Using GoldSim to Evaluate Long-Term Performance of Underground Single-Shell Storage Tanks Containing Residual Radioactive Contamination at Hanford, Washington

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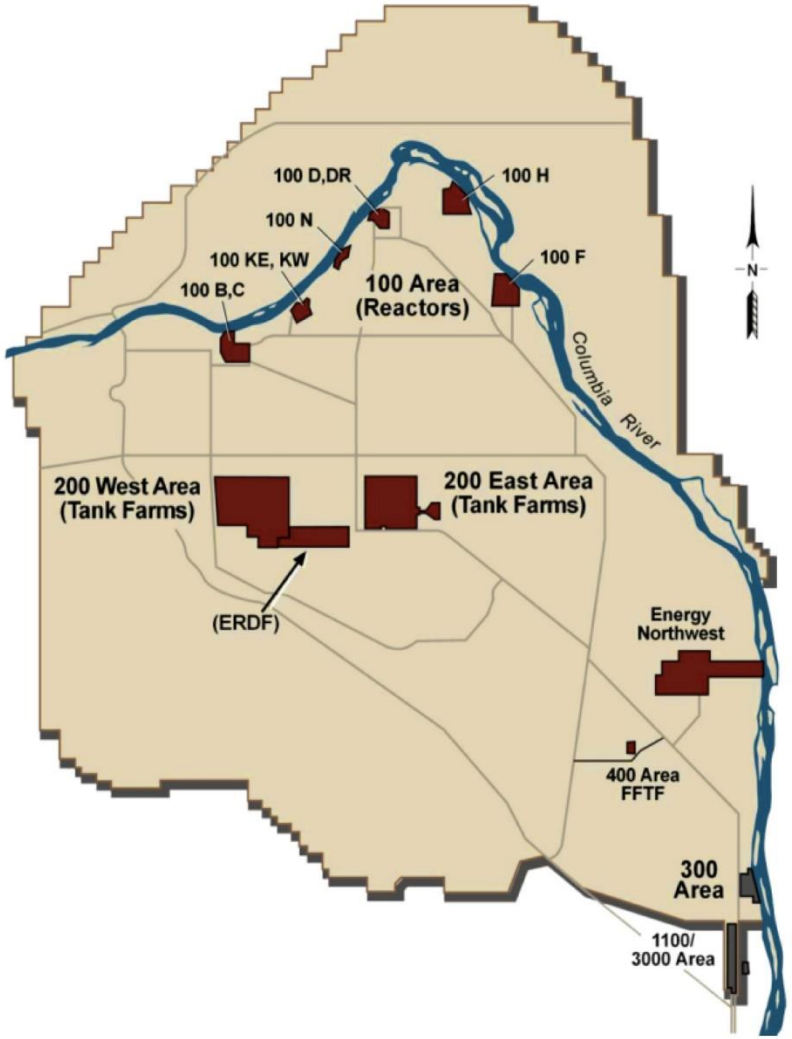
INTERA
GEOSCIENCE & ENGINEERING SOLUTIONS

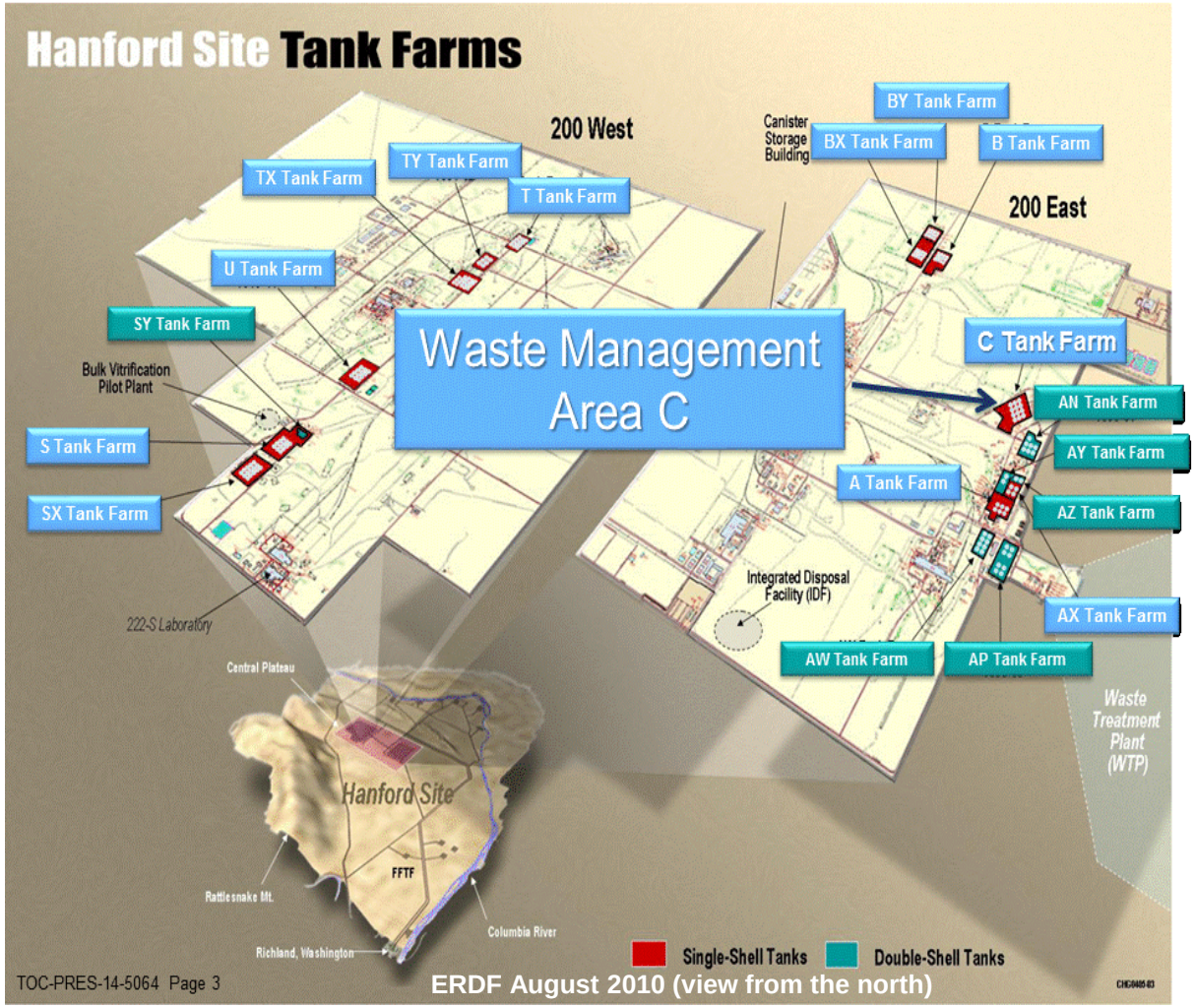
Hanford Site, Washington



- Decommissioned nuclear production complex operated by U.S. Federal Government on the Columbia River in the State of Washington.
- Occupies 586 square miles (1,518 km^2); ~half the size of Rhode Island.
- Established in 1943 as part of the Manhattan Project at Hanford, southeast Washington.
- During Cold War the project expanded to include 9 nuclear reactors (River Corridor) and large plutonium processing complexes for nuclear weapons (Central Plateau).
- In 1989 mission changed from production to clean-up of the site
  - Superfund site (CERCLA); RCRA; DOE Order

