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Evaluation of Vadose Zone Heterogeneities Under Waste Management Area C

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Background Information

- This development effort was undertaken at the request of the Washington State Department of Ecology (Ecology) during an August 21, 2018, meeting with the U.S. Department of Energy (DOE) and its prime contractor, Washington River Protection Solutions LLC (WRPS) during review of Waste Management Area (WMA) C documents
  - A presentation was made by Ecology's Dib Goswami titled "C Tank Farm Heterogeneity: The Thin Layers," in which information from Nez Perce (2014) report was presented on nature and extent of fine-grain thin layers
- Ecology asked for an impact evaluation on migration of contaminants under the C Tank Farm due to the presence of fine-grained thin layers that may be laterally extensive and continuous
  - Ecology acknowledged that the data may have some uncertainties but the proposed scenario must be evaluated as one of the alternatives
- DOE agreed to develop the model as requested by Ecology

Purpose

- Develop a two-dimensional (2-D) numerical model extending from the southwest to the northeast (along the apparent dip) using Subsurface Transport Over Multiple Phases (STOMP) software
- Incorporate the fine-grained units (FGU) as identified by the Nez Perce within WMA C Performance Assessment model to represent the heterogeneity (as per Ecology's request)
  - Use the information developed from the Geoframework model
- Evaluate the effect of FGUs on water flow and contaminant transport in the vadose zone and compare with Equivalent Homogeneous Media (EHM) model

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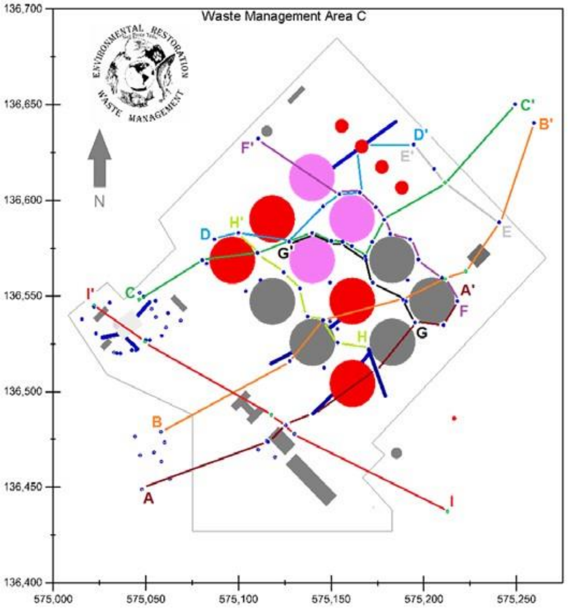
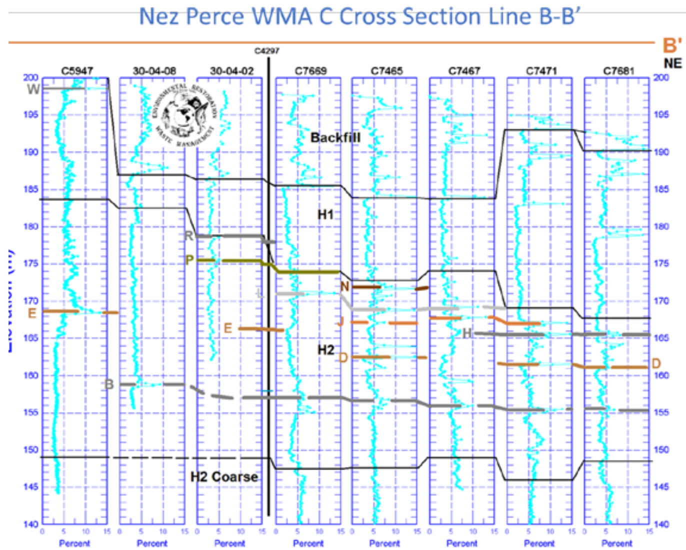
Nez Perce Interpretations (2014) of WMA C Moisture Data





ll	H1	Silt_Z	Silt_X	Silt_W	Silt_V	Silt U	H2	Silt T	Silt R	Silt P	silt N	Silt L	Silt J	Silt H	Silt E	Silt D	Silt B
4	198.571	absent	absent	absent	absent	absent	173.581	absent	absent	absent	172.5	absent	absent	absent	absent	absent	156.2
-01	184.588	absent	absent	absent	absent	absent	172.398	absent	absent	absent	170.754	168.925	167.096	absent	absent	162.524	short
-03	184.492	absent	absent	absent	absent	absent	172.4	absent	absent	absent	short	short	short	short	short	short	short
-05	185.025	absent	absent	absent	absent	absent	172.5	absent	absent	absent	172.3	169.661	short	short	short	short	short
-07	185.713	absent	absent	absent	absent	absent	174.743	absent	absent	absent	173.702	170.959	short	short	short	short	short
-09	185.403	absent	absent	absent	absent	absent	175.043	absent	absent	absent	171.263	169.13	short	short	short	short	short
-01	186.7	absent	absent	absent	absent	absent	180	absent	short	short	short	short	short	short	short	short	short
-02	186.344	absent	absent	absent	absent	absent	178.724	absent	178.605	175.557	absent	absent	absent	absent	absent	absent	short
-03	186.789	absent	absent	absent	absent	absent	179.3	absent	short	short	short	short	short	short	short	short	short
-04	186.771	absent	absent	absent	absent	absent	179.301	absent	178.267	175.524	absent	short	short	short	short	short	short
-05	186.765	absent	absent	absent	absent	absent	180.365	absent	176.8	short	short	short	short	short	short	short	short
-08	187.059	absent	absent	absent	absent	absent	182.799	absent	absent	absent	absent	absent	absent	absent	absent	absent	158.792
-12	186.496	absent	absent	absent	absent	absent	180.406	absent	177	absent	171.746	absent	absent	absent	absent	short	short
-02	186.392	absent	absent	absent	absent	absent	175.722	absent	absent	absent	172.521	absent	absent	absent	absent	short	short
-06	186.382	absent	absent	absent	absent	absent	176.2	absent	short	short	short	short	short	short	short	short	short
-10	185.898	absent	absent	absent	absent	absent	176.138	short	short	short	short	short	short	short	short	short	short
-02	185.454	absent	absent	absent	absent	183.014	173.874	absent	absent	absent	absent	169.602	absent	absent	absent	absent	short
-03	185.459	absent	absent	absent	absent	183.552	173.269	absent	absent	absent	absent	169.684	short	short	short	short	short
-04	184.784	absent	absent	absent	absent	184.559	173.514	absent	absent	absent	173.4	170.691	absent	absent	absent	164.671	short
-09	186.089	absent	absent	absent	absent	absent	175.419	absent	absent	absent	172.223	absent	short	short	short	short	short
-10	185.308	absent	absent	absent	absent	184.702	175.248	absent	absent	absent	absent	170.376	absent	absent	absent	absent	short
-12	184.748	absent	absent	absent	absent	183.408	174.421	absent	absent	absent	173.654	170.454	absent	short	short	short	short
-01	186.59	absent	absent	absent	absent	absent	179.88	absent	178.541	short	short	short	short	short	short	short	short
-02	185.963	absent	absent	absent	absent	absent	179.863	absent	177.609	short	short	short	short	short	short	short	short
-10	186.771	absent	absent	absent	absent	absent	184.631	absent	absent	absent	absent	absent	short	short	short	short	short
-11	186.684	absent	absent	absent	absent	absent	183.024	absent	176.196	absent	absent	absent	short	short	short	short	short
-02	186.371	absent	absent	absent	absent	absent	175.091	absent	absent	absent	173.236	absent	short	short	short	short	short
-03	186.374	absent	absent	absent	absent	absent	175.1	absent	absent	short	short	short	short	short	short	short	short
-12	186.403	absent	absent	absent	absent	absent	176.033	absent	absent	short	short	short	short	short	short	short	short
-01	183.943	absent	absent	absent	absent	183.52	174.803	absent	absent	absent	absent	171.328	absent	short	short	short	short
-02	184.963	absent	absent	absent	absent	183.011	174.903	absent	absent	absent	absent	170.819	absent	short	short	short	short
-06	186.378	absent	absent	absent	absent	absent	176.008	absent	absent	absent	172.812	absent	short	short	short	short	short
-07	185.958	absent	absent	absent	absent	absent	176.208	absent	absent	absent	173.236	absent	absent	absent	absent	short	short
-10	185.045	absent	absent	absent	absent	absent	174.985	absent	absent	absent	173.644	absent	short	short	short	short	short
-11	185.208	absent	absent	absent	absent	absent	173.328	absent	absent	absent	172.288	171.678	absent	short	short	short	short
-01	186.628	absent	absent	absent	absent	absent	182.968	182.541	177.969	absent	absent	short	short	short	short	short	short
-02	186.748	absent	absent	absent	absent	absent	181.108	absent	178.244	absent	absent	short	short	short	short	short	short

- Nez Perce report associated peaks in moisture content with FGUs and identified 15 FGUs distributed vertically with variable lateral extent
- Elevation of FGUs at various wells is presented in a table

