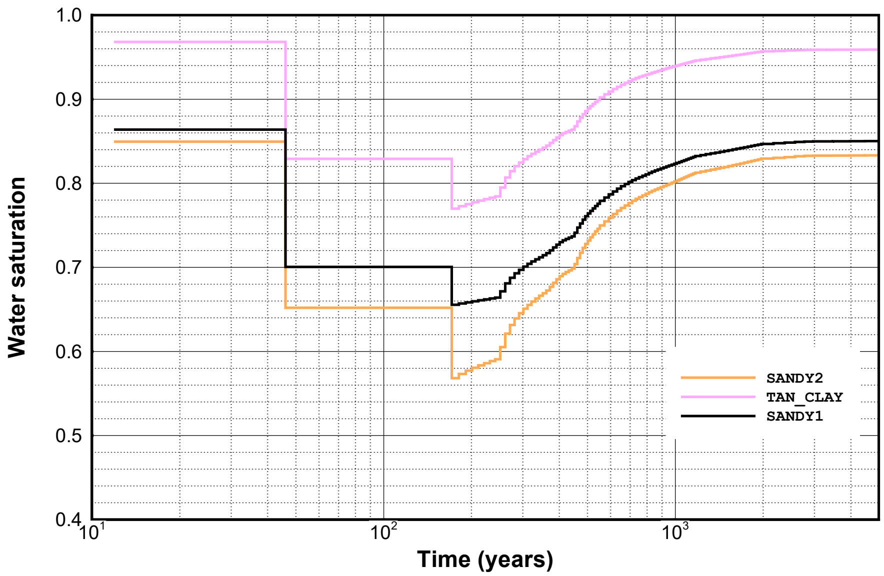

Figure 4-53. ST06/ST Case11b water saturations in slit segment 5 (LVZ).

The ST06/ST Case11b water saturations between slit segments 4 and 5 (LVZ) are shown in Figure 4-54. The SANDY2, TAN_CLAY and SANDY1 water saturations are data inputs to the Saturation_US_BS (UpperSandyLayer), Saturation_TC_BS (TanClayLayer) and Saturation_LS_BS (LowerSandyLayer) expression elements, respectively in the /Transport/VadoseZoneST/VadoseZone_Subsided container.

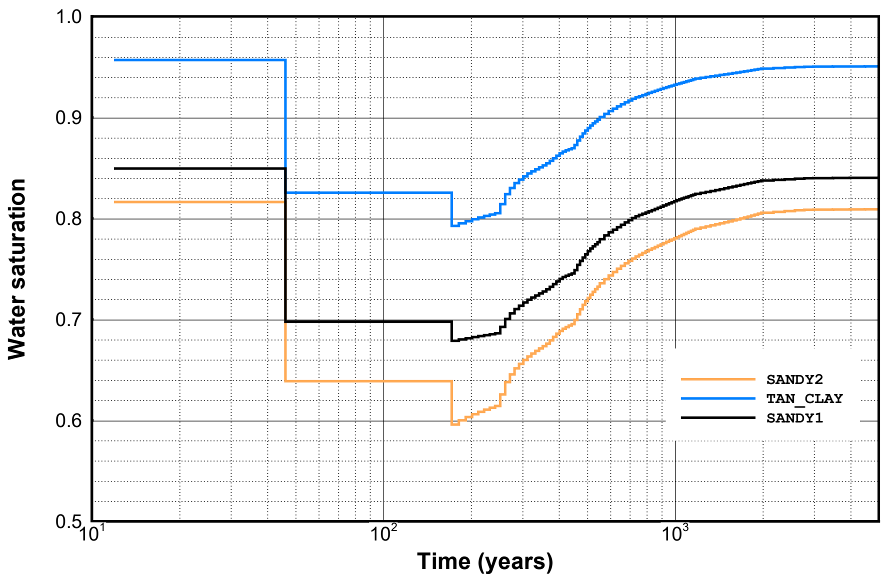

Figure 4-54. ST06/ST Case11b water saturations between slit segments 4 and 5 (LVZ).

The ST06/ST Case11b water saturations in H2 of slit segment 5 (LVZ) are shown in Figure 4-55. The SANDY2, TAN_CLAY and SANDY1 water saturations are data inputs to the Saturation_US_H2 (UpperSandyLayer), Saturation_TC_H2 (TanClayLayer) and Saturation_LS_H2 (LowerSandyLayer) expression elements, respectively in the /Transport/VadoseZoneST /VadoseZone_Subsided container.

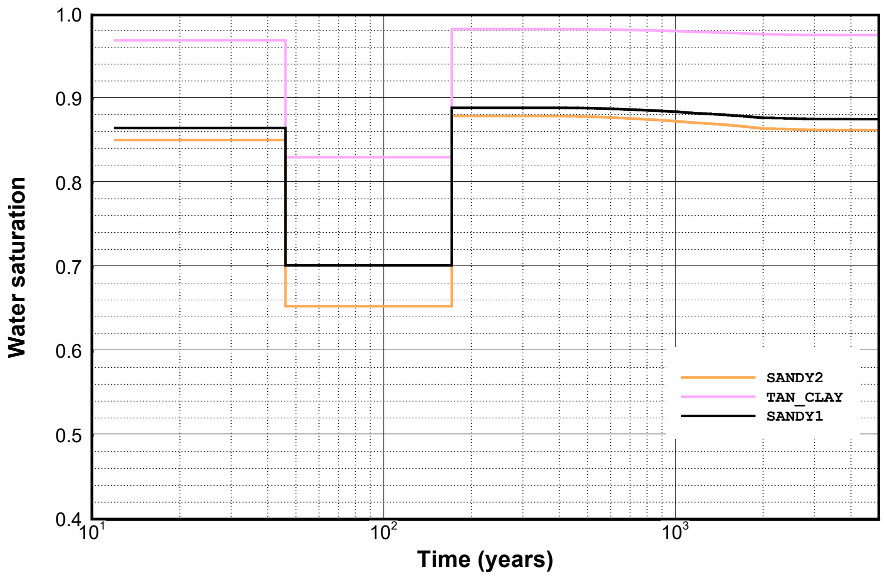

Figure 4-55. ST06/ST Case11b water saturations in H2 of slit segment 5 (LVZ).

5.0 GoldSim Model Benchmarking to PORFLOW

Total species fluxes (advective and diffusive) from the waste zone and to the water table were computed for comparison between the 3-D PORFLOW and simplified 1-D GoldSim vadose zone transport models. The GoldSim ET waste and vadose models span the entire footprint of the active disposal unit. The GoldSim ST waste and vadose models include intact and subsided single slit trench and non-waste segment models with 1/5 of the parent species inventories.

5.1 Flux from the Waste Zone

The total species fluxes from the GoldSim ET waste zone for Case01 is the sum of the advective and diffusive fluxes from WasteZone_Crushed container. The total species fluxes from the GoldSim ET waste zone for Case11b is the sum of the advective and diffusive fluxes from WasteZone_Crushed and WasteZone_Noncrushed containers.

The total species fluxes from the GoldSim ST waste zone for Case01 is 5 times the total fluxes from WasteZone_Intact container. The total species fluxes from the GoldSim ST waste zone for Case11b is the sum of the total fluxes from WasteZone_Intact and 4 times the total fluxes from the WasteZone_Subsided containers.

5.1.1 ET Case01 WZ Fluxes

The ST06/ET Case01 fluxes from the waste zone are shown in Figure 5-1 for C-14, H-3, I-129 and Np-237. The GoldSim model accurately simulates the flux from the WZ over the entire time period. The back diffusion from the DC_WASTE to the NDC_WASTE, following dynamic compaction of the WZ, is shown by the gap in values for C-14 and the Np-237 short-chain, between 171 and 350 years.

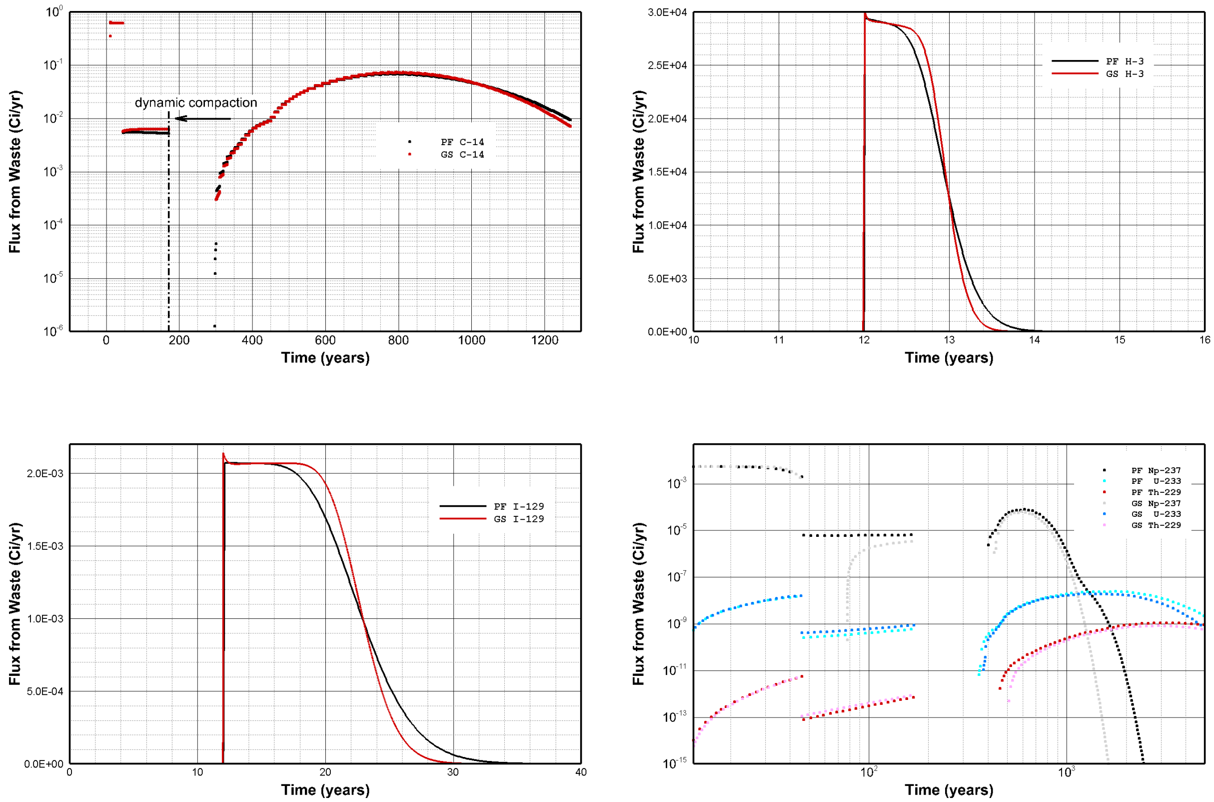

Figure 5-1. ST06/ET Case01 flux from the waste zone (C-14, H-3, I-129 and Np-237).