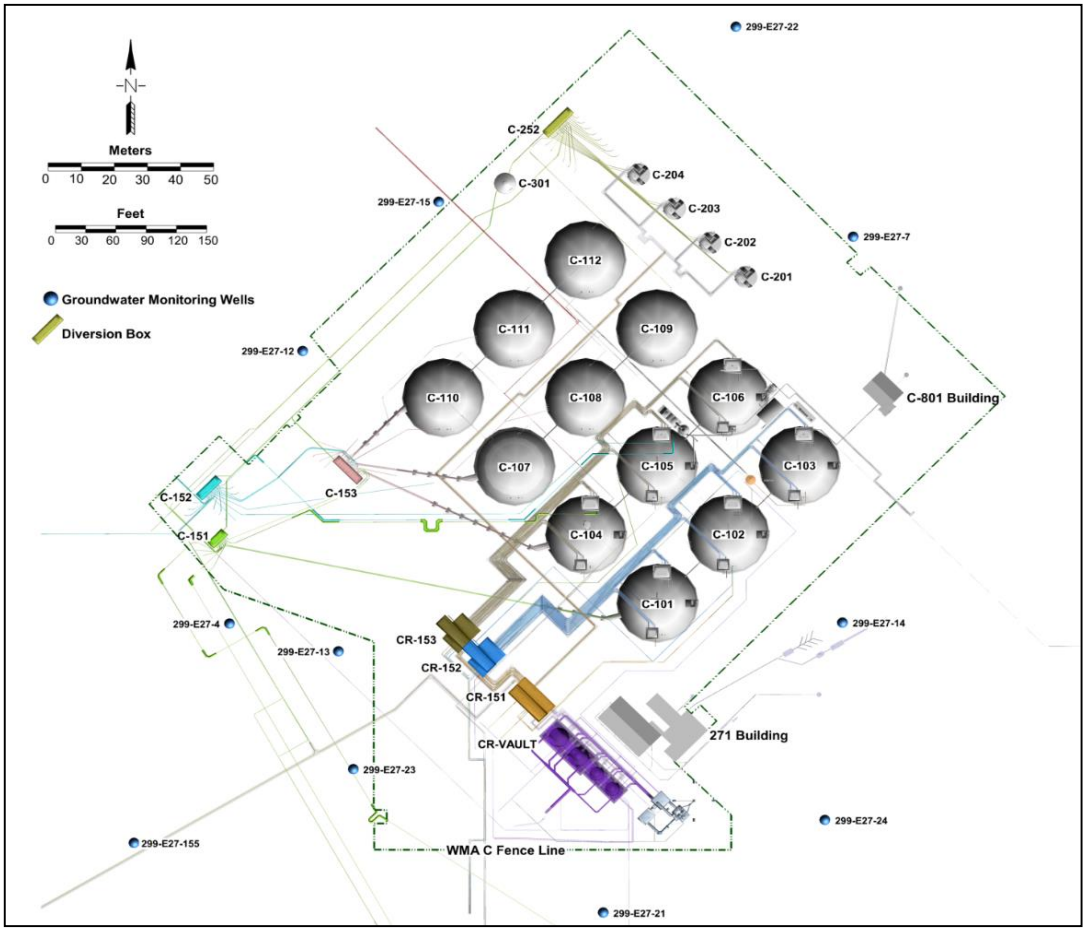
Hanford Tank Farms Layout

- Large amounts of radioactive waste was generated during operations
- 149 underground Single Shell tanks built (1943-1964)
  - 12 Single-Shell tank farms
  - All drainable liquid has been pumped out
- 28 underground Double Shell tanks built (1968-1986)
  - 6 Double-Shell tank farms
- Contains ~53 Million gallons of radioactive waste generated from processing of irradiated fuel



ERDF August 2010 (view from the north)

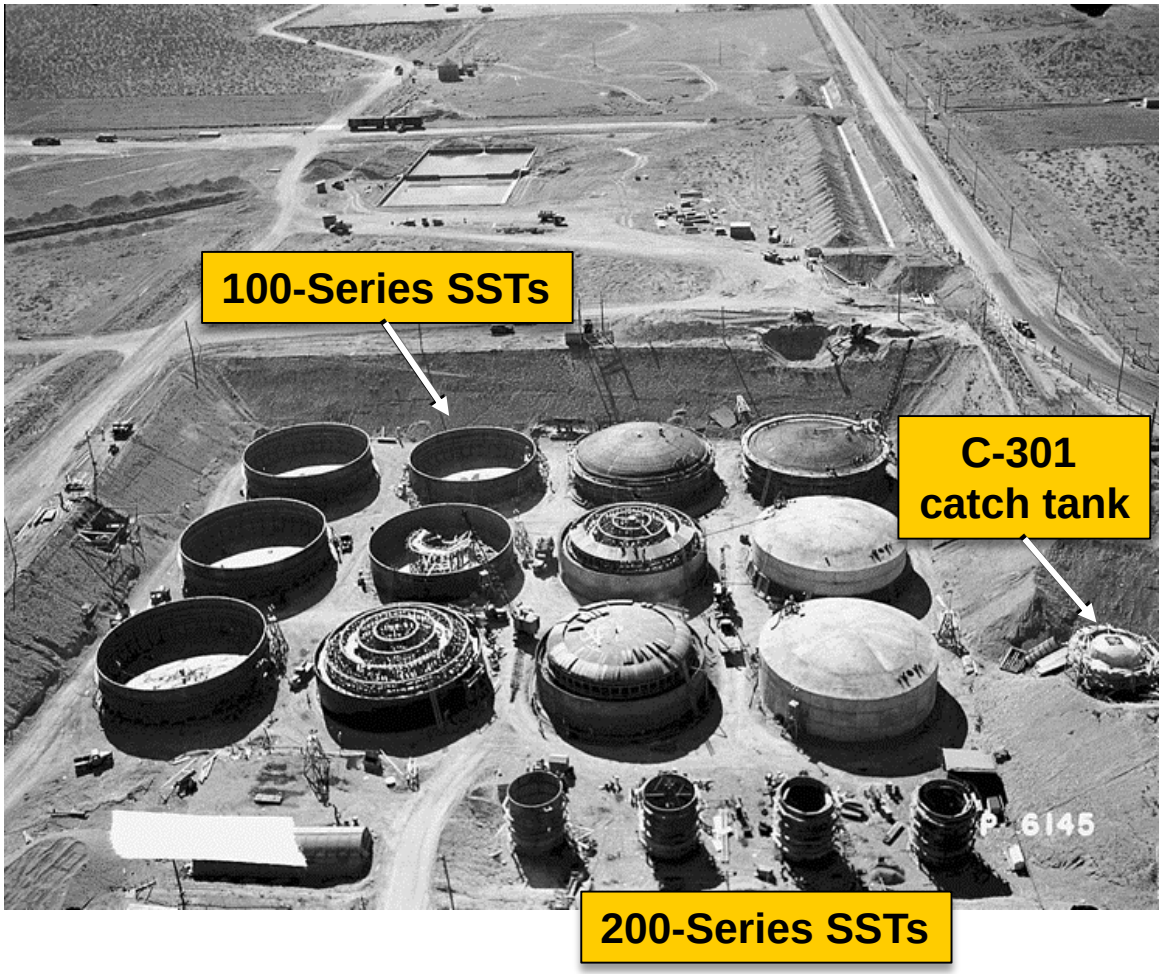
WMA C Tanks and Associated Infrastructure