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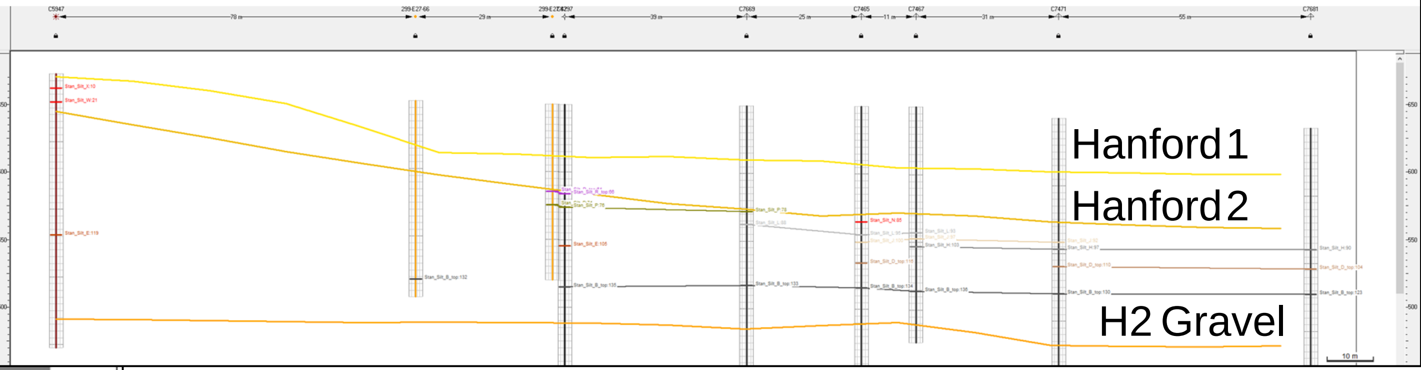
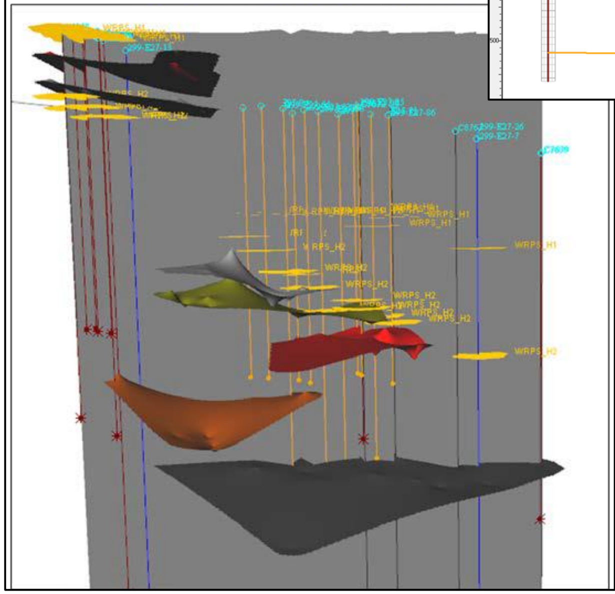
Step in 2-D Model Development

Nez Perce B-B’ Scaled 1:1 in Kingdom



Grids for Advocacy Model



The Nez Perce interpreted picks of the top of FGUs were interpolated within a Geoframework model using Kingdom Software to create a continuous grid for the numerical model.

General Modeling Limitations

- The limitation of modeling flow and transport in the 2-D cross section was discussed with Ecology
- The injected water (from past leaks) and contaminants can spread in only two directions (vertical and along the cross section) and therefore the results cannot be directly compared with the results of the 3-D model

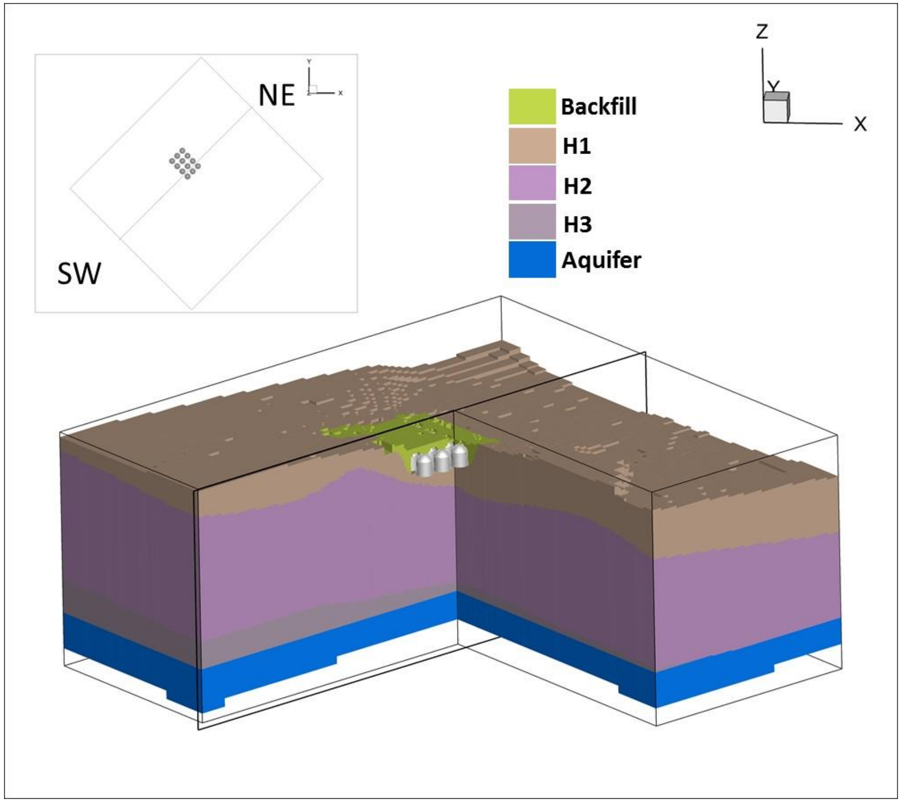
Key Assumptions During Model Implementation

- Continuity of assumed FGUs maintained to match the interpolations in the Nez Perce report, even though FGUs were detected in only a few boreholes
- All FGUs assumed to have thickness of approximately 1.5 feet
- All FGUs assigned same hydraulic properties as requested by Ecology

2-D Model Construction

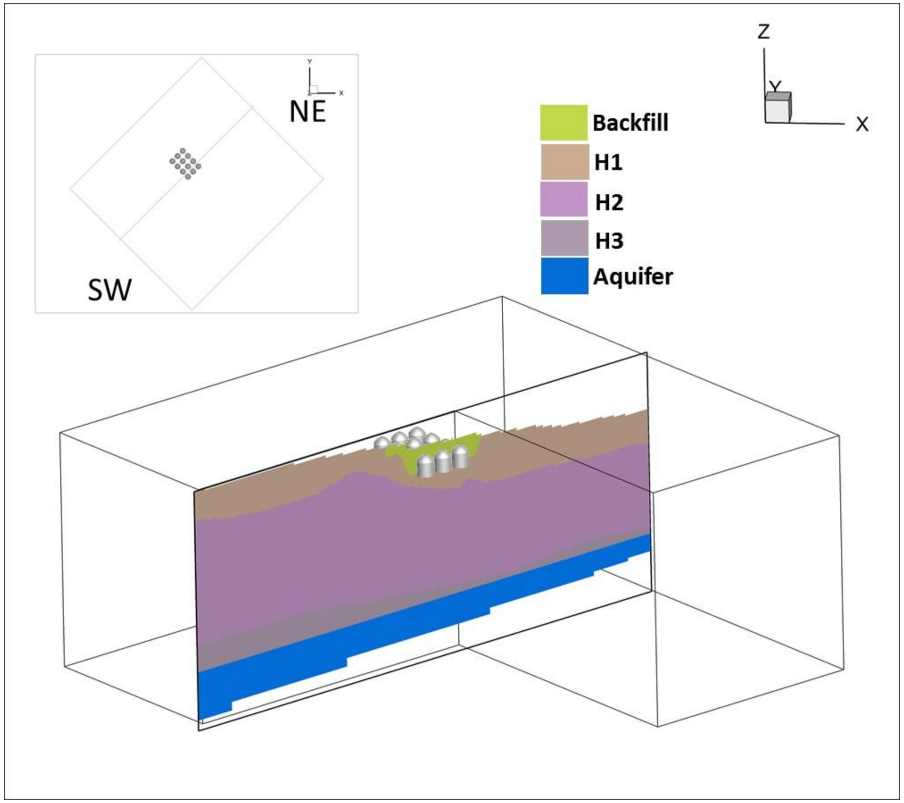
WMA C Past Leak 3-D EHM Model:

Variable grids spacing
3.8 m x 3.8 m x 1 m in tank farm area



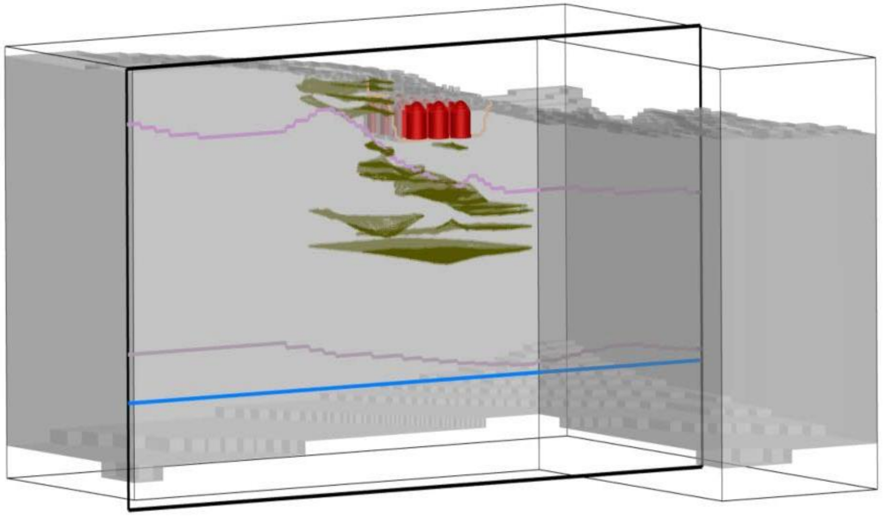
2-D EHM Model:

Uniform grids spacing
1 m x 0.15 m (lateral x vertical)

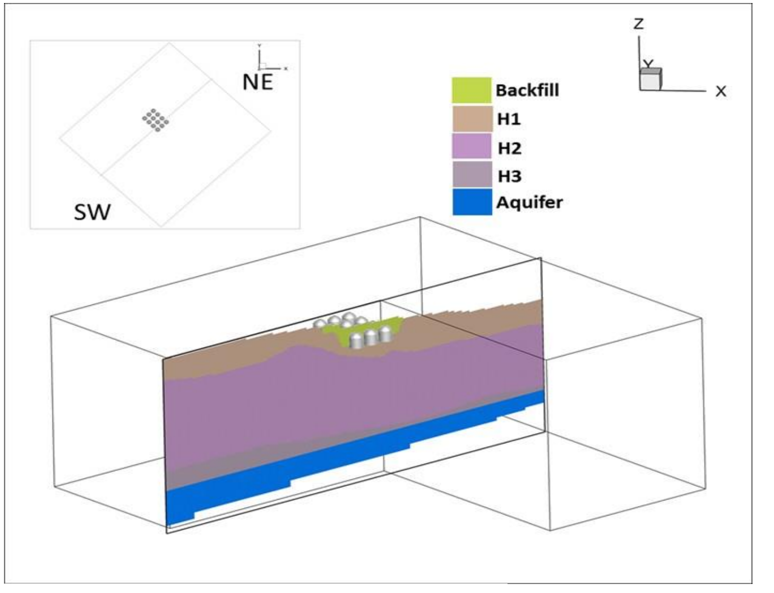


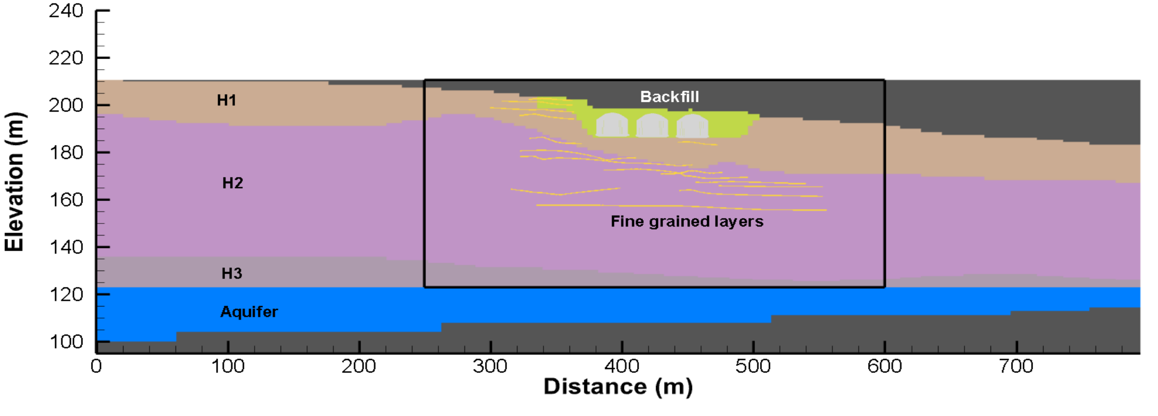
2-D Fine-Grained Unit Model Construction

3-D FGUs



2-D EHM model





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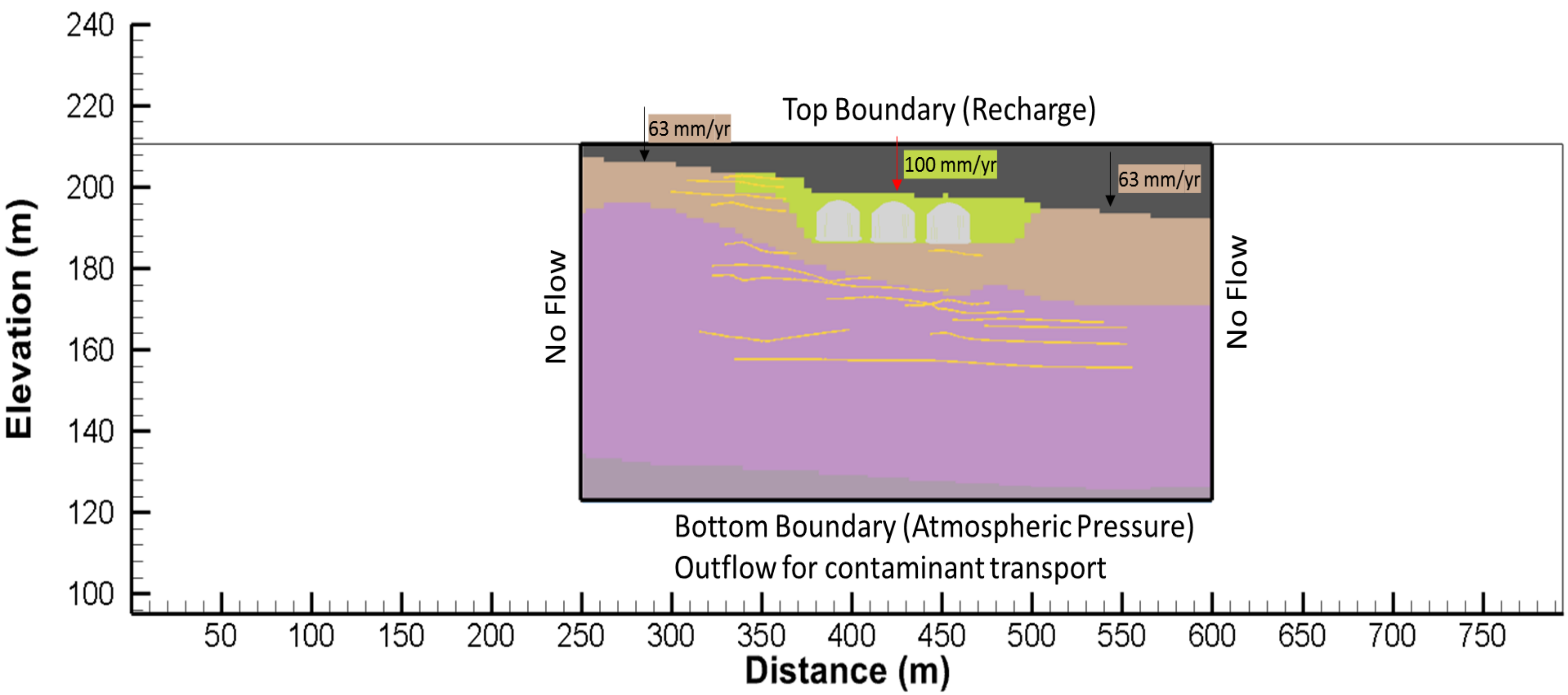
STOMP 2-D Model Domain and Boundary Conditions



Source Volume, Inventory, and Release Period:

20,500 gallons and 10 Ci technetium-99 released in 5 years (1963-1968)