The ST06/ET Case01 fluxes from the waste zone are shown in Figure 5-2 for Sr-90, Tc-99, U-238 and Tracer. The GoldSim model accurately simulates the flux from the WZ over the entire time period. The back diffusion from the DC_WASTE to the NDC_WASTE, following dynamic compaction of the WZ, is shown by the gap in values for Sr-90 between 171 and 350 years.

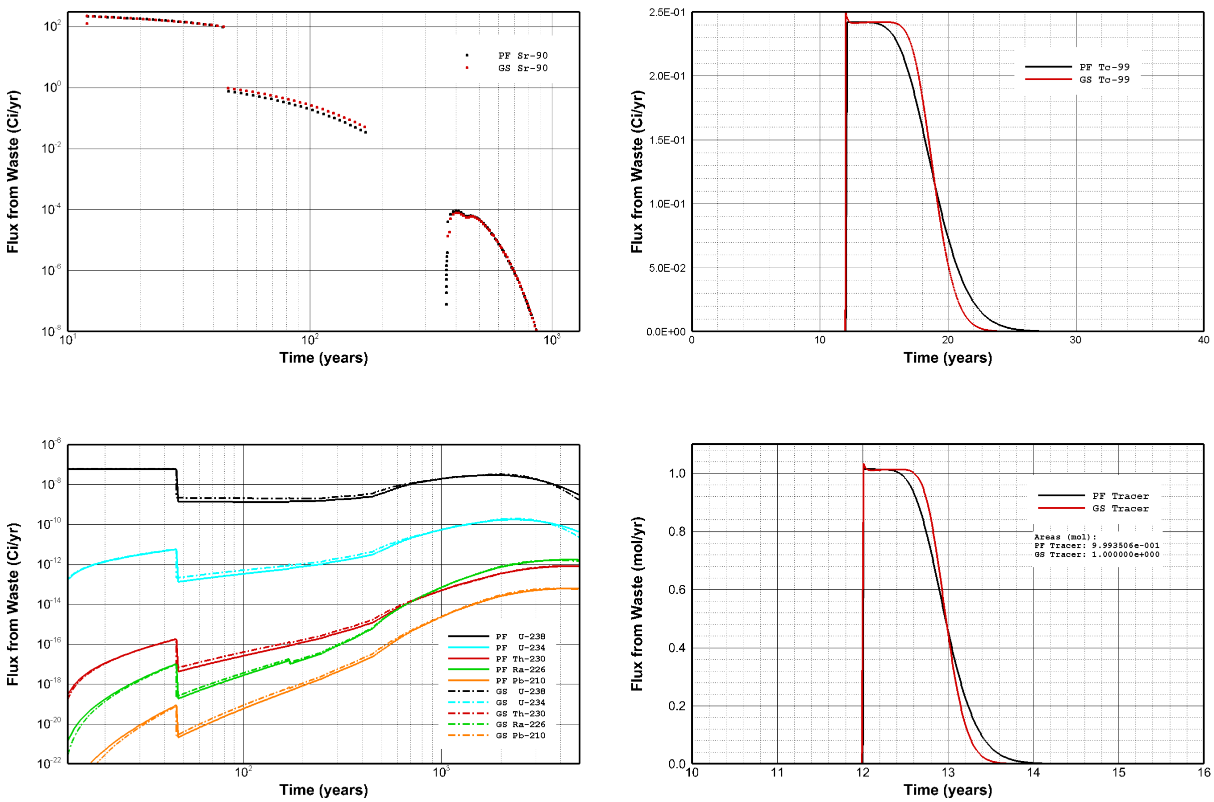

Figure 5-2. ST06/ET Case01 flux from the waste zone (Sr-90, Tc-99, U-238 and Tracer).

5.1.2 ET Case11b WZ Fluxes

The ST06/ET Case11b fluxes from the waste zone are shown in Figure 5-3 for C-14, H-3, I-129 and Np-237. The GoldSim and PORFLOW models show back diffusion and flux increase from the WZ following dynamic compaction and subsidence, respectively, for C-14. The back diffusion from the DC_WASTE to the NDC_WASTE, following dynamic compaction and subsidence of the WZ, is shown by the gap in values for the Np-237 short-chain between 171 and 350 years.

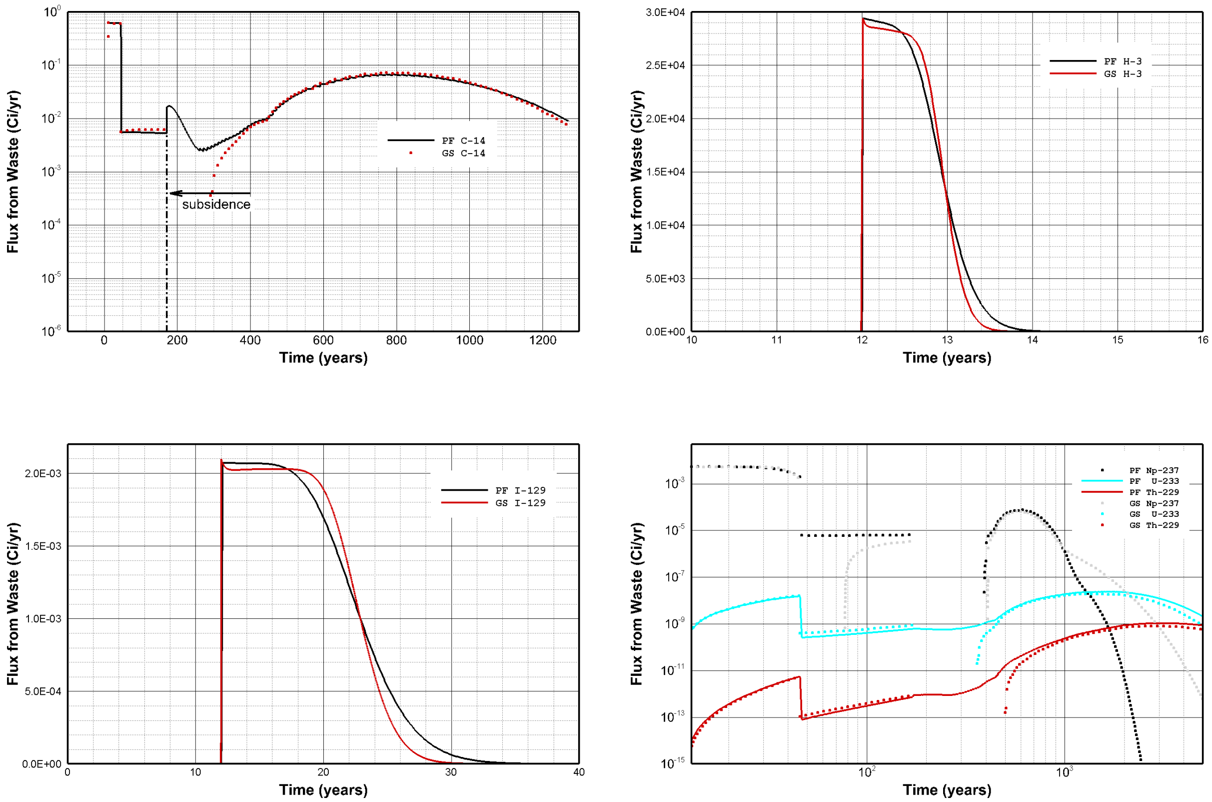

Figure 5-3. ST06/ET Case11b flux from the waste zone (C-14, H-3, I-129 and Np-237).

The ST06/ET Case11b fluxes from the waste zone are shown in Figure 5-4 for Sr-90, Tc-99, U-238 and Tracer. The back diffusion from the DC_WASTE to the NDC_WASTE, following dynamic compaction and subsidence of the WZ, is shown by the gap in values for Sr-90 between 171 and 350 years.

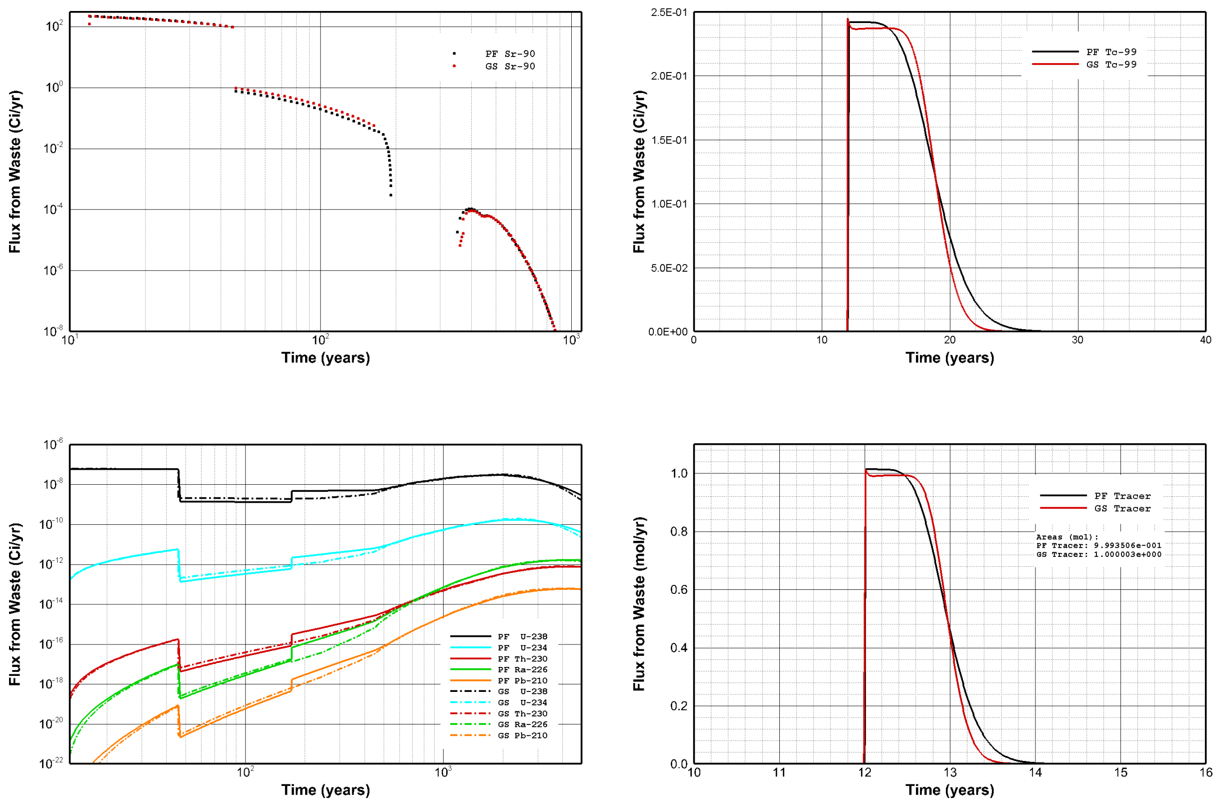

Figure 5-4. ST06/ET Case11b flux from the waste zone (Sr-90, Tc-99, U-238 and Tracer).