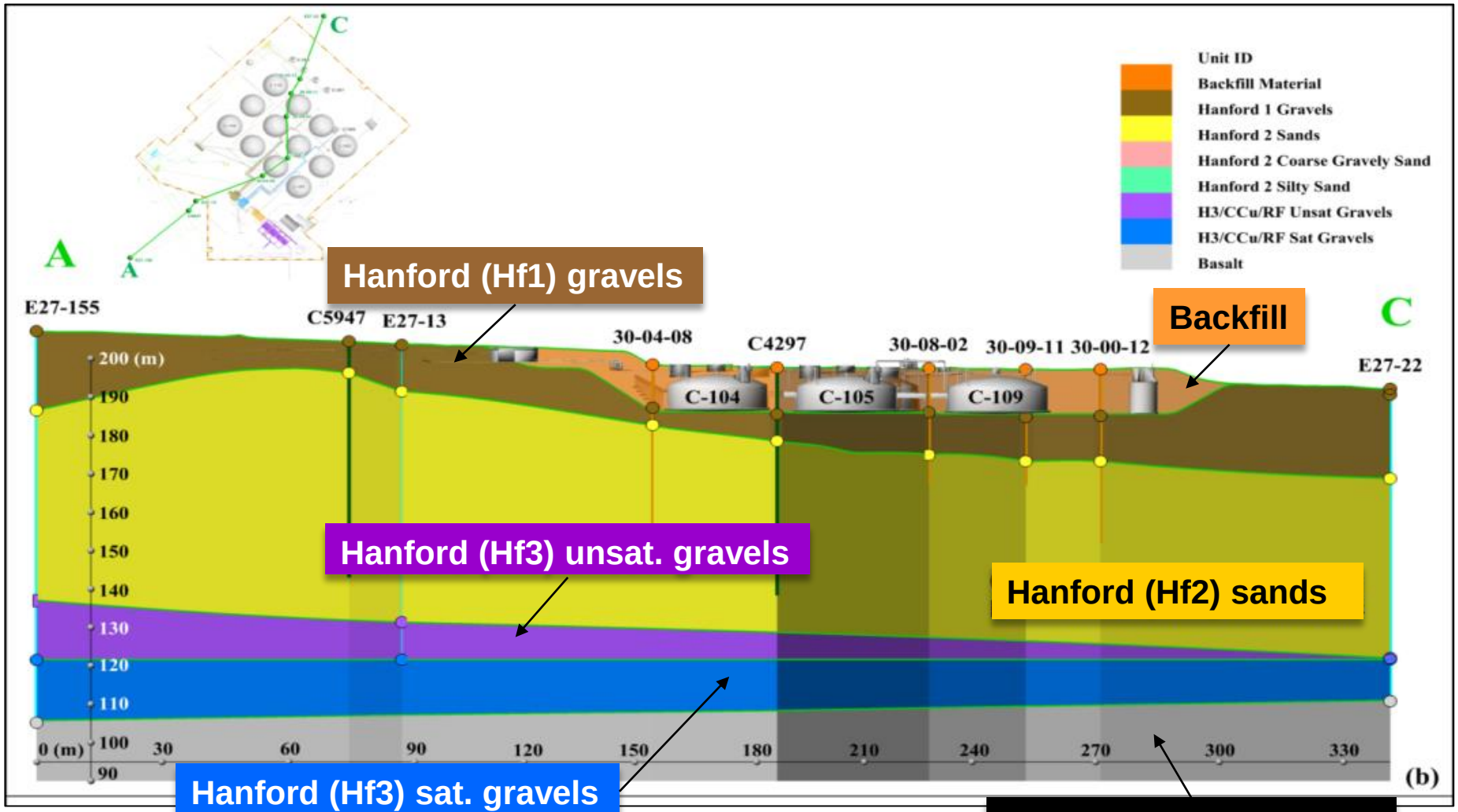
- **Twelve 100 series tanks** each with a waste capacity of 530,000 gals
- **Four 200-series tanks** each with a waste capacity of 50,000 gals and
- **Related ancillary equipment** that includes:
  - C-244 CR-Vaults
  - C-301 catch tank
  - Seven diversion boxes
  - About 7 miles of waste transfer pipelines

WMA C Tank Farm

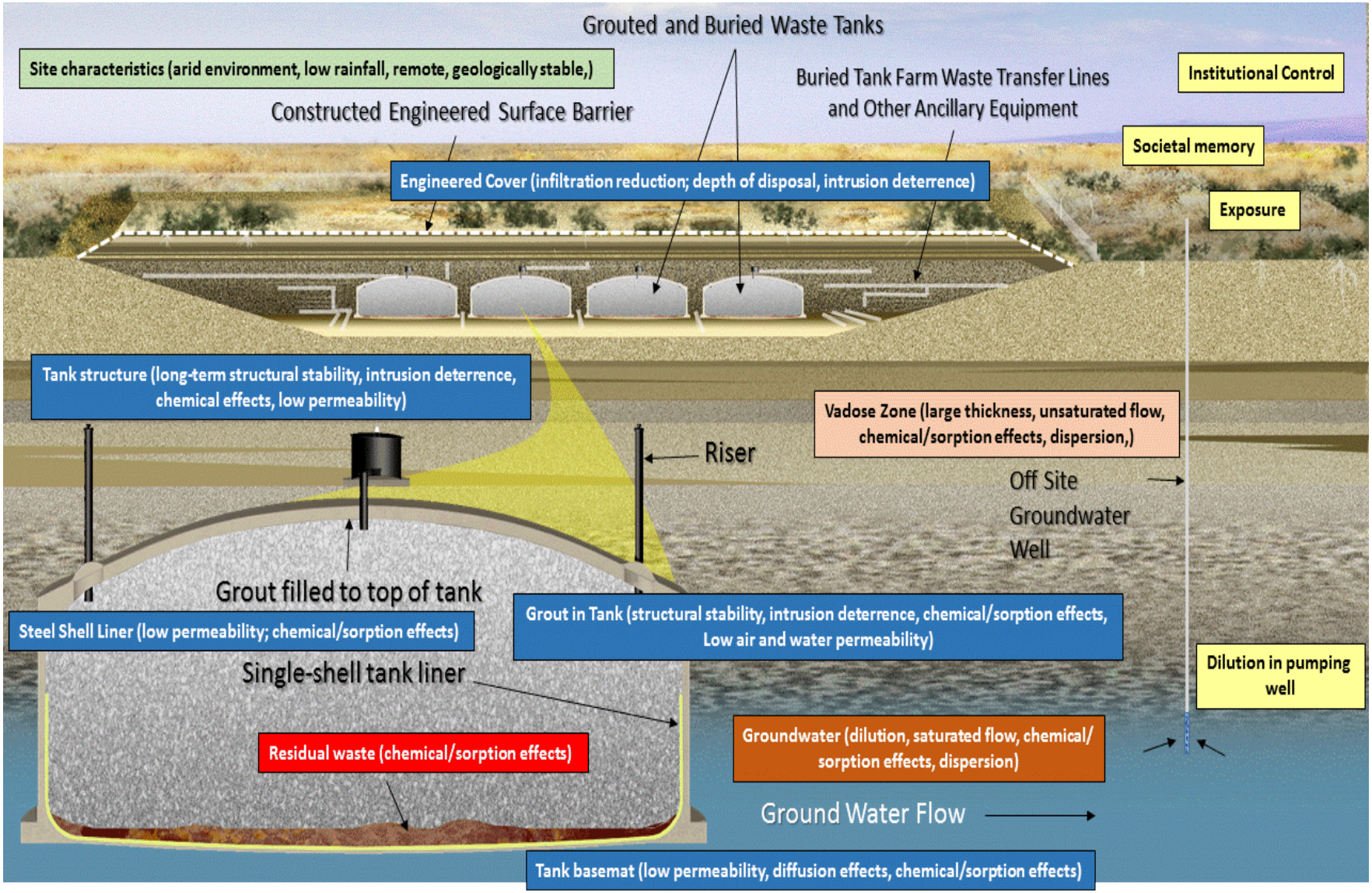
- Constructed in 1943-1944
- Operated from 1946 through mid-1980s storing and transferring waste
- Due to long operational history, WMA C received waste generated by essentially all of the Hanford Site major chemical processing operations