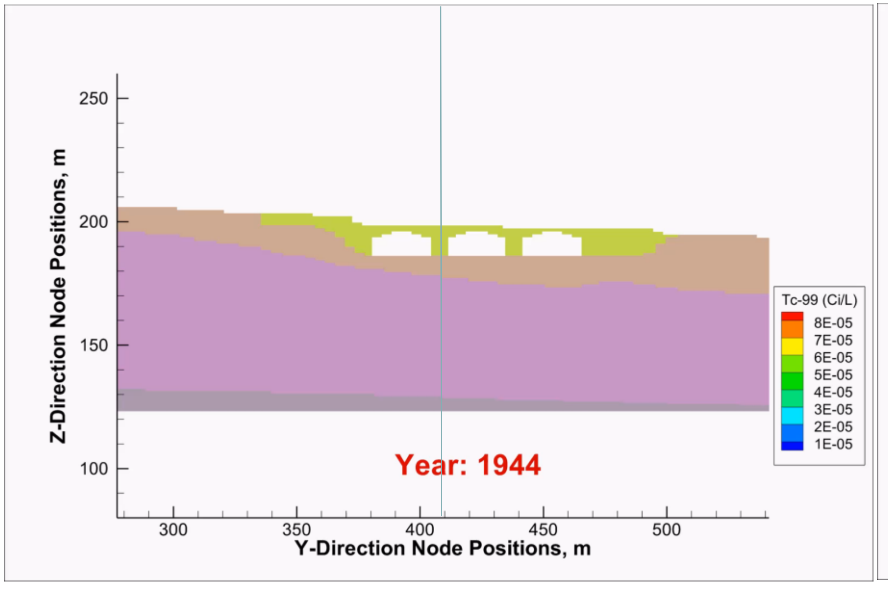
Outline of Simulation Cases and Results

- **Primary Case:**
  - Comparison of EHM model and FGU model to see the effect of the FGUs
  - FGU model uses site-wide average hydraulic properties for Hanford sandy silt (HSS), obtained from PNNL-14702 (suggested by Ecology)
- **Sensitivity Cases:**
  - Effect of eliminating water volume in conjunction with source release
  - Effect of removing impermeable tank structures from flow field
  - Effect of modified hydraulic properties in the FGUs
- **Results:**
  - Vadose zone plume animation
  - Technetium-99 flux arriving at water table
  - Vertical moisture profile and comparison with observed data

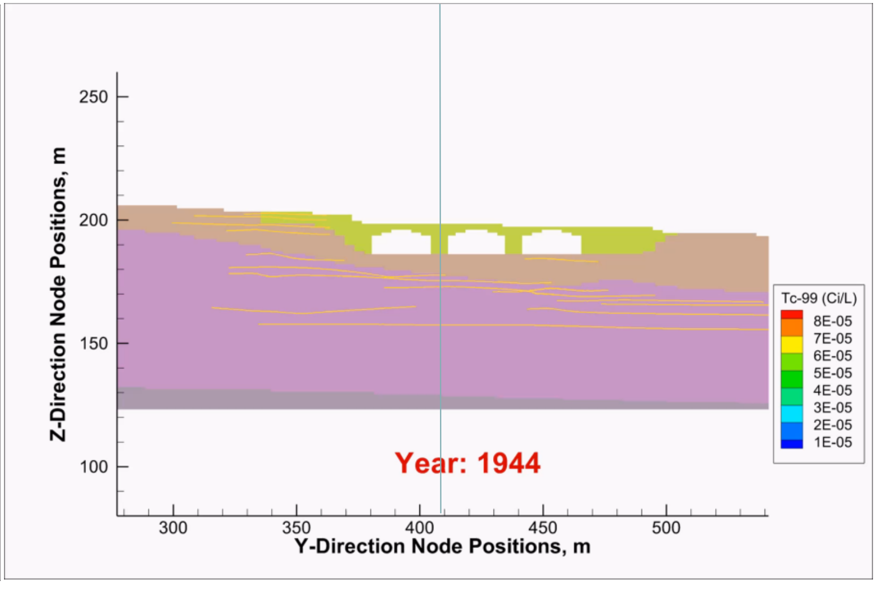
Primary Case Results
(Effect of Fine-Grained Units)

Vadose Zone Plume Animation

EHM

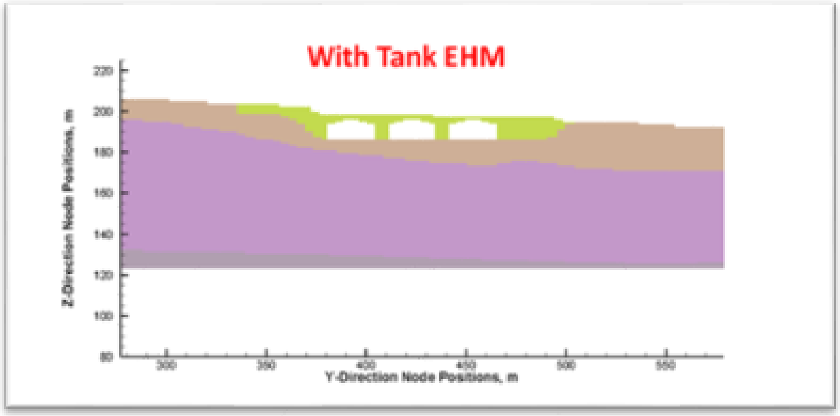


HSS

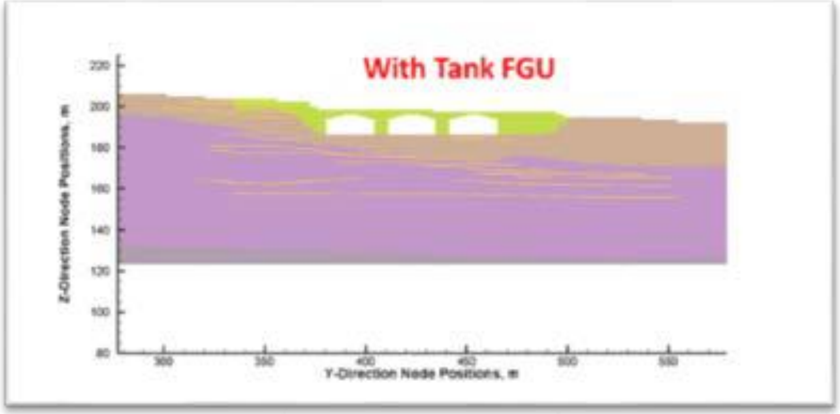


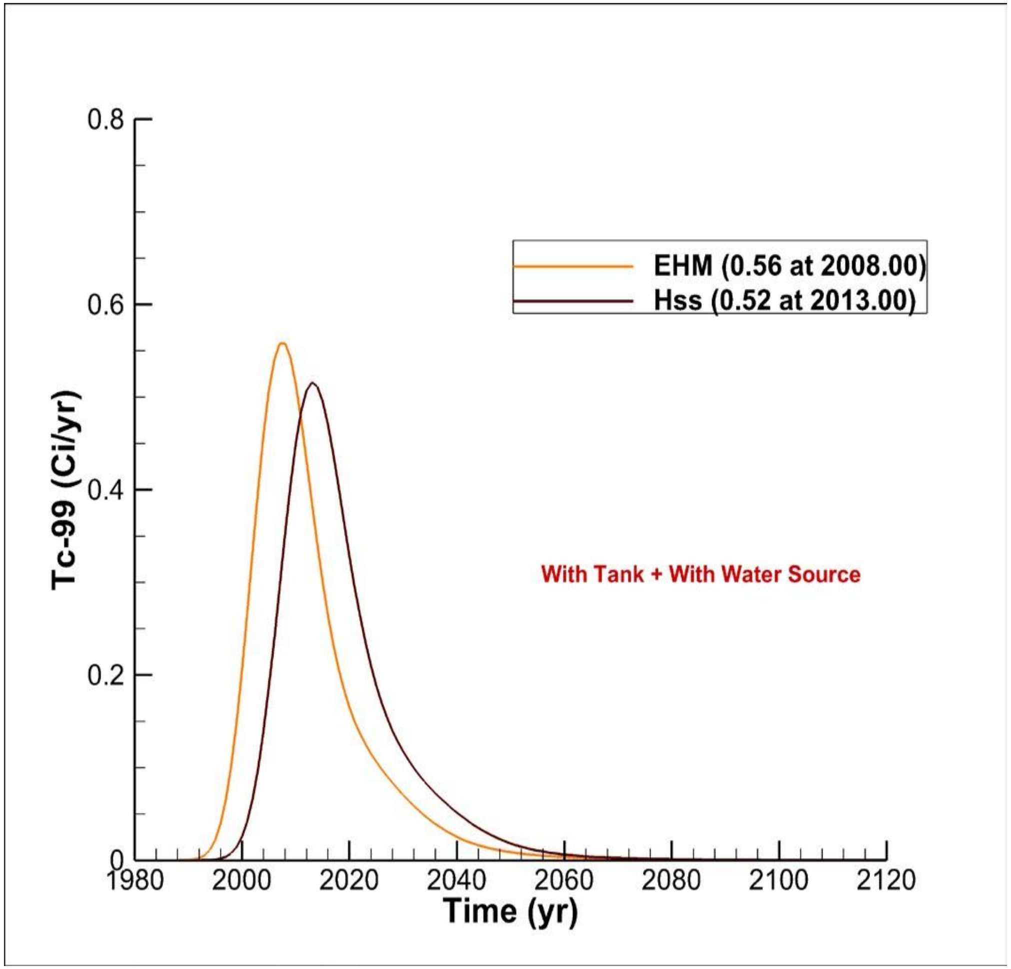
Mass Flux Arriving at Water Table (Effect of Fine-Grained Units)