5.1.3 ST Case01 WZ Fluxes

The ST06/ST Case01 fluxes from the waste zone are shown in Figure 5-5 for C-14, H-3, I-129 and Np-237. The back diffusion from the DC_WASTE to the NDC_WASTE, following dynamic compaction of the WZ, is shown by the gap in values for C-14, Np-237 and Th-229 between 171 and 350 years. The GoldSim flux profiles from the WZ for H-3 and I-129 undulate in comparison to PORFLOW. This behavior is not understood at this time.

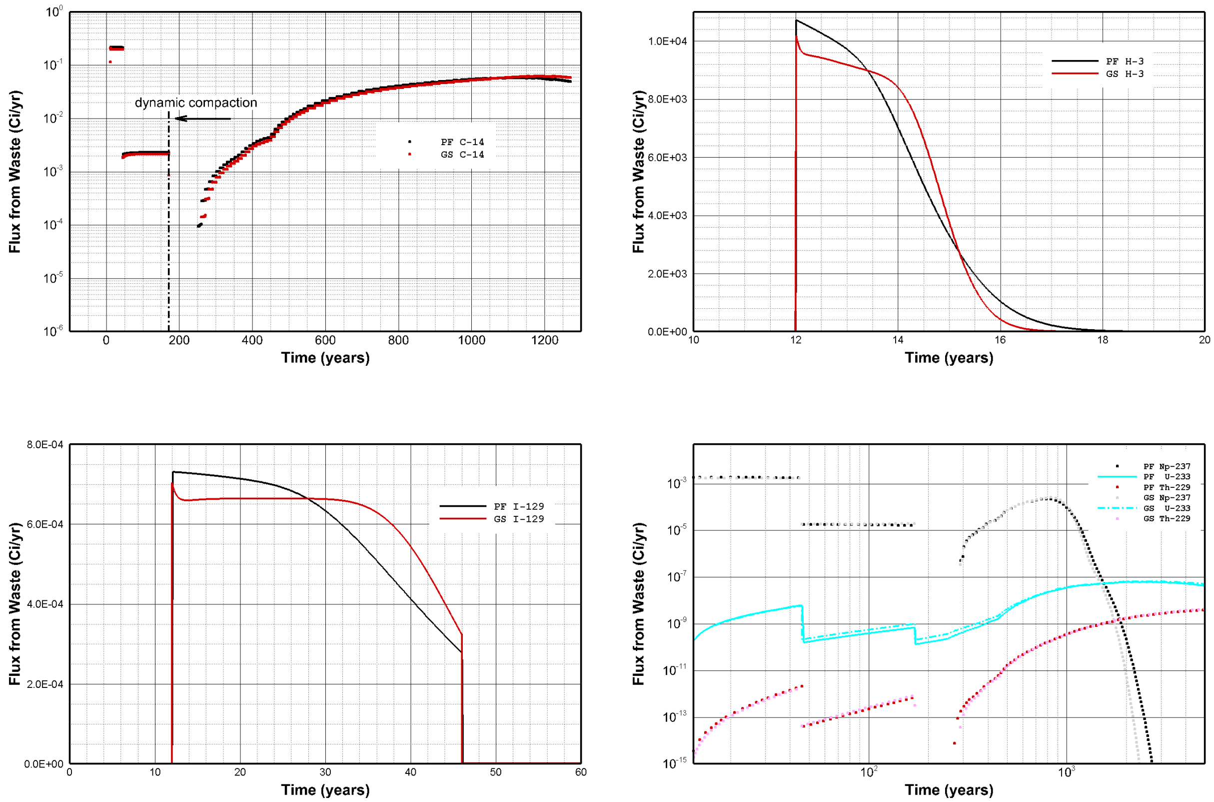

Figure 5-5. ST06/ST Case01 flux from the waste zone (C-14, H-3, I-129 and Np-237).

The ST06/ST Case01 fluxes from the waste zone are shown in Figure 5-6 for Sr-90, Tc-99, U-238 and Tracer. The back diffusion from the DC_WASTE to the NDC_WASTE, following dynamic compaction of the WZ, is shown by the gap in values for Sr-90 between 171 and 275 years. The GoldSim flux profiles from the WZ for Tc-99 and Tracer undulate in comparison to PORFLOW. This behavior is not understood at this time. The fluxes from the WZ for the U-238 short-chain show excellent agreement.

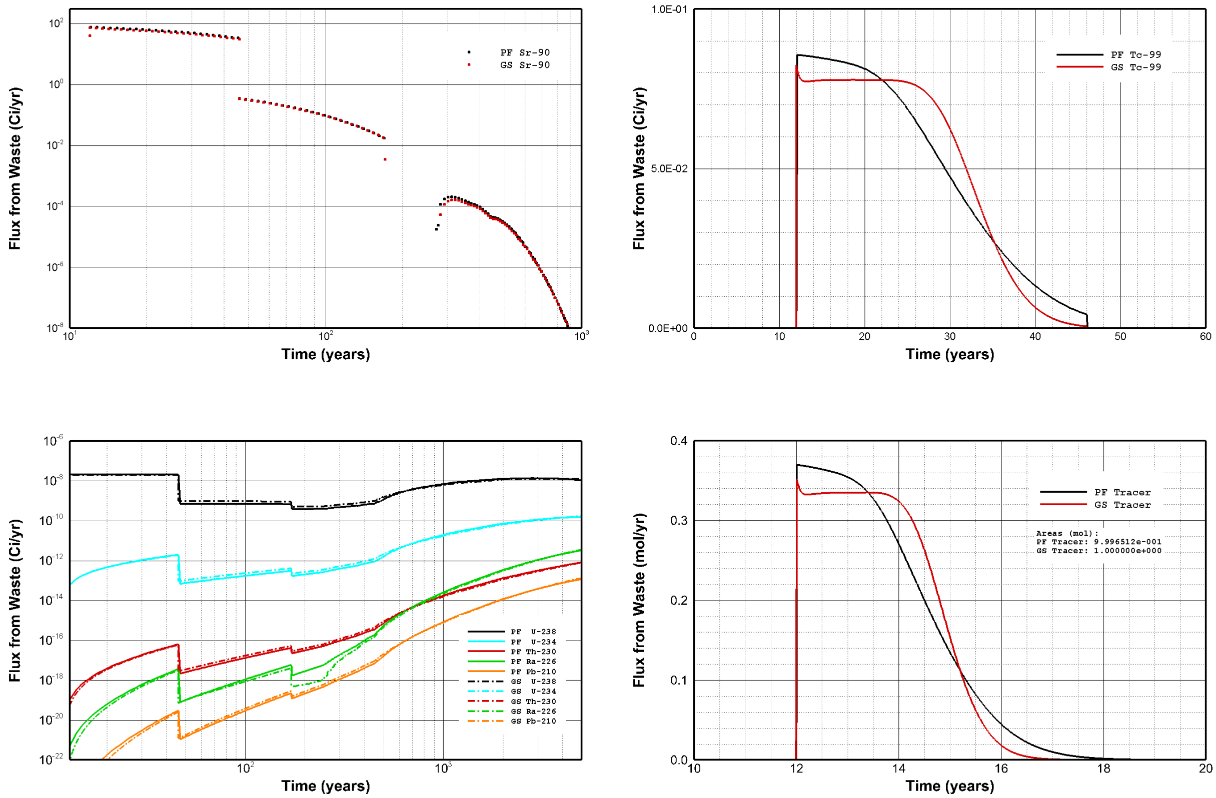

Figure 5-6. ST06/ST Case01 flux from the waste zone (Sr-90, Tc-99, U-238 and Tracer).

5.1.4 ST Case11b WZ Fluxes

The ST06/ST Case11b fluxes from the waste zone are shown in Figure 5-7 for C-14, H-3, I-129 and Np-237. The increase in flux from the WZ following subsidence is in good agreement between PORFLOW and GoldSim for C-14 and the Np-237 short-chain. The GoldSim flux profiles from the WZ for H-3 and I-129 undulate in comparison to PORFLOW. This behavior is not understood at this time.

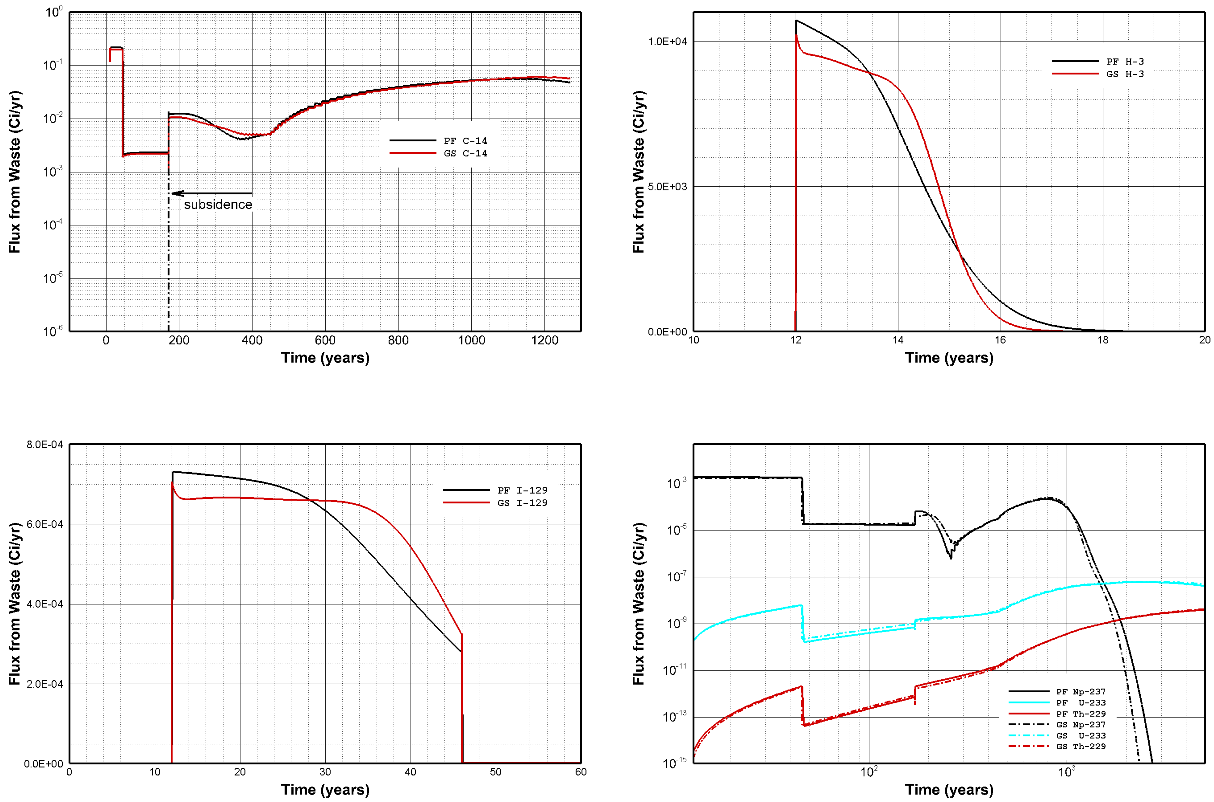

Figure 5-7. ST06/ST Case11b flux from the waste zone (C-14, H-3, I-129 and Np-237).