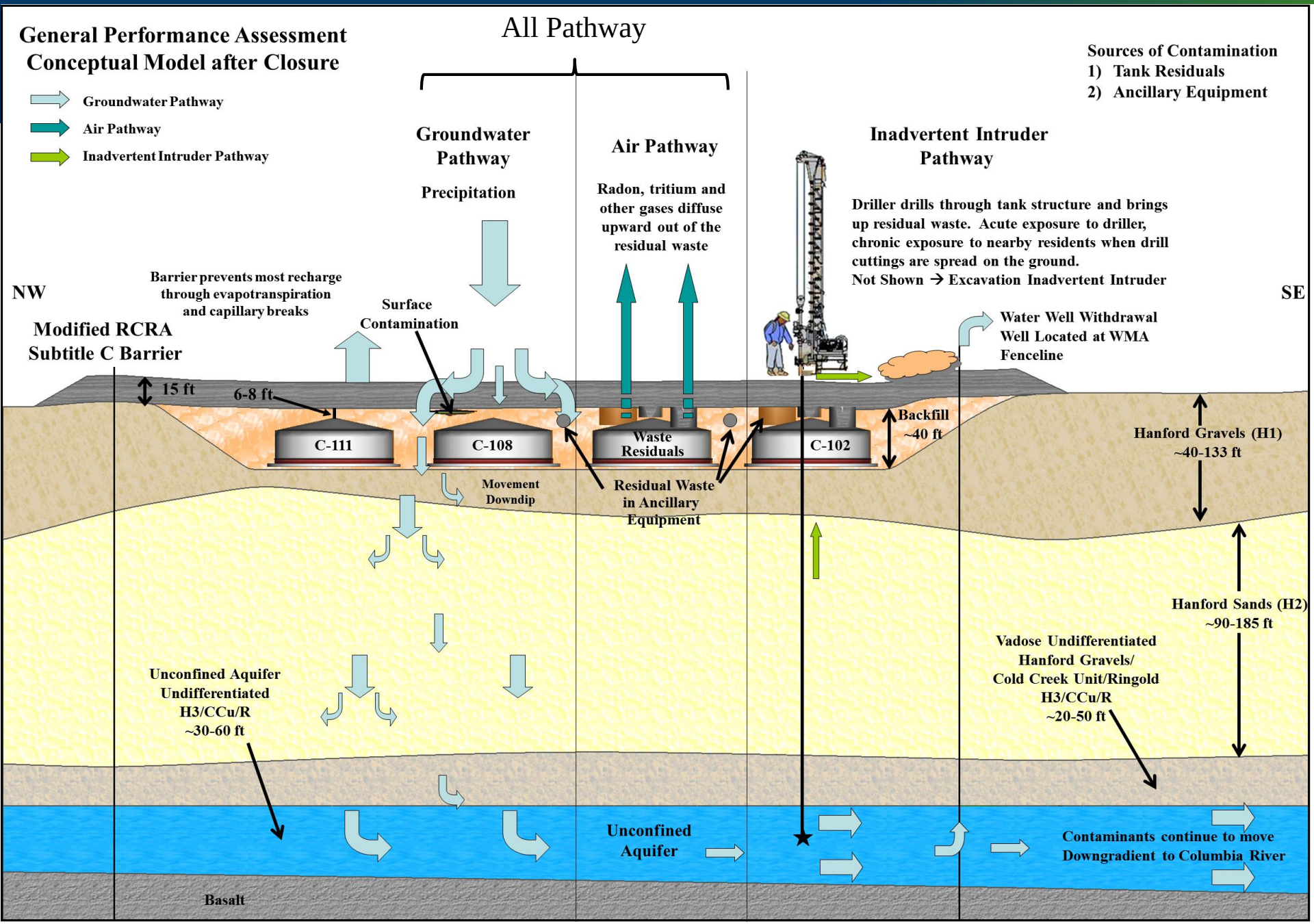


Hydrogeologic Framework

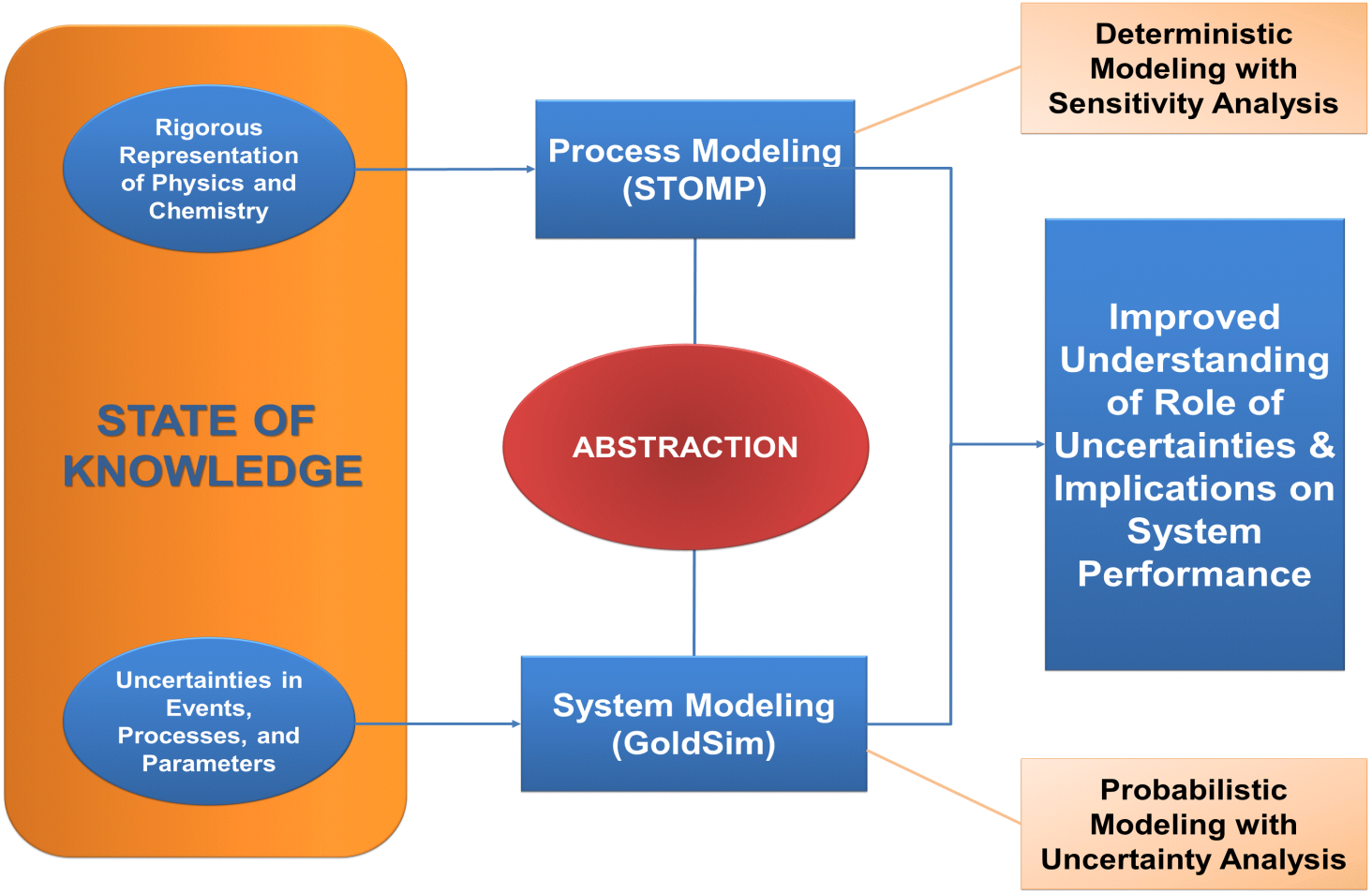


WMA C: Closure State

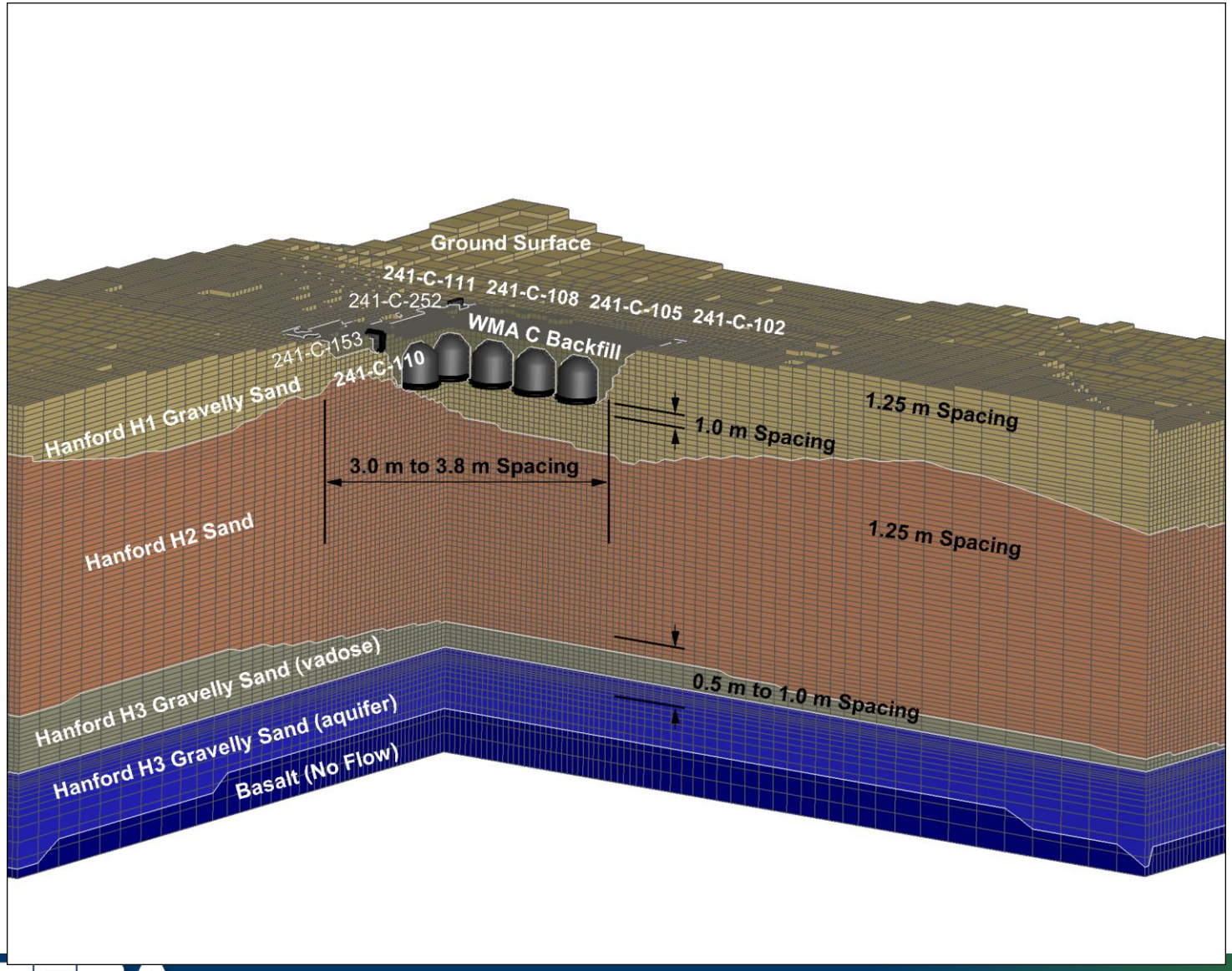



General Performance Assessment
Conceptual Model after Closure
All Pathway
Groundwater Pathway
Air Pathway
Inadvertent Intruder Pathway
Sources of Contamination
1) Tank Residuals
2) Ancillary Equipment
Groundwater Pathway
Precipitation
Air Pathway
Radon, tritium and other gases diffuse upward out of the residual waste
Inadvertent Intruder Pathway
Driller drills through tank structure and brings up residual waste. Acute exposure to driller, chronic exposure to nearby residents when drill cuttings are spread on the ground.
Not Shown → Excavation Inadvertent Intruder
NW
SE
Barrier prevents most recharge through evapotranspiration and capillary breaks
Surface Contamination
Modified RCRA Subtitle C Barrier
Water Well Withdrawal Well Located at WMA Fenceline
15 ft
6-8 ft
C-111
C-108
Waste Residuals
C-102
Backfill ~40 ft
Hanford Gravels (H1) ~40-133 ft
Movement Downdip
Residual Waste in Ancillary Equipment
Hanford Sands (H2) ~90-185 ft
Vadose Undifferentiated Hanford Gravels/ Cold Creek Unit/Ringold H3/CCu/R ~20-50 ft
Unconfined Aquifer Undifferentiated H3/CCu/R ~30-60 ft
Unconfined Aquifer
Contaminants continue to move Downgradient to Columbia River
Basalt