EHM



HSS

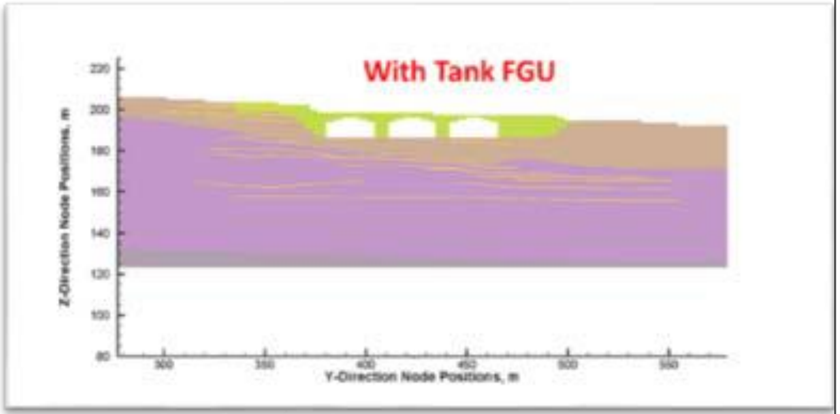


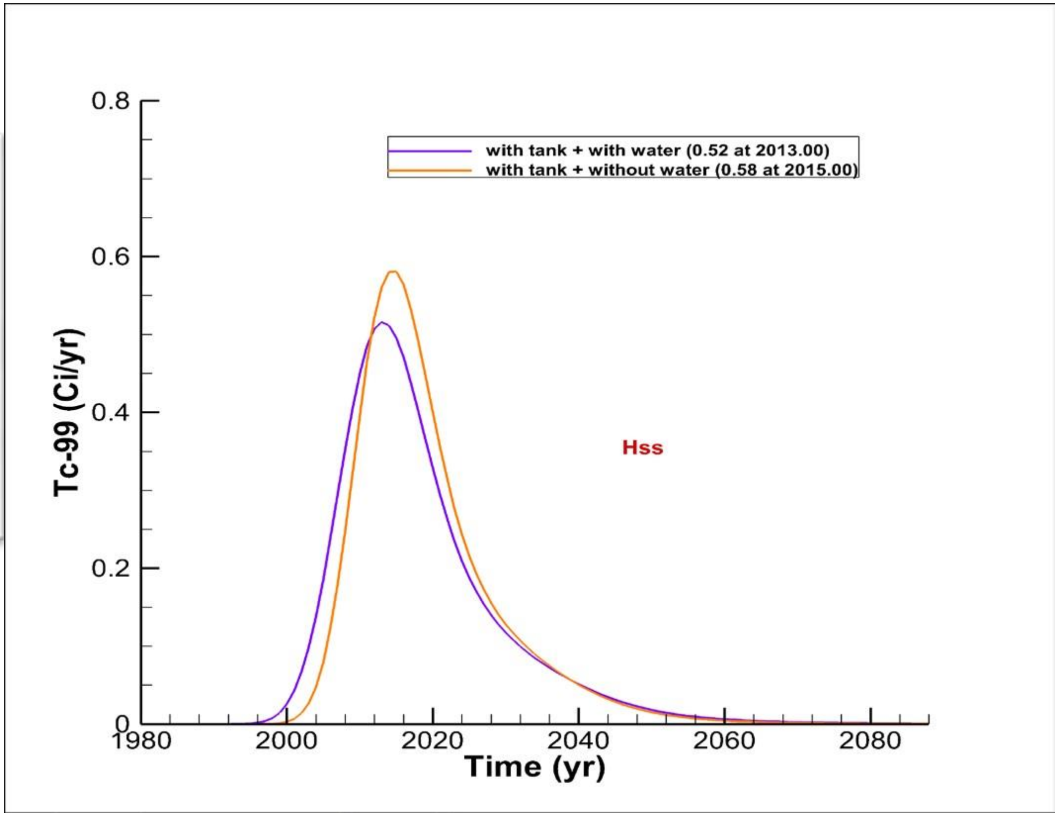


Sensitivity Case Results
(Effect of Removing Water Source)

Mass Flux Arriving at Water Table (Effect of Removing Water Source)

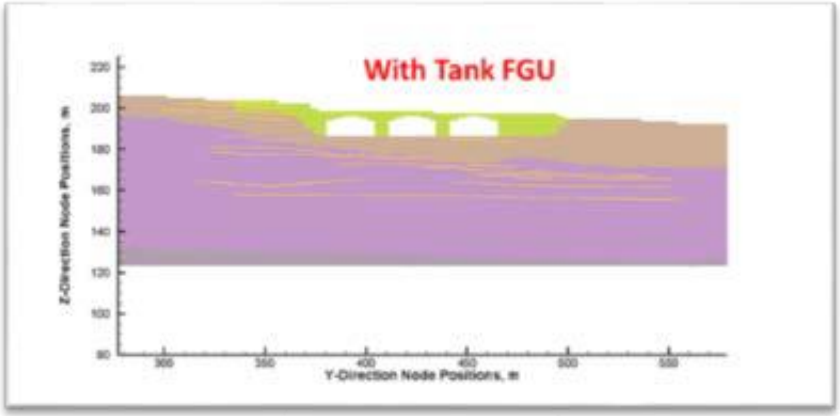
HSS

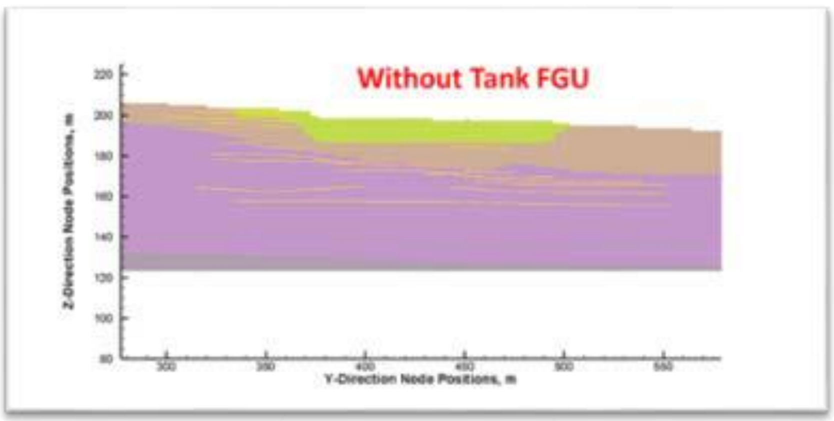


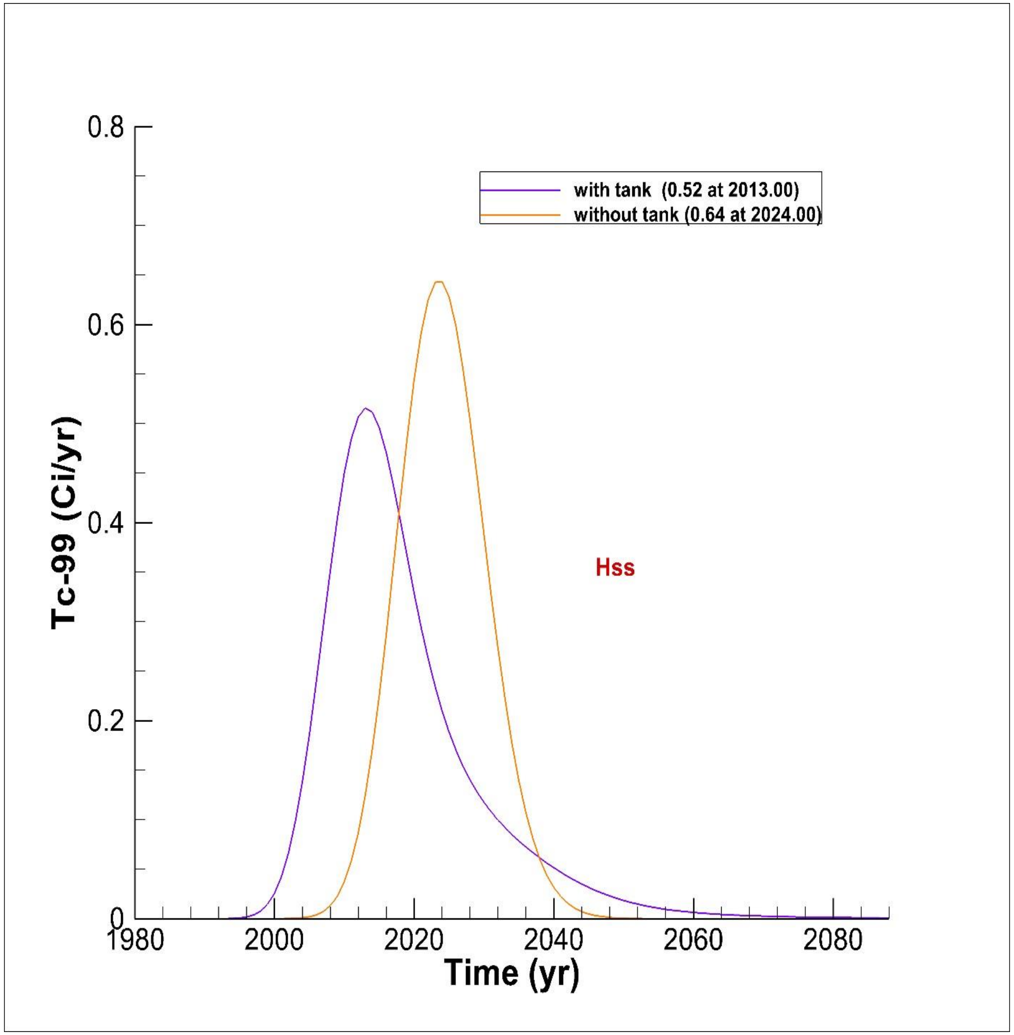


Sensitivity Case Results
(Effect of Removing Tank Structures)

Mass Flux Arriving at Water Table (Effect of Removing Tank Structures)







Sensitivity Case Results
(Effect of Other Hydraulic Properties of the FGUs)

Range of Hydraulic Property Cases

Equivalent Homogeneous Media:

Each of the hydrostratigraphic units (H1, H2, H3) are treated as homogeneous media but the small-scale (laboratory core scale) heterogeneities are incorporated through the parameter "upscaling" process to predict bulk or mean flow behavior at the field scale.