The ST06/ST Case11b fluxes from the waste zone are shown in Figure 5-8 for Sr-90, Tc-99, U-238 and Tracer. The increase in flux from the WZ following subsidence is in good agreement between PORFLOW and GoldSim for Sr-90 and the U-238 short-chain. The GoldSim flux profiles from the WZ for Tc-99 and Tracer undulate in comparison to PORFLOW. This behavior is not understood at this time.

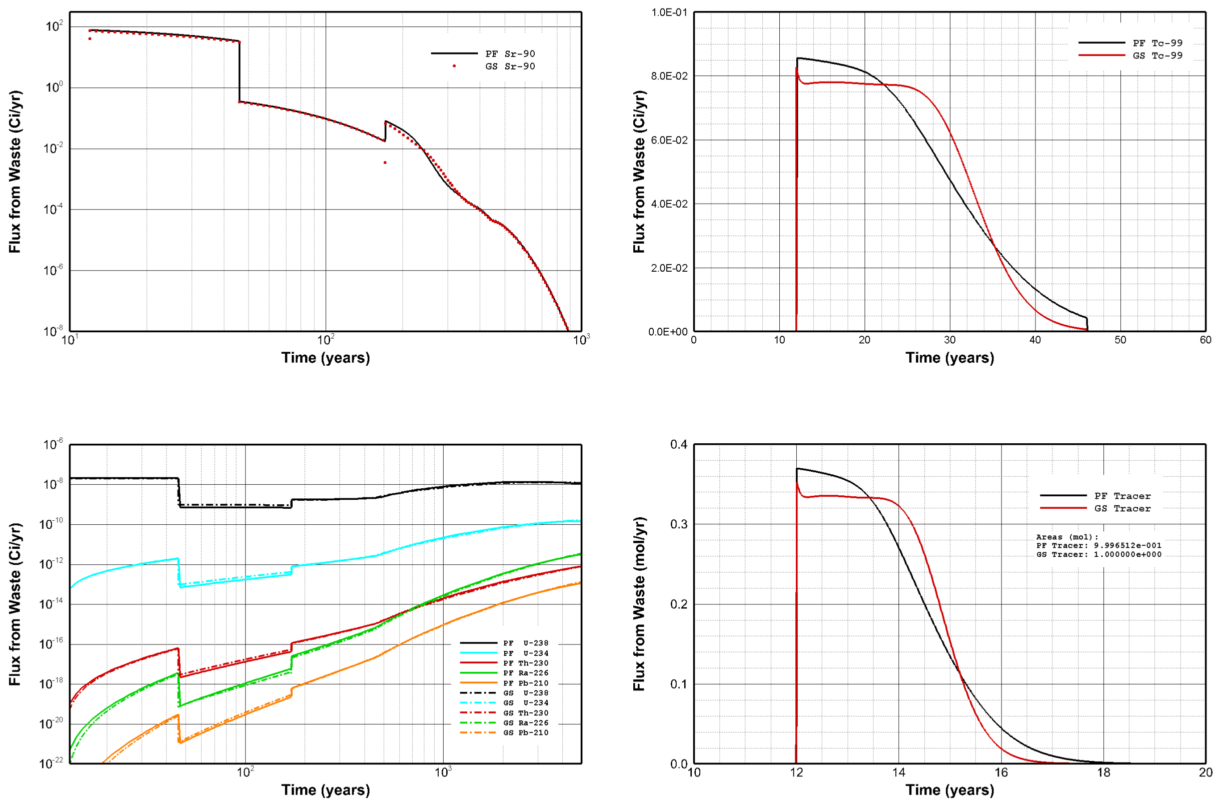

Figure 5-8. ST06/ST Case11b flux from the waste zone (Sr-90, Tc-99, U-238 and Tracer).

5.2 Flux to the Water Table

The total species fluxes from the GoldSim ET vadose zone for Case01 is the total fluxes from VadoseZone_Crushed container. The total species fluxes from the GoldSim ET vadose zone for Case11b is the sum of the total fluxes from VadoseZone_Crushed and VadoseZone_Noncrushed containers.

The total species fluxes from the GoldSim ST vadose zone for Case01 is 5 times the total fluxes from VadoseZone_Intact container. The total species fluxes from the GoldSim ST vadose zone for Case11b is the sum of the total fluxes from VadoseZone_Intact and 4 times the total fluxes from the VadoseZone_Subsided containers.

5.2.1 ET Case01 VZ Fluxes

The ST06/ET Case01 fluxes to the water table are shown in Figure 5-9 for C-14, H-3, I-129 and Np-237. The fluxes to the water table for C-14 show excellent agreement. Fluxes to the water table in GoldSim are orders of magnitude below PORFLOW after placement of the interim and final covers for I-129 and the Np-237 short-chain. As the final cover degrades, the fluxes from both models converge. The differences in peak flux to the water table for H-3 between models are probably due to mesh and time step refinement and numerical diffusion.

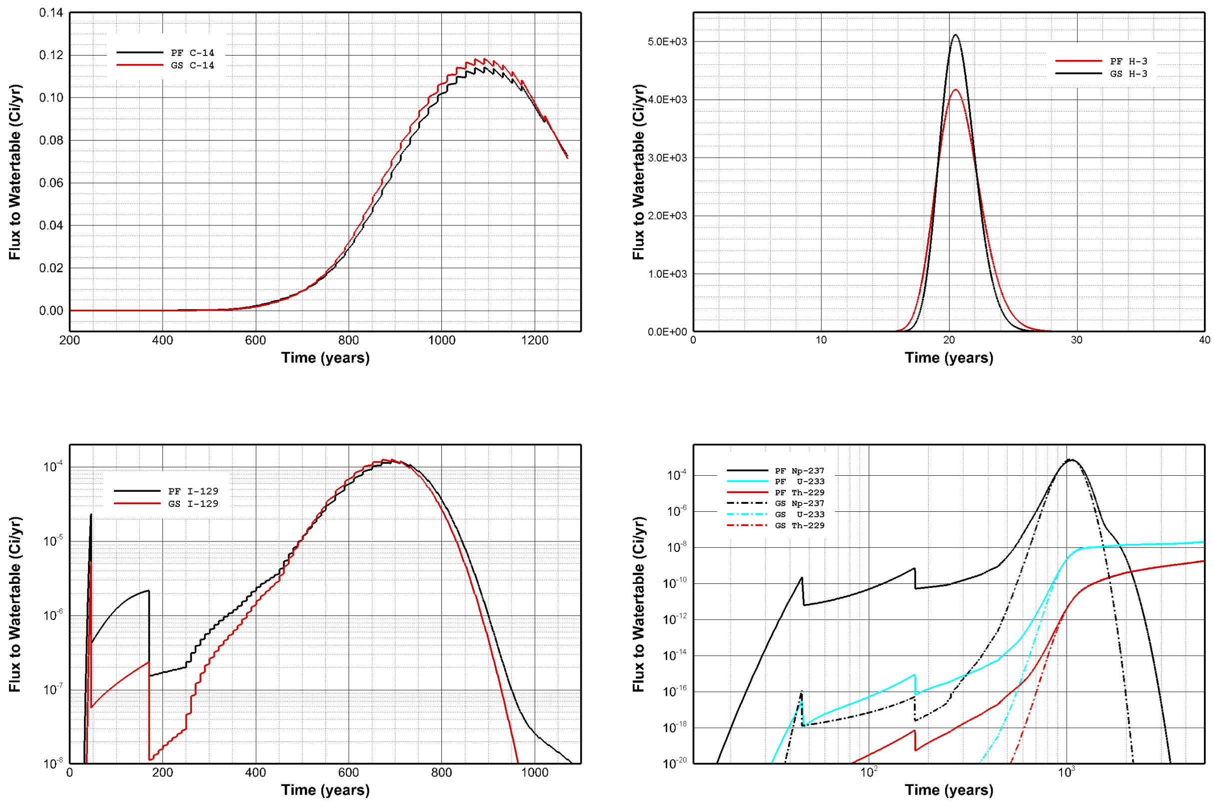

Figure 5-9. ST06/ET Case01 flux to the water table (C-14, H-3, I-129 and Np-237).

The ST06/ET Case01 fluxes to the water table are shown in Figure 5-10 for Sr-90, Tc-99, U-238 and Tracer. The Sr-90 GoldSim model does not capture the spike in the flux between 46 and 171 years. The Sr-90 peak fluxes after 1000 years are different in magnitude and lag each other. Examination of PORFLOW slices through the center of the domain and at the water table reveal spikes in concentrations at the east and west edges of the ET footprint. These edges are near the 40-foot overhang of the final cover where intact infiltration can enter the edges of the waste footprint and advective fluxes to the water table are faster than in the interior core of the footprint. The fluxes to the water table for Tc-99 are in good agreement between both models. Fluxes to the water table in GoldSim are orders of magnitude below PORFLOW after placement of the interim and final covers for the U-238 short-chain. As the final cover degrades, the fluxes from both models converge. The differences in peak flux to the water table for H-3 between models are probably due to mesh and time step refinement and numerical diffusion.