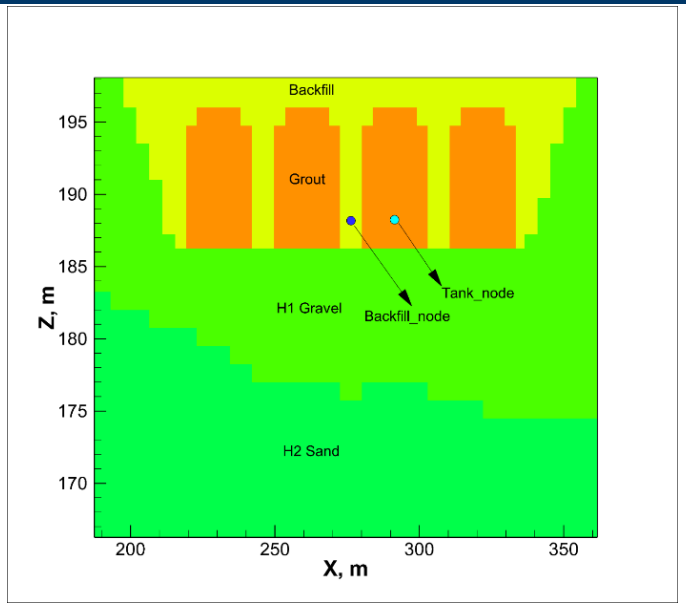
Complimentary Use of Process-Level & System-Level Models

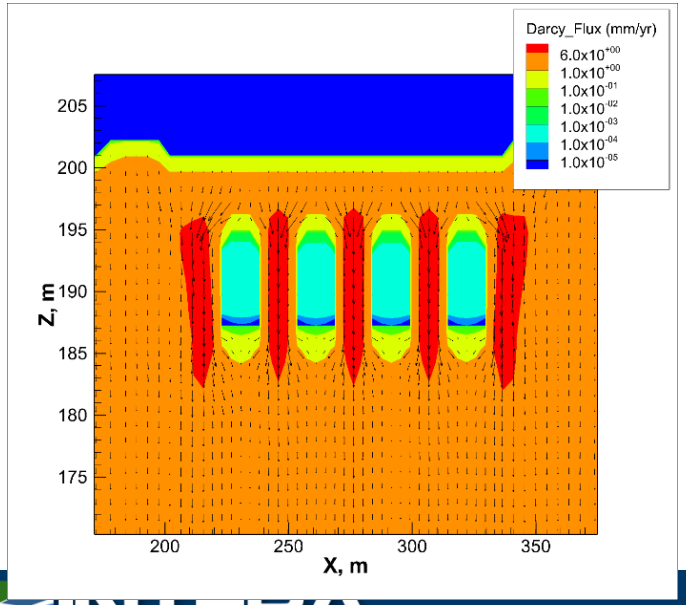


3-D Flow and Transport (Process) Model



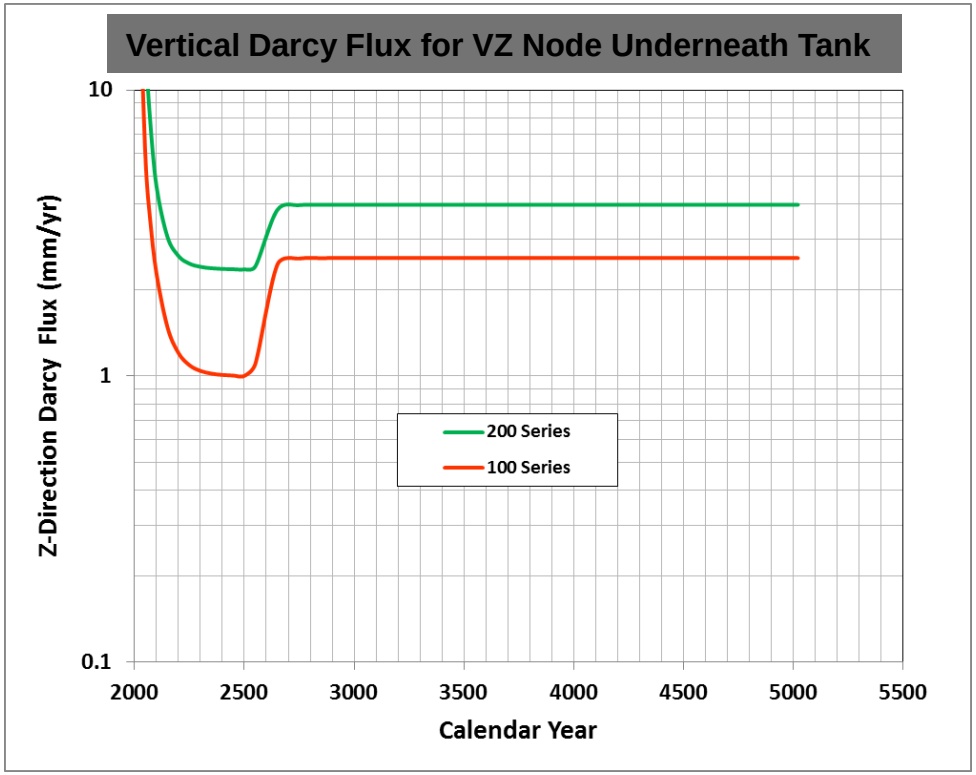
Flow-Field Abstraction (3-D F&T Model)