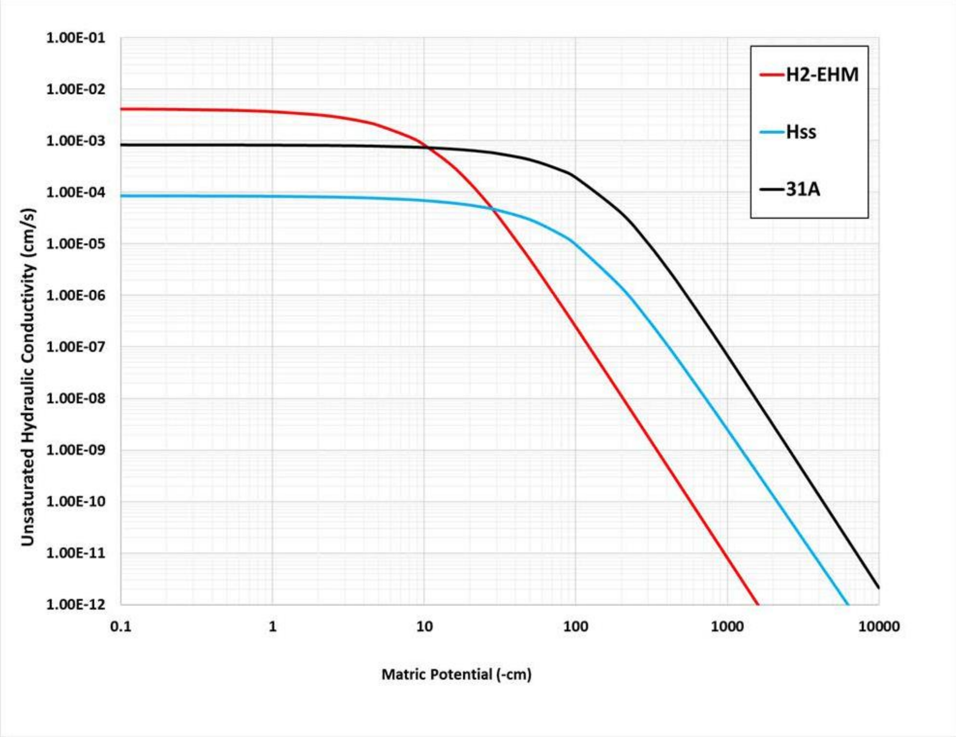
Low permeable fine-grained unit (HSS):

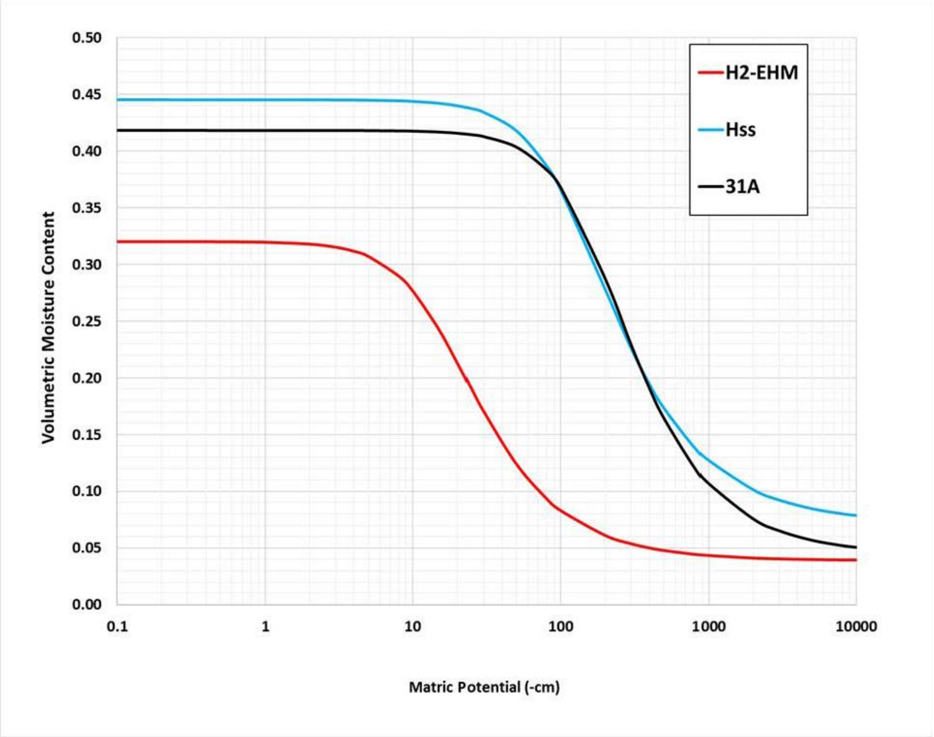
FGUs were simulated with Hanford Site-wide average hydraulic properties provided for Silty-Sand in PNNL-14702 (modified from Khaleel and Freeman, 1995), as suggested by Ecology. **This case was used as the primary case.**

High permeable fine-grained unit (31A):

FGUs were simulated with hydraulic property obtained from Silty-Sand sample 31A (RPP-20621) from Integrated Disposal Facility (200 East Area). **This case was used as a sensitivity case to evaluate the effect of the hydraulic properties assigned to the FGUs. This set of hydraulic properties was used for high-moisture zones beneath WMA C within a WRPS-developed moisture content-based heterogeneous model.**

Comparison of Hydraulic Properties

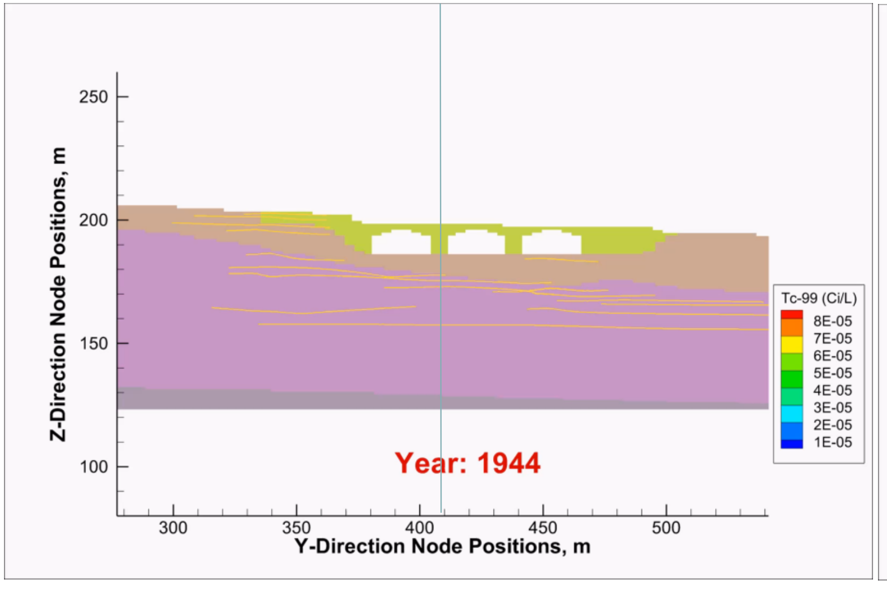




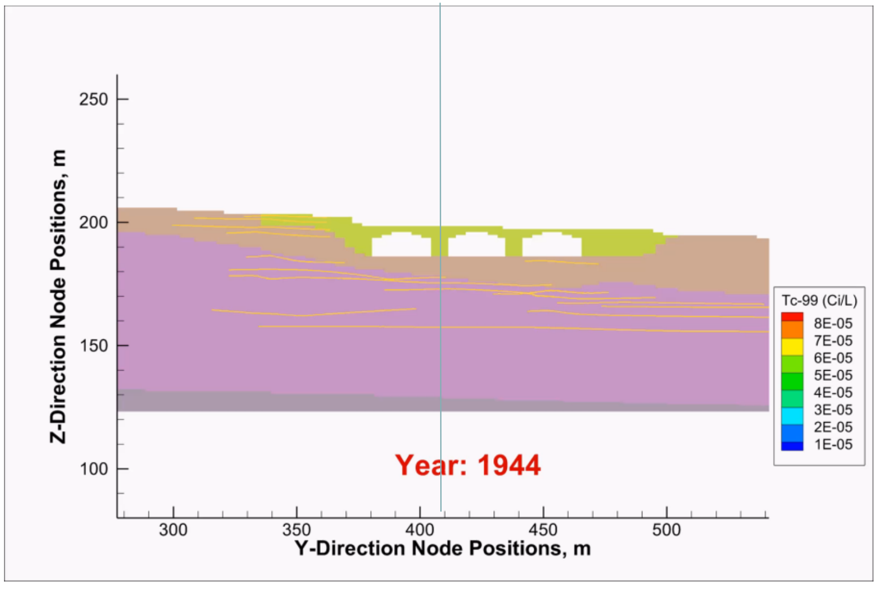
	K (cm/s)	theta_s	Sr	theta_r	alpha (1/cm)	n	m(=1-1/n)	l
Silty-Sand (31A)	8.21E-04	0.418	0.106	0.044	0.006	2.012	0.503	0.5
EHM-H2 Sand	4.15E-03	0.315	0.012	0.039	0.063	2.000	0.500	0.5
Silty-Sand (Hss)	8.58E-05	0.445	0.162	0.072	0.008	1.915	0.478	0.5