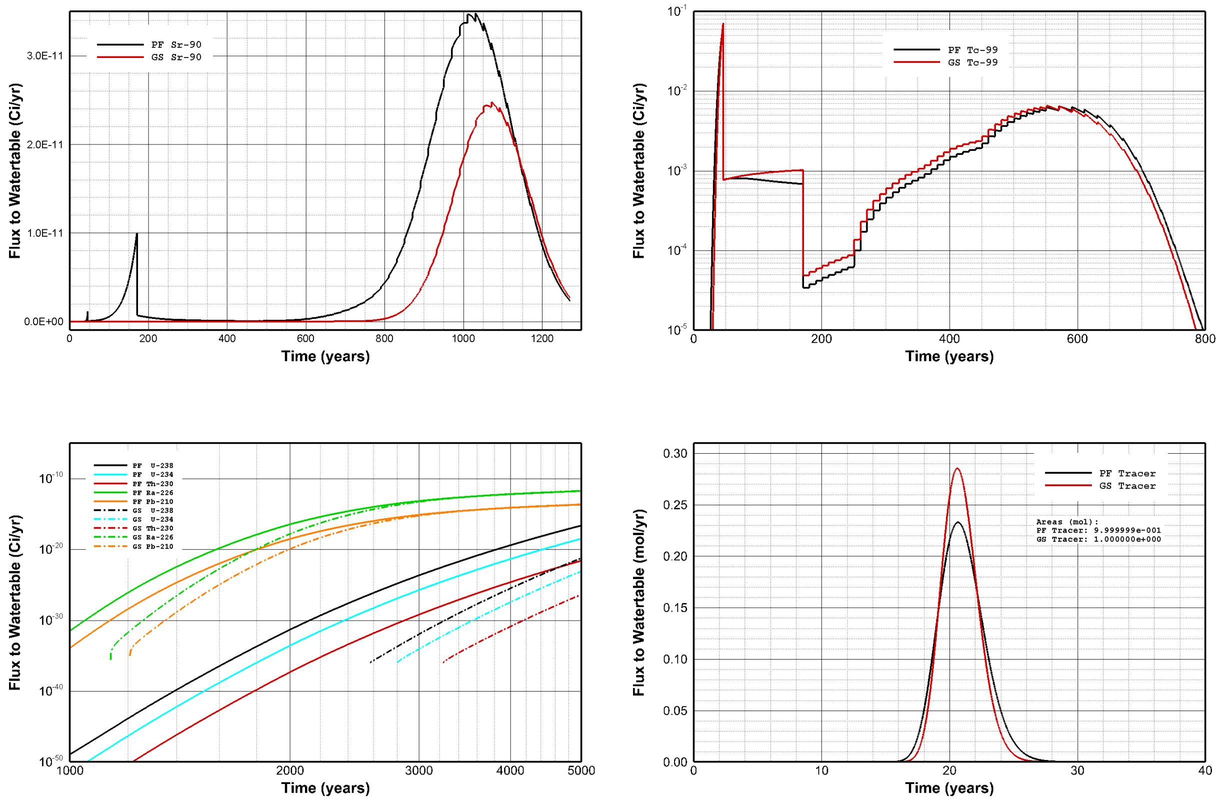

Figure 5-10. ST06/ET Case01 flux to the water table (Sr-90, Tc-99, U-238 and Tracer).

5.2.2 ET Case11b VZ Fluxes

The ST06/ET Case11b fluxes to the water table are shown in Figure 5-11 for C-14, H-3, I-129 and Np-237. The C-14 flux to the WT tracks the response in PORFLOW except for the period immediately following dynamic compaction and installation of the final cover. Fluxes to the water table in GoldSim are orders of magnitude below PORFLOW prior to dynamic compaction and subsidence for I-129 and the Np-237 short-chain. The increase in fluxes to the WT at subsidence in GoldSim are orders of magnitude below PORFLOW for the Np-237 short-chain and I-129. The Np-237 short-chain flux to the WT in GoldSim tracks the response of PORFLOW following subsidence. As the final cover degrades, the fluxes from both models converge. The differences in peak flux to the water table for H-3 between models are probably due to mesh and time step refinement and numerical diffusion.

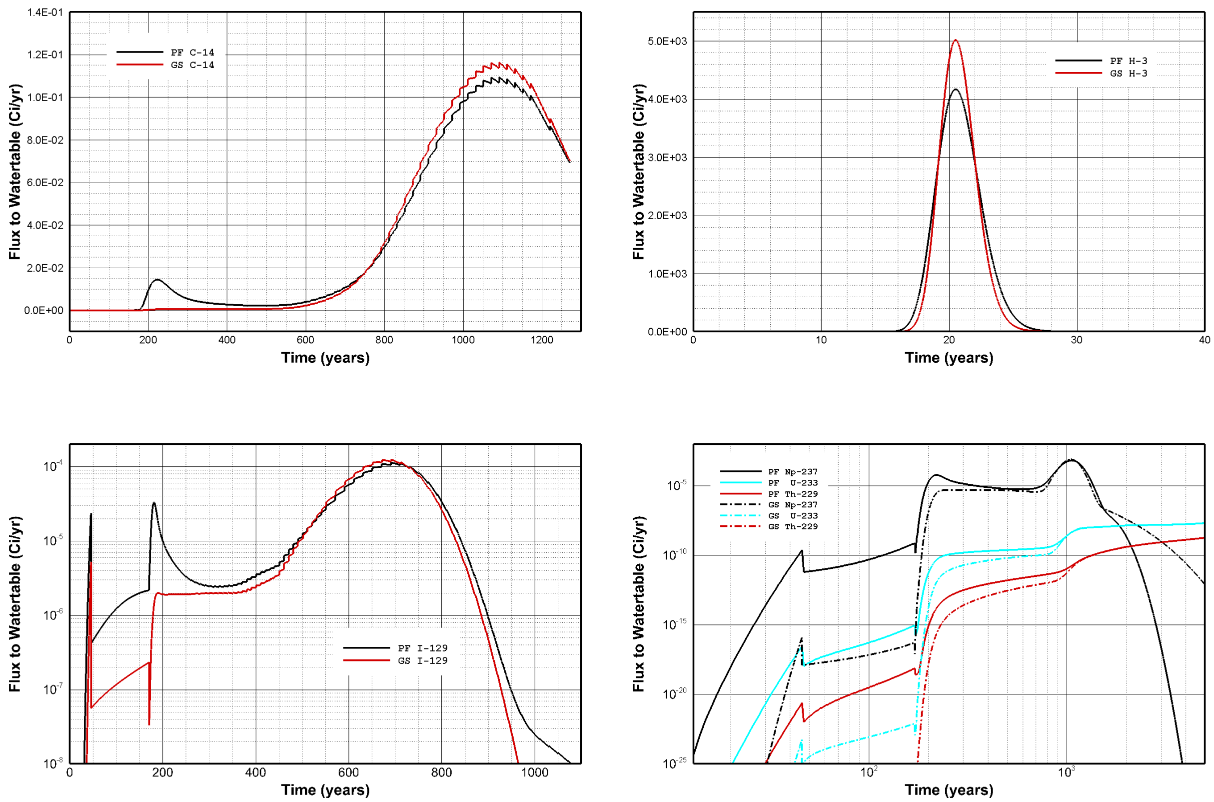

Figure 5-11. ST06/ET Case11b flux to the water table (C-14, H-3, I-129 and Np-237).

The ST06/ET Case11b fluxes to the water table are shown in Figure 5-12 for Sr-90, Tc-99, U-238 and Tracer. Fluxes to the water table in GoldSim are orders of magnitude below PORFLOW prior to dynamic compaction and subsidence for Sr-90. The fluxes to the WT following subsidence in GoldSim track below PORFLOW fluxes for Sr-90. The fluxes to the water table for Tc-99 in GoldSim increase but are orders of magnitude below PORFLOW after subsidence. Fluxes to the water table in GoldSim are orders of magnitude below PORFLOW after placement of the interim and final covers for the U-238 short-chain. Note that prior to cover placement, the U-238 short-chain concentrations are below the trackable limit for GoldSim. As the final cover degrades, the fluxes from both models converge. The differences in peak flux to the water table for Tracer between models are probably due to mesh and time step refinement and numerical diffusion.

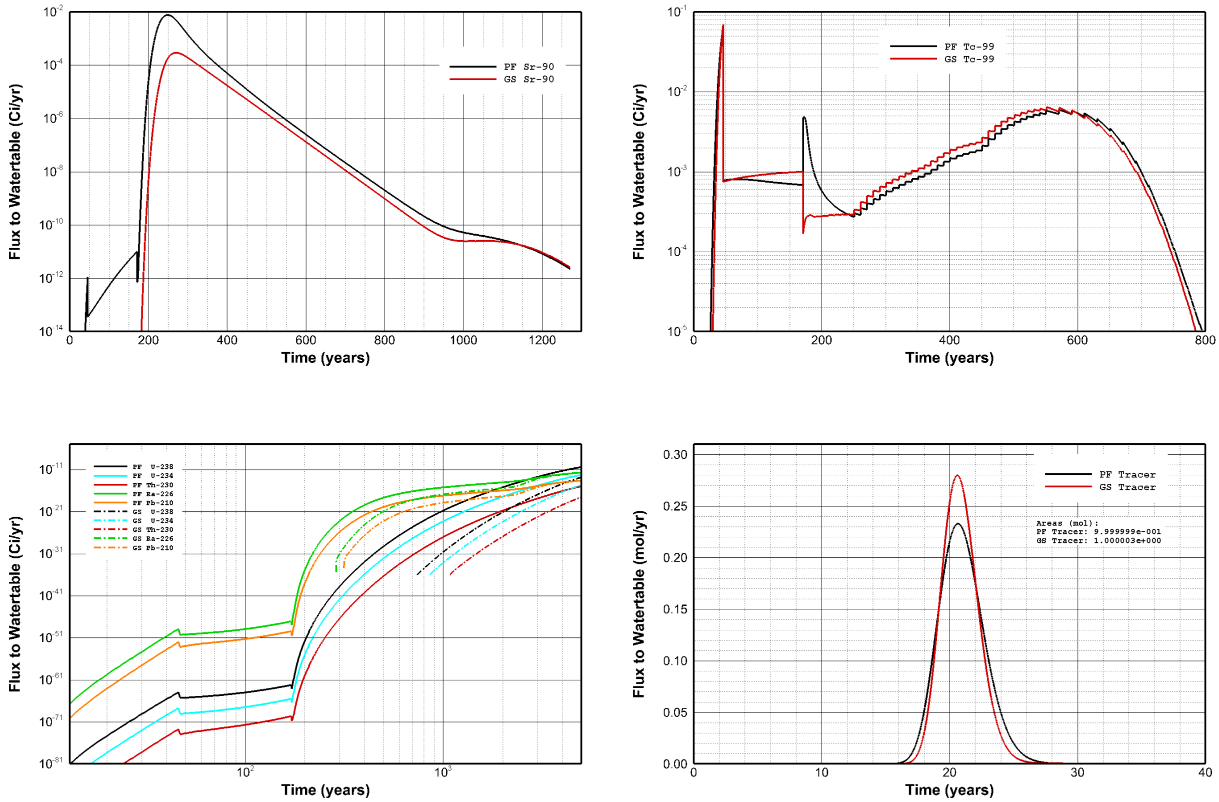

Figure 5-12. ST06/ET Case11b flux to the water table (Sr-90, Tc-99, U-238 and Tracer).