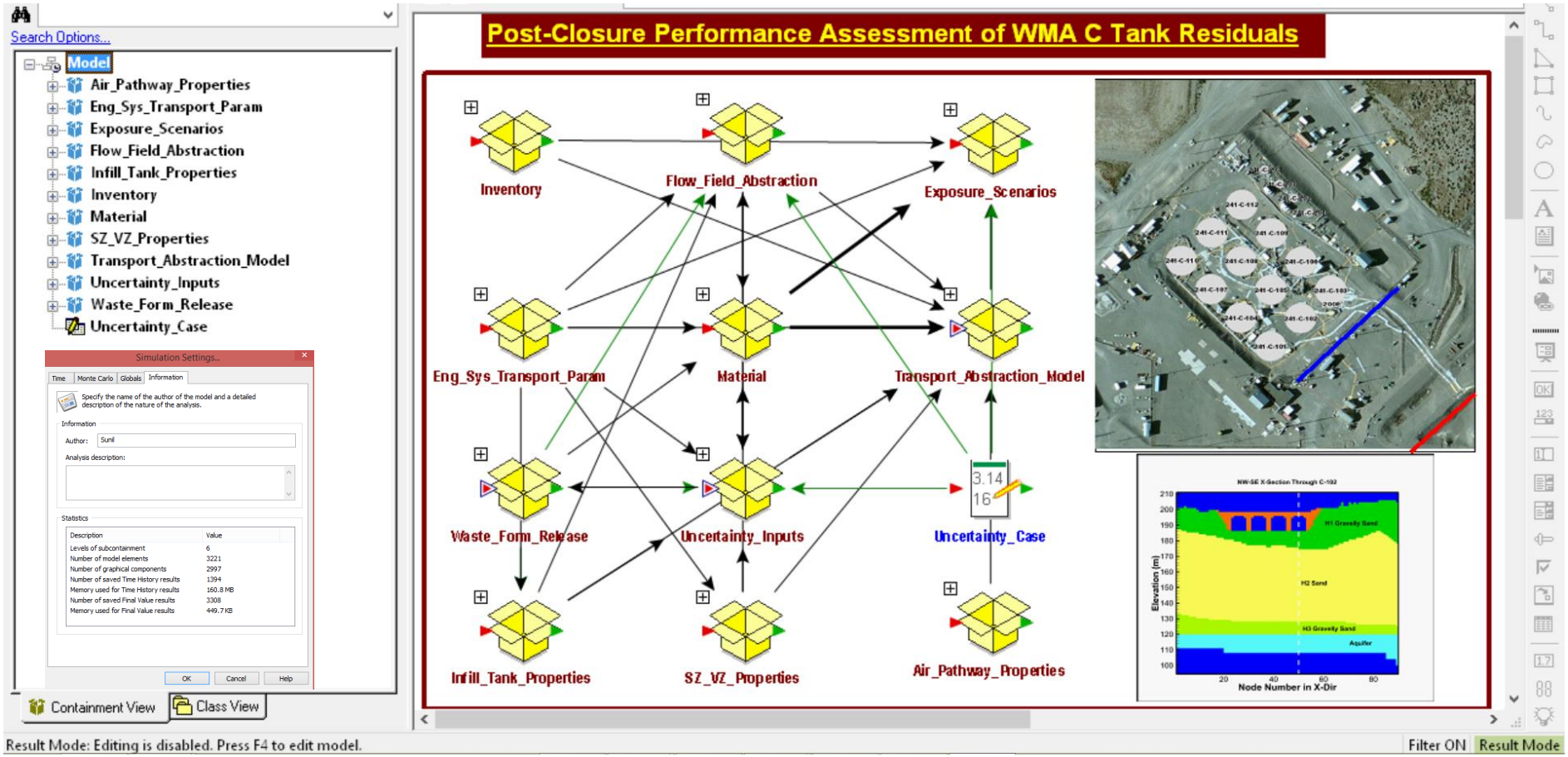
Representative geologic columns were built for 100 Series and 200 Series tanks separately

- **To differentiate any flow diversion around the tanks**
- **100 Series tanks are 75 ft in diameter compared to 20 ft for 200 Series**



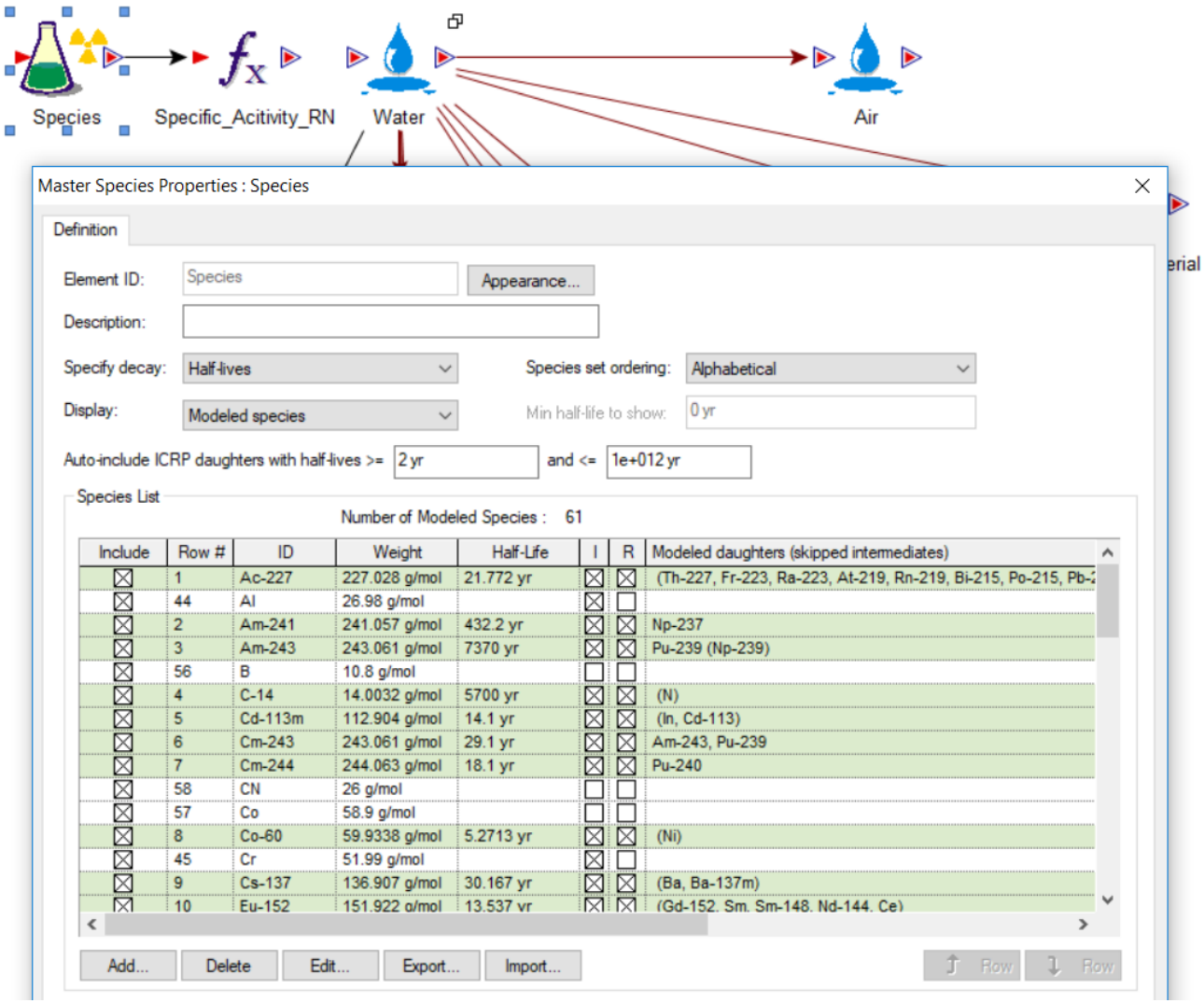
System Model – Assess Overall Performance

- Implemented using GoldSim version 11.1
- Uses RT Module



Populate the Species List

- Used the in-built ICRP database (Publication 107) of nuclide decay data
- ~40 radionuclides are considered
- ~20 chemicals are considered
- Tank residual volumes and inventories are either known (for retrieved tanks) or estimated (for tanks undergoing retrieval)