Vadose Zone Plume Animation

HSS

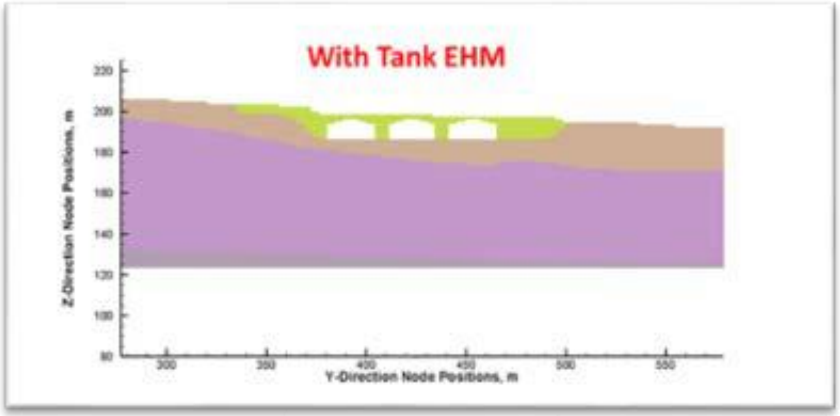


31A

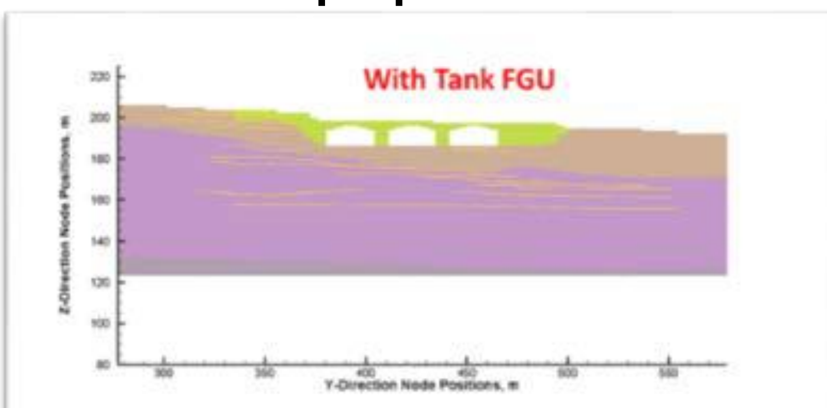


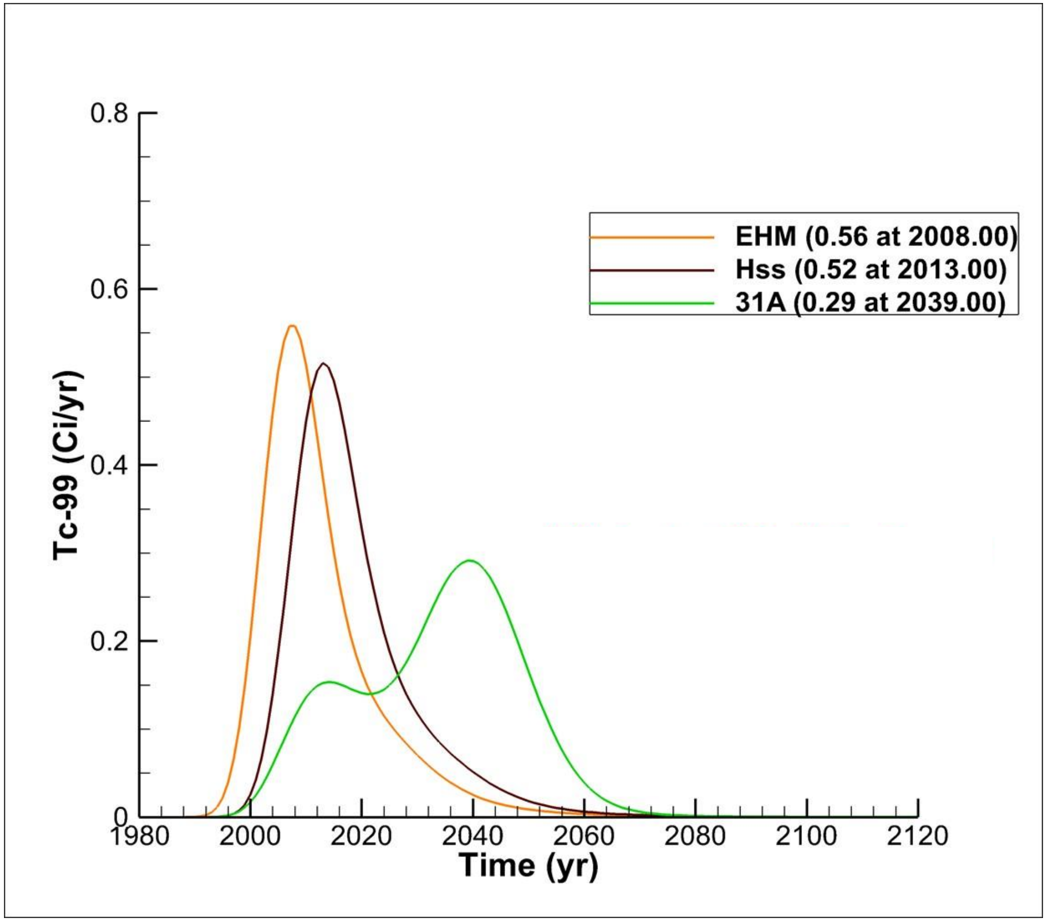
Mass Flux Arriving at Water Table

EHM

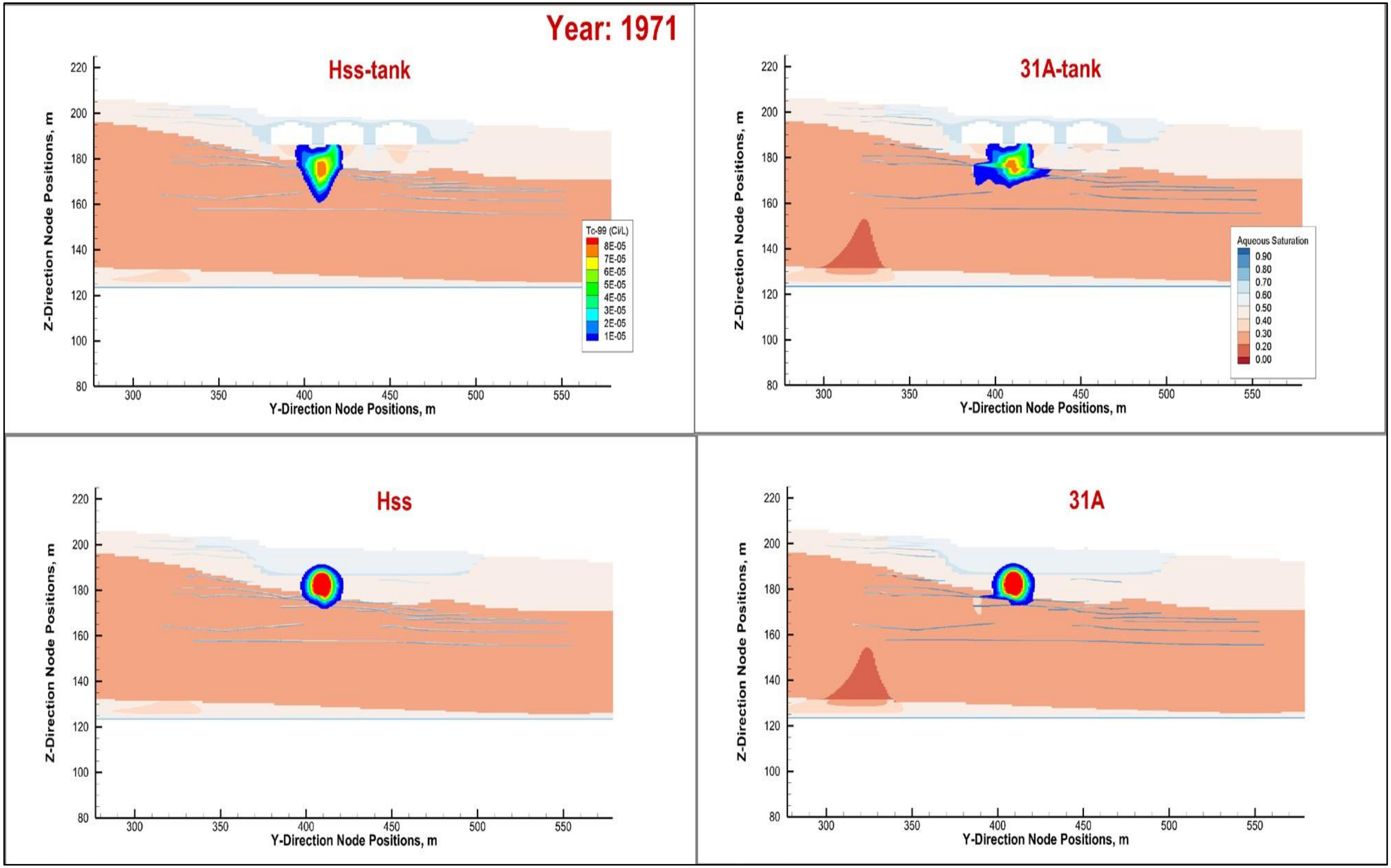


FGUs with two different properties

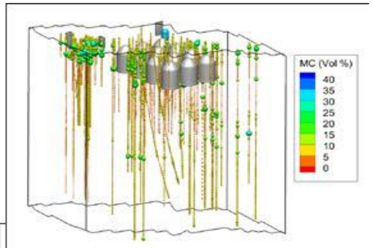


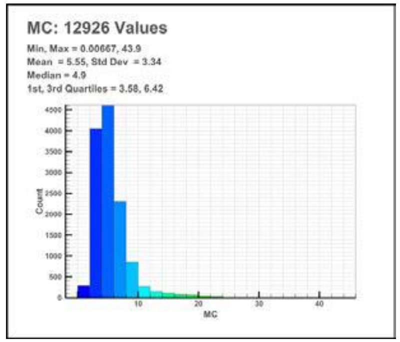


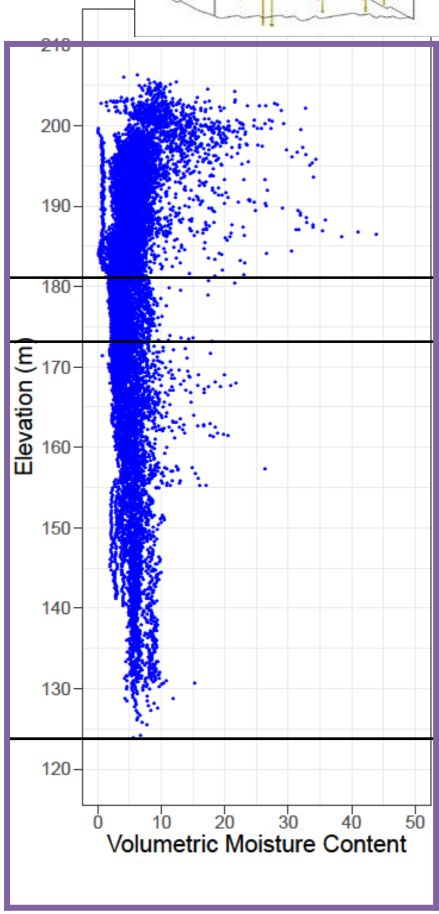
Technetium-99 Plume (Foreground Contour) and Water Saturation (Background Contour)

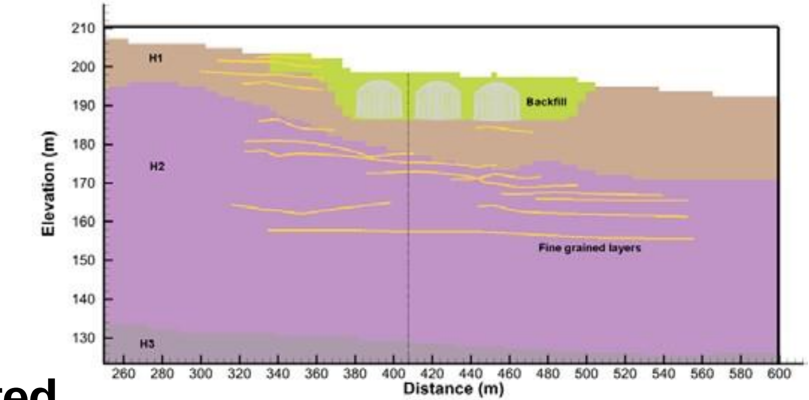


Comparison of Observed and Simulated Moisture Content

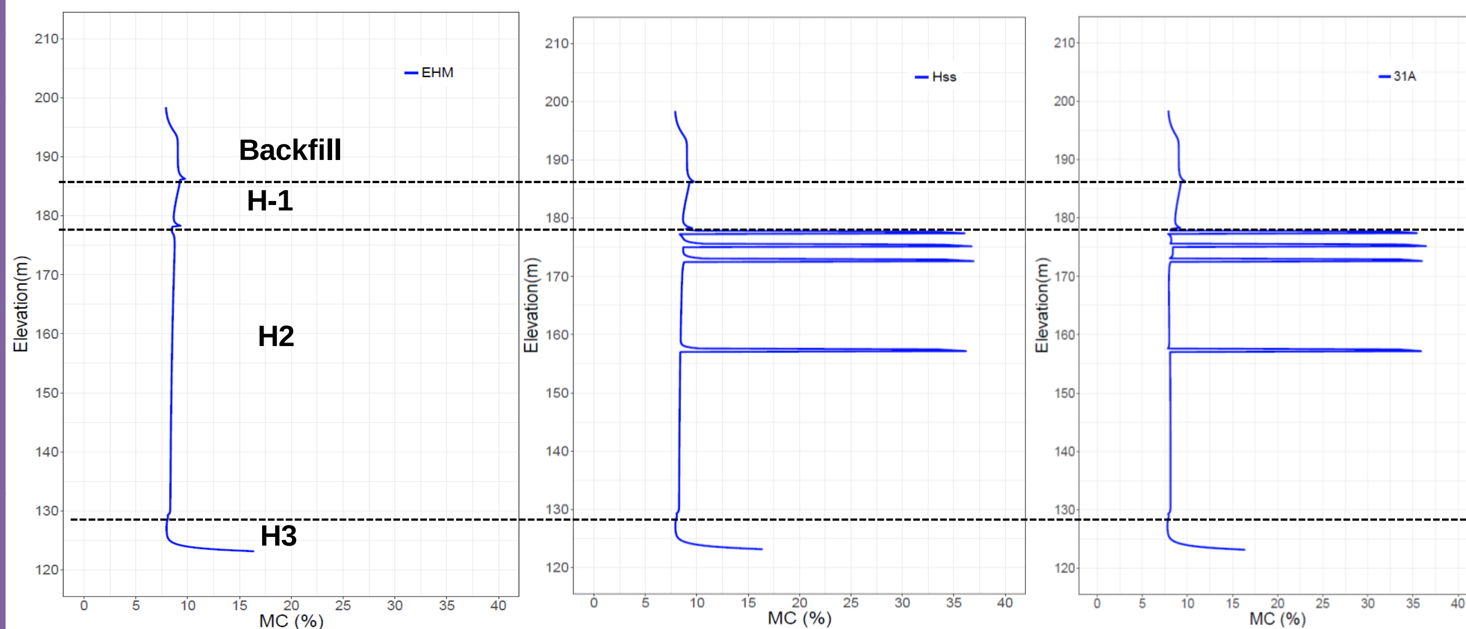








Simulated



General Observations from Range of Simulation Cases Evaluated

All simulations that incorporated hypothetical heterogeneity in this comparative analysis indicated the following:

- Only an incremental increase in plume spreading over what was observed in simulations using the EHM concept
- Contaminant plume centers of mass continue to migrate downward directly below the source (including those simulations that incorporated the hypothetical FGUs)

All simulations that used the silty-sand hydraulic properties (suggested for use by Ecology) for the hypothetical FGUs indicated the following:

- A similar degree of plume spreading with some attenuation of mass flux peaks at the water table **when compared to the EHM modeling results**
- Less plume spreading and mass flux peak attenuation **when compared to simulation results that used silty-sand hydraulic properties used for high-moisture zones in the WRPS heterogeneous model(s)**

General Observations from Range of Simulation Cases Evaluated (Cont.)

The EHM representation of the vadose zone (without the hypothetical heterogeneity) showed relatively higher mass flux peaks and earlier occurrence in time of peak fluxes at the water table.

Conversely, incorporating hypothetical heterogeneities into the vadose zone showed the following:

- Lower mass flux peaks at the water table and later times of occurrence of mass flux peaks at the water table
- Significantly higher moisture contents (very close to saturated conditions) within the FGUs when compared to the highest moisture contents that have been generally observed in the vadose zone beneath WMA C (see slide 25)

Key Take Home Points

- Results from alternative models with heterogeneities indicated only an incremental increase in lateral plume spreading within the vadose zone as the plumes migrate to groundwater
- Centers of mass generally remain below the source release and continue to migrate vertically downward to the underlying groundwater
- Spreading of contaminant plumes in the vadose zone leads to a decrease in predicted contaminant concentrations and later arrival of peak concentrations in groundwater