5.2.3 ST Case01 VZ Fluxes

The ST06/ST Case01 fluxes to the water table are shown in Figure 5-13 for C-14, H-3, I-129 and Np-237. Fluxes to the water table in GoldSim are orders of magnitude below PORFLOW after placement of the interim and final covers for C-14, I-129 (order of magnitude with cross-over) and the Np-237 short-chain. As the final cover degrades, the fluxes from both models converge. The differences in peak flux to the water table for H-3 between models are probably due to mesh and time step refinement and numerical diffusion.

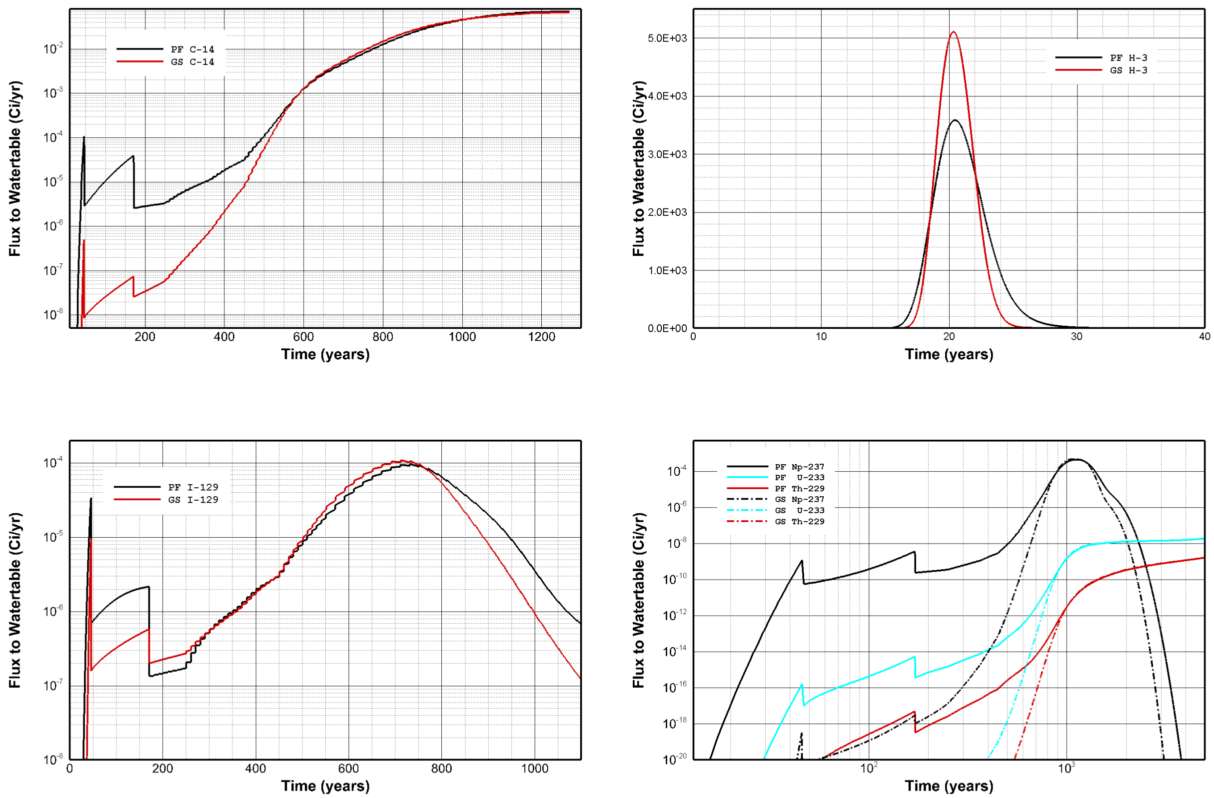

Figure 5-13. ST06/ST Case01 flux to the water table (C-14, H-3, I-129 and Np-237).

The ST06/ST Case01 fluxes to the water table are shown in Figure 5-14 for Sr-90, Tc-99, U-238 and Tracer. The Sr-90 GoldSim model does not capture the spike in the flux between 46 and 171 years. The Sr-90 peak fluxes after 1000 years are different in magnitude and lag each other. Examination of PORFLOW slices through the center of the domain and at the water table reveal spikes in concentrations at the east and west edges of the ST footprint. These edges are near the 40-foot overhang of the final cover where intact infiltration can enter the edges of the waste footprint and advective fluxes to the water table are faster than in the interior core of the footprint. The fluxes to the water table in GoldSim are higher than PORFLOW for the first 650 years for Tc-99. Fluxes to the water table in GoldSim are orders of magnitude below PORFLOW after placement of the interim and final covers for the U-238 short-chain. As the final cover degrades, the fluxes from both models converge. The differences in peak flux to the water table for Tracer between models are probably due to mesh and time step refinement and numerical diffusion.

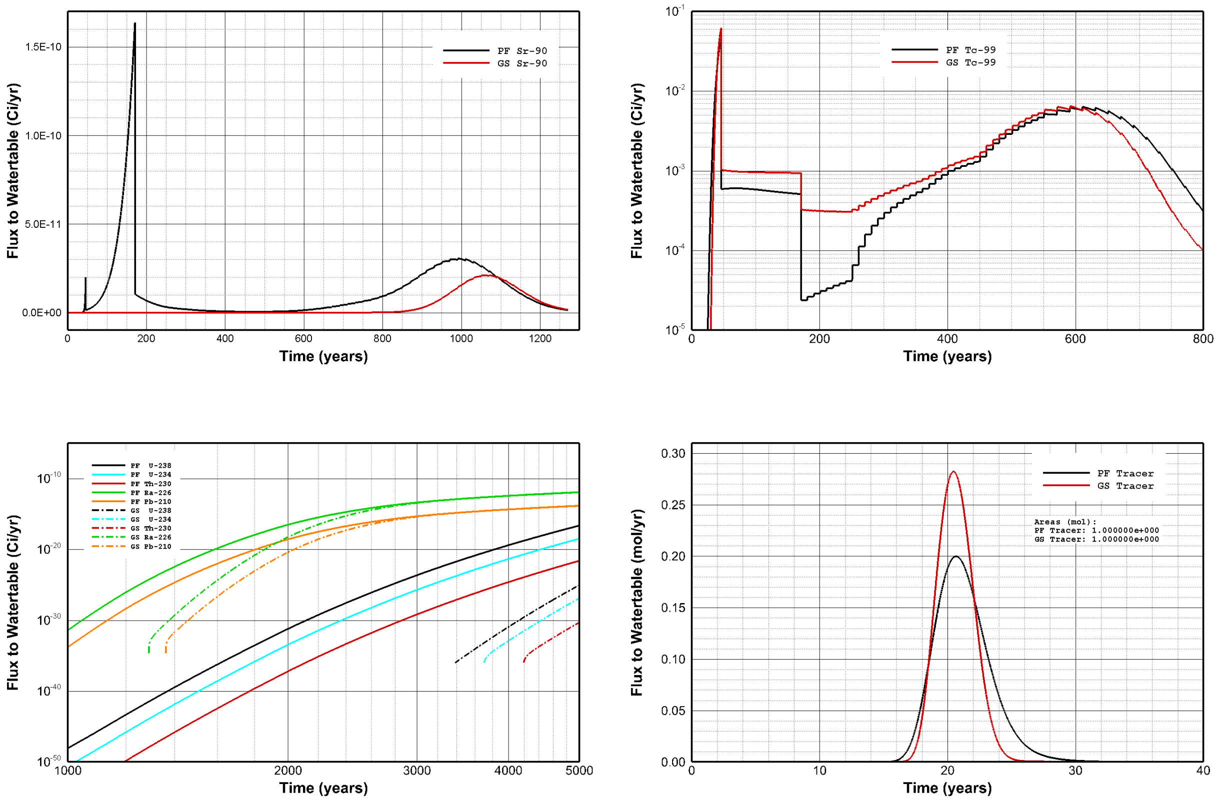

Figure 5-14. ST06/ST Case01 flux to the water table (Sr-90, Tc-99, U-238 and Tracer).

5.2.4 ST Case11b VZ Fluxes

The ST06/ST Case11b fluxes to the water table are shown in Figure 5-15 for C-14, H-3, I-129 and Np-237. Fluxes to the water table in GoldSim are orders of magnitude below PORFLOW prior to dynamic compaction and subsidence for C-14, I-129 and the Np-237 short-chain. The fluxes to the WT following subsidence in GoldSim track the PORFLOW fluxes for C-14, I-129 and the Np-237 short-chain. The differences in peak flux to the water table for H-3 between models are probably due to mesh and time step refinement and numerical diffusion.

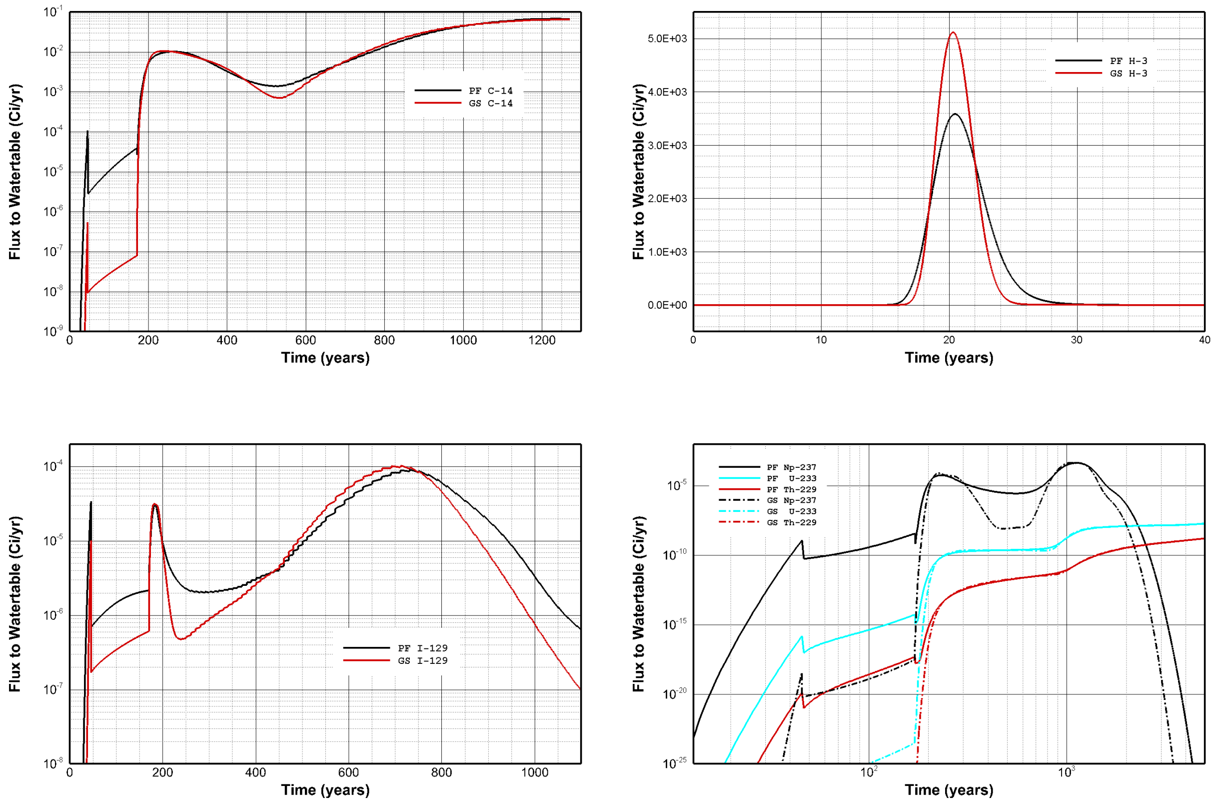

Figure 5-15. ST06/ST Case11b flux to the water table (C-14, H-3, I-129 and Np-237).

The ST06/ST Case11b fluxes to the water table are shown in Figure 5-16 for Sr-90, Tc-99, U-238 and Tracer. Fluxes to the water table in GoldSim are orders of magnitude below PORFLOW prior to dynamic compaction and subsidence for Sr-90. The fluxes to the WT following subsidence in GoldSim track the PORFLOW fluxes for Sr-90. The fluxes to the water table for Tc-99 in GoldSim track above the PORFLOW fluxes before and after subsidence to the peak value at 600 years. Fluxes to the water table in GoldSim are orders of magnitude below PORFLOW after placement of the interim and final covers for the U-238 short-chain. As the final cover degrades, the fluxes from both models converge. The differences in peak flux to the water table for Tracer between models are probably due to mesh and time step refinement and numerical diffusion.

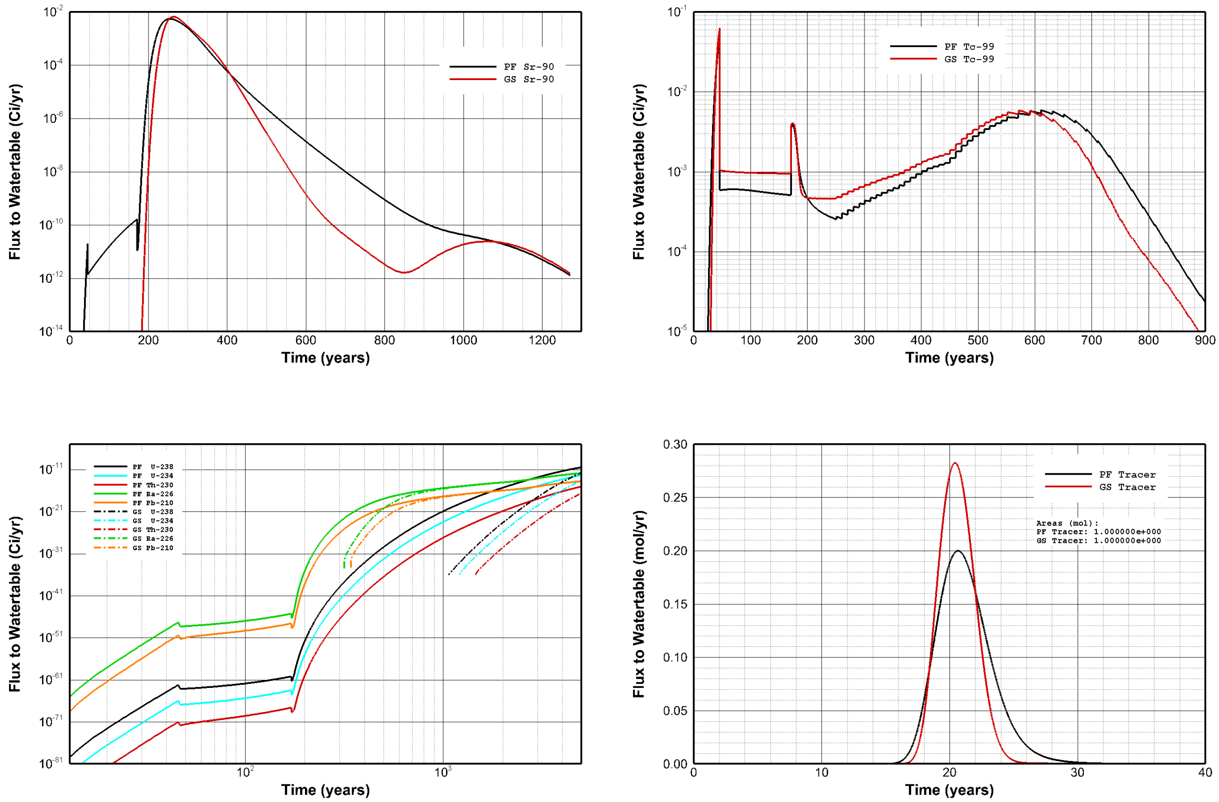

Figure 5-16. ST06/ST Case11b flux to the water table (Sr-90, Tc-99, U-238 and Tracer).

6.0 Summary and Conclusions

This report documents the development and benchmarking of the ELLWF GoldSim ET and ST vadose zone models. GoldSim cell and cell network models were developed to model the transport of radionuclides from the waste zone within the ET and ST footprint through the vadose zone to the water table using the ST06 hydrostratigraphy. The model calculates advective and diffusive fluxes for parent and daughter radionuclides and a tracer. During the development of the GoldSim vadose zone model, results from the PORFLOW 3D ET and ST vadose zone models were postprocessed to generate soil layer Darcy velocities and water saturations as input to the GoldSim models.

Results from PORFLOW transport simulations were used to benchmark the GoldSim model. Complete results from this code-to-code benchmarking are provided in Section 5.0 of this report. GoldSim model results were found to be comparable to those obtained by PORFLOW 3D models given the limitations of 1D GoldSim transport models. These results are for benchmarking only, no calibration was performed, reassessments will be made when the GoldSim ET and ST vadose zone models are be connected to the GoldSim aquifer zone model.

A comparison of PORFLOW and GoldSim peak fluxes to the water table and peak times for ET Case01 are shown prior to and after dynamic compaction in Table 6-1 and Table 6-2, respectively.

Table 6-1. Comparison of PORFLOW and GoldSim peak fluxes to the water table and peak times for ET Case01 (T ≤ 171 years).

	PORFLOW		GoldSim		Ratio	
	Max Flux	Max Time	Max Flux	Max Time	GoldSim/PORFLOW	
Nuclides	Ci/yr	Year	Ci/yr	Year	Ci/Ci	yr/yr
C-14	5.304E-05	46	6.582E-07	46	1.24E-02	1.00
H-3	4.169E+03	21	5.113E+03	21	1.23E+00	1.00
I-129	2.366E-05	46	5.331E-06	46	2.25E-01	1.00
Np-237	7.465E-10	171	1.242E-16	46	1.66E-07	0.27
U-233	9.421E-16	171	8.224E-23	171	8.73E-08	1.00
Th-229	7.595E-19	171	8.092E-26	171	1.07E-07	1.00
Sr-90	9.963E-12	171	5.964E-20	46	5.99E-09	0.27
Tc-99	6.244E-02	46	7.130E-02	46	1.14E+00	1.00
U-238	5.774E-63	171	< sp			
U-234	3.045E-66	171	< sp			
Th-230	2.208E-70	171	< sp			
Ra-226	7.913E-48	171	< sp			
Pb-210	3.574E-50	171	< sp			
	mol/yr		**mol/yr**			
Tracer	2.329E-01	21	2.852E-01	21	1.22E+00	1.00

Note: <sp – lower than single precision

Table 6-2. Comparison of PORFLOW and GoldSim peak fluxes to the water table and peak times for ET Case01 (T > 171 years).

	PORFLOW		GoldSim		Ratio	
	Max Flux	Max Time	Max Flux	Max Time	GoldSim/PORFLOW	
Nuclides	Ci/yr	Year	Ci/yr	Year	Ci/Ci	yr/yr
C-14	1.143E-01	1092	1.183E-01	1092	1.04E+00	1.00
H-3	7.123E-17	171	0.000E+00		0.00E+00	0.00
I-129	1.202E-04	691	1.265E-04	692	1.05E+00	1.00
Np-237	6.971E-04	1072	7.977E-04	1052	1.14E+00	0.98
U-233	2.045E-08	5000	2.084E-08	5000	1.02E+00	1.00
Th-229	1.806E-09	5000	1.838E-09	5000	1.02E+00	1.00
Sr-90	3.478E-11	1031	2.475E-11	1072	7.12E-01	1.04
Tc-99	6.449E-03	571	6.594E-03	552	1.02E+00	0.97
U-238	2.322E-17	5000	5.851E-22	5000	2.52E-05	1.00
U-234	3.261E-19	5000	8.187E-24	5000	2.51E-05	1.00
Th-230	2.529E-22	5000	4.271E-27	5000	1.69E-05	1.00
Ra-226	1.714E-12	5000	1.803E-12	5000	1.05E+00	1.00
Pb-210	2.105E-14	5000	2.215E-14	5000	1.05E+00	1.00
	mol/yr		mol/yr			
Tracer	8.153E-16	471	0.000E+00			

A comparison of PORFLOW and GoldSim peak fluxes to the water table and peak times for ET Case11b are shown prior to and after dynamic compaction and subsidence in Table 6-3 and Table 6-4, respectively.

Table 6-3. Comparison of PORFLOW and GoldSim peak fluxes to the water table and peak times for ET Case11b (T ≤ 171 years).

	PORFLOW		GoldSim		Ratio	
	Max Flux	Max Time	Max Flux	Max Time	GoldSim/PORFLOW	
Nuclides	Ci/yr	Year	Ci/yr	Year	Ci/Ci	yr/yr
C-14	5.304E-05	46	6.453E-07	46	1.22E-02	1.00
H-3	4.169E+03	21	5.015E+03	21	1.20E+00	1.00
I-129	2.366E-05	46	5.227E-06	46	2.21E-01	1.00
Np-237	7.465E-10	171	1.218E-16	46	1.63E-07	0.27
U-233	9.421E-16	171	8.062E-23	171	8.56E-08	1.00
Th-229	7.595E-19	171	7.934E-26	171	1.04E-07	1.00
Sr-90	9.963E-12	171	5.847E-20	46	5.87E-09	0.27
Tc-99	6.244E-02	46	6.991E-02	46	1.12E+00	1.00
U-238	5.774E-63	171	< sp			
U-234	3.045E-66	171	< sp			
Th-230	2.208E-70	171	< sp			
Ra-226	7.913E-48	171	< sp			
Pb-210	3.574E-50	171	< sp			
	mol/yr		mol/yr			
Tracer	2.329E-01	21	2.798E-01	21	1.20E+00	1.00

Table 6-4. Comparison of PORFLOW and GoldSim peak fluxes to the water table and peak times for ET Case11b (T > 171 years).

	PORFLOW		GoldSim		Ratio	
	Max Flux	Max Time	Max Flux	Max Time	GoldSim/PORFLOW	
Nuclides	Ci/yr	Year	Ci/yr	Year	Ci/Ci	yr/yr
C-14	1.095E-01	1092	1.164E-01	1092	1.06E+00	1.00
H-3	1.065E-14	171	3.578E-03	171	3.36E+11	1.00
I-129	1.127E-04	691	1.240E-04	692	1.10E+00	1.00
Np-237	6.627E-04	1072	7.830E-04	1052	1.18E+00	0.98
U-233	2.044E-08	5000	2.054E-08	5000	1.00E+00	1.00
Th-229	1.806E-09	5000	1.815E-09	5000	1.01E+00	1.00
Sr-90	7.610E-03	249	2.915E-04	271	3.83E-02	1.09
Tc-99	5.966E-03	571	6.462E-03	552	1.08E+00	0.97
U-238	3.590E-11	5000	1.461E-13	5000	4.07E-03	1.00
U-234	5.029E-13	5000	2.043E-15	5000	4.06E-03	1.00

Nuclides	PORFLOW		GoldSim		Ratio	
	Max Flux	Max Time	Max Flux	Max Time	GoldSim/PORFLOW	
	Ci/yr	Year	Ci/yr	Year	Ci/Ci	yr/yr
Th-230	1.009E-15	5000	2.578E-18	5000	2.55E-03	1.00
Ra-226	1.838E-12	5000	1.780E-12	5000	9.69E-01	1.00
Pb-210	2.259E-14	5000	2.187E-14	5000	9.68E-01	1.00
	mol/yr		**mol/yr**			
Tracer	2.696E-15	171	9.721E-04	172	3.61E+11	1.00

A comparison of PORFLOW and GoldSim peak fluxes to the water table and peak times for ST Case01 are shown prior to and after dynamic compaction in Table 6-5 and Table 6-6, respectively.

Table 6-5. Comparison of PORFLOW and GoldSim peak fluxes to the water table and peak times for ST Case01 (T ≤ 171 years).

Nuclides	PORFLOW		GoldSim		Ratio	
	Max Flux	Max Time	Max Flux	Max Time	GoldSim/PORFLOW	
	Ci/yr	Year	Ci/yr	Year	Ci/Ci	yr/yr
C-14	1.069E-04	46	5.051E-07	46	4.72E-03	1.00
H-3	3.582E+03	20	5.104E+03	20	1.43E+00	0.99
I-129	3.415E-05	46	9.480E-06	46	2.78E-01	1.00
Np-237	3.715E-09	171	2.970E-18	171	7.99E-10	1.00
U-233	5.503E-15	171	3.065E-24	171	5.57E-10	1.00
Th-229	5.030E-18	171	2.064E-27	171	4.10E-10	1.00
Sr-90	1.637E-10	171	7.575E-25	171	4.63E-15	1.00
Tc-99	4.477E-02	46	6.175E-02	46	1.38E+00	1.00
U-238	6.101E-61	171	< sp			
U-234	3.217E-64	171	< sp			
Th-230	2.425E-68	171	< sp			
Ra-226	5.162E-46	171	< sp			
Pb-210	2.433E-48	171	< sp			
	mol/yr		**mol/yr**			
Tracer	1.999E-01	21	2.823E-01	20	1.41E+00	0.99

Table 6-6. Comparison of PORFLOW and GoldSim peak fluxes to the water table and peak times for ST Case01 (T > 171 years).

	PORFLOW		GoldSim		Ratio	
	Max Flux	Max Time	Max Flux	Max Time	GoldSim/PORFLOW	
Nuclides	Ci/yr	Year	Ci/yr	Year	Ci/Ci	yr/yr
C-14	7.006E-02	1222	6.617E-02	1223	9.44E-01	1.00
H-3	1.895E-12	171	8.442E-12	171	4.45E+00	1.00
I-129	9.655E-05	731	1.087E-04	712	1.13E+00	0.97
Np-237	4.556E-04	1132	4.745E-04	1092	1.04E+00	0.96
U-233	1.871E-08	5000	1.9501E-08	5000	1.04E+00	1.00
Th-229	1.639E-09	5000	1.649E-09	5000	1.01E+00	1.00
Sr-90	3.060E-11	991	2.114E-11	1072	6.91E-01	1.08
Tc-99	6.3502E-03	611	6.484E-03	592	1.02E+00	0.97
U-238	2.279E-17	5000	9.280E-26	5000	4.07E-09	1.00
U-234	3.200E-19	5000	1.299E-27	5000	4.06E-09	1.00
Th-230	2.487E-22	5000	5.009E-31	5000	2.01E-09	1.00
Ra-226	1.147E-12	5000	1.196E-12	5000	1.04E+00	1.00
Pb-210	1.403E-14	5000	1.462E-14	5000	1.04E+00	1.00
	mol/yr		**mol/yr**			
Tracer	2.243E-11	471	2.230E-12	171	9.94E-02	0.36

A comparison of PORFLOW and GoldSim peak fluxes to the water table and peak times for ST Case11b are shown prior to and after dynamic compaction and subsidence in Table 6-7 and Table 6-8, respectively.

Table 6-7. Comparison of PORFLOW and GoldSim peak fluxes to the water table and peak times for ST Case11b (T ≤ 171 years).

	PORFLOW		**GoldSim**		**Ratio**	
	Max Flux	**Max Time**	**Max Flux**	**Max Time**	**GoldSim/PORFLOW**	
Nuclides	**Ci/yr**	**Year**	**Ci/yr**	**Year**	**Ci/Ci**	**yr/yr**
C-14	1.069E-04	46	5.488E-07	46	5.13E-03	1.00
H-3	3.582E+03	20	5.115E+03	20	1.43E+00	0.99
I-129	3.415E-05	46	1.010E-05	46	2.96E-01	1.00
Np-237	3.715E-09	171	3.179E-18	171	8.56E-10	1.00
U-233	5.503E-15	171	3.286E-24	171	5.97E-10	1.00
Th-229	5.030E-18	171	2.214E-27	171	4.40E-10	1.00
Sr-90	1.637E-10	171	7.991E-25	171	4.88E-15	1.00

Nuclides	PORFLOW Max Flux Ci/yr	PORFLOW Max Time Year	GoldSim Max Flux Ci/yr	GoldSim Max Time Year	Ratio GoldSim/PORFLOW Ci/Ci	Ratio GoldSim/PORFLOW yr/yr
Tc-99	4.477E-02	46	6.257E-02	46	1.40E+00	1.00
U-238	6.101E-61	171	< sp			
U-234	3.217E-64	171	< sp			
Th-230	2.425E-68	171	< sp			
Ra-226	5.162E-46	171	< sp			
Pb-210	2.433E-48	171	< sp			
	mol/yr		mol/yr			
Tracer	1.999E-01	21	2.823E-01	20	1.41E+00	0.99

Table 6-8. Comparison of PORFLOW and GoldSim peak fluxes to the water table and peak times for ST Case11b (T > 171 years).

Nuclides	PORFLOW Max Flux Ci/yr	PORFLOW Max Time Year	GoldSim Max Flux Ci/yr	GoldSim Max Time Year	Ratio GoldSim/PORFLOW Ci/Ci	Ratio GoldSim/PORFLOW yr/yr
C-14	6.753E-02	1222	6.453E-02	1223	9.56E-01	1.00
H-3	3.356E-10	171	2.404E-11	171	7.16E-02	1.00
I-129	9.061E-05	731	1.029E-04	712	1.14E+00	0.97
Np-237	4.350E-04	1132	4.586E-04	1072	1.05E+00	0.95
U-233	1.862E-08	5000	1.9409E-08	5000	1.04E+00	1.00
Th-229	1.633E-09	5000	1.639E-09	5000	1.00E+00	1.00
Sr-90	5.458E-03	255	6.568E-03	264	1.20E+00	1.04
Tc-99	5.8901E-03	611	5.858E-03	572	9.95E-01	0.94
U-238	3.222E-11	5000	1.579E-12	5000	4.90E-02	1.00
U-234	4.514E-13	5000	2.209E-14	5000	4.89E-02	1.00
Th-230	8.856E-16	5000	2.174E-17	5000	2.45E-02	1.00
Ra-226	1.301E-12	5000	1.361E-12	5000	1.05E+00	1.00
Pb-210	1.594E-14	5000	1.666E-14	5000	1.05E+00	1.00
	mol/yr		mol/yr			
Tracer	8.559E-11	171	6.381E-12	171	7.45E-02	1.00

7.0 Recommendations, Path Forward or Future Work

The GoldSim ET and ST vadose zone models can be expanded to model advective and diffusive flux links to and from adjacent soil regions outside the waste footprint to capture edge effects from cover overhangs.

The GoldSim ST vadose model can be extended to include vertical and transverse advective and diffusive flux links for the five slit segments, four non-waste segments and two edge non-waste segments.

The GoldSim ET and ST vadose zone models are intended to be used for Monte Carlo analysis to determine uncertainty in radionuclide concentrations at the 100-m POA. Reassessments will be made when the GoldSim ET and ST vadose zone models are be connected to the GoldSim aquifer zone model via advective and diffusive flux links.

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