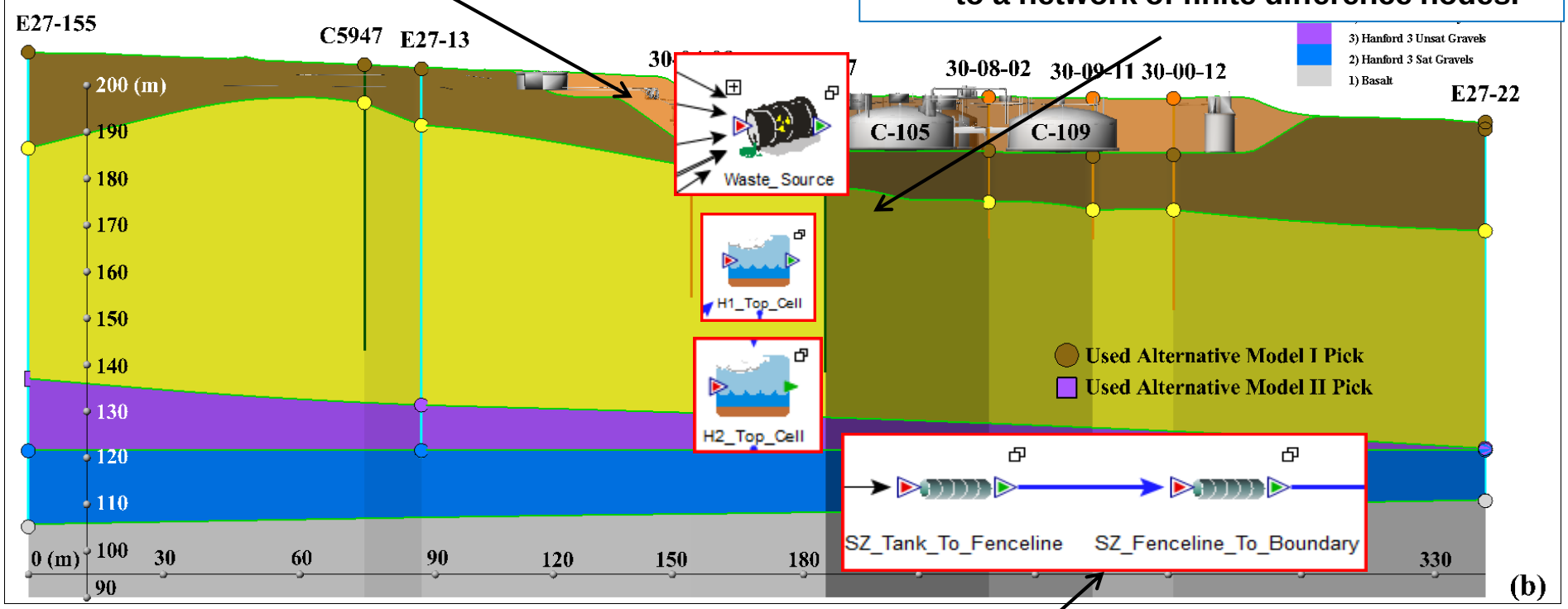
Include	Row #	ID	Weight	Half-Life	I	R	Modeled daughters (skipped intermediates)
☒	1	Ac-227	227.028 g/mol	21.772 yr	☒	☒	(Th-227, Fr-223, Ra-223, At-219, Rn-219, Bi-215, Po-215, Pb-
☒	44	Al	26.98 g/mol		☒	☐	
☒	2	Am-241	241.057 g/mol	432.2 yr	☒	☒	Np-237
☒	3	Am-243	243.061 g/mol	7370 yr	☒	☒	Pu-239 (Np-239)
☒	56	B	10.8 g/mol		☐	☐	
☒	4	C-14	14.0032 g/mol	5700 yr	☒	☒	(N)
☒	5	Cd-113m	112.904 g/mol	14.1 yr	☒	☒	(In, Cd-113)
☒	6	Cm-243	243.061 g/mol	29.1 yr	☒	☒	Am-243, Pu-239
☒	7	Cm-244	244.063 g/mol	18.1 yr	☒	☒	Pu-240
☒	58	CN	26 g/mol		☐	☐	
☒	57	Co	58.9 g/mol		☐	☐	
☒	8	Co-60	59.9338 g/mol	5.2713 yr	☒	☒	(Ni)
☒	45	Cr	51.99 g/mol		☒	☐	
☒	9	Cs-137	136.907 g/mol	30.167 yr	☒	☒	(Ba, Ba-137m)
☒	10	Eu-152	151.922 g/mol	13.537 yr	☒	☒	(Gd-152, Sm, Sm-148, Nd-144, Ce)

System Model: GoldSim Implementation

A specialized GoldSim element called Source is used to model the inventory release from waste matrix to the cell pathway

Transport model through Vadose Zone built using the Cell Pathway element

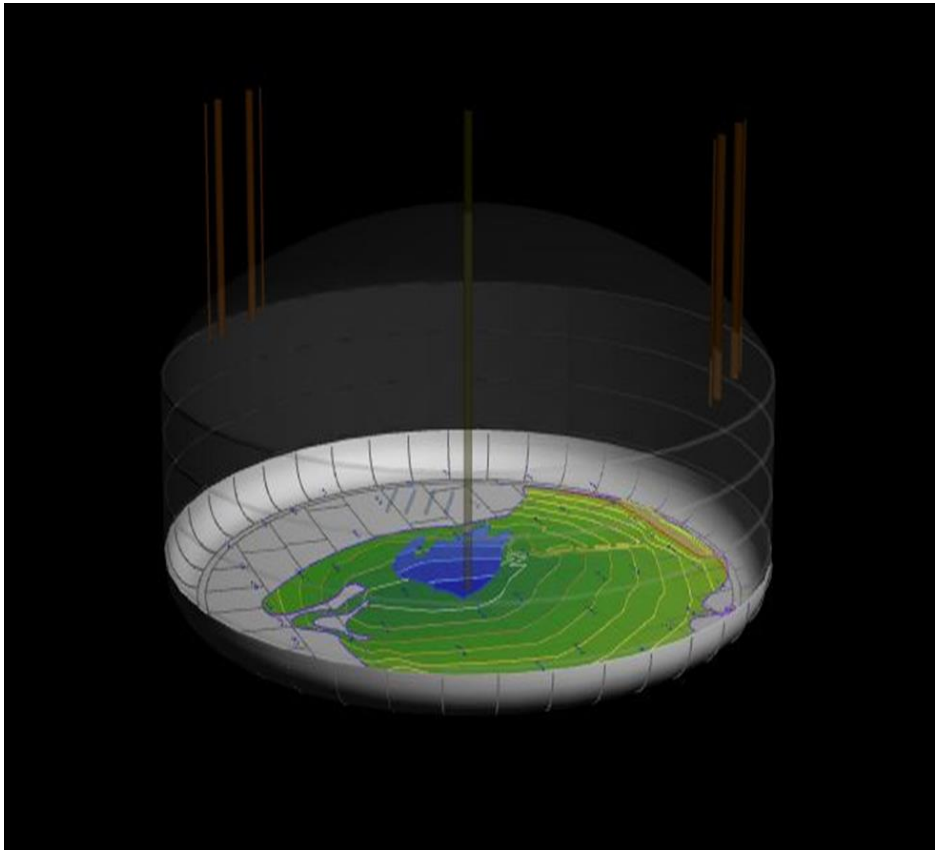
- Equivalent to batch-reactor mixing cell
- Cell network is mathematically identical to a network of finite difference nodes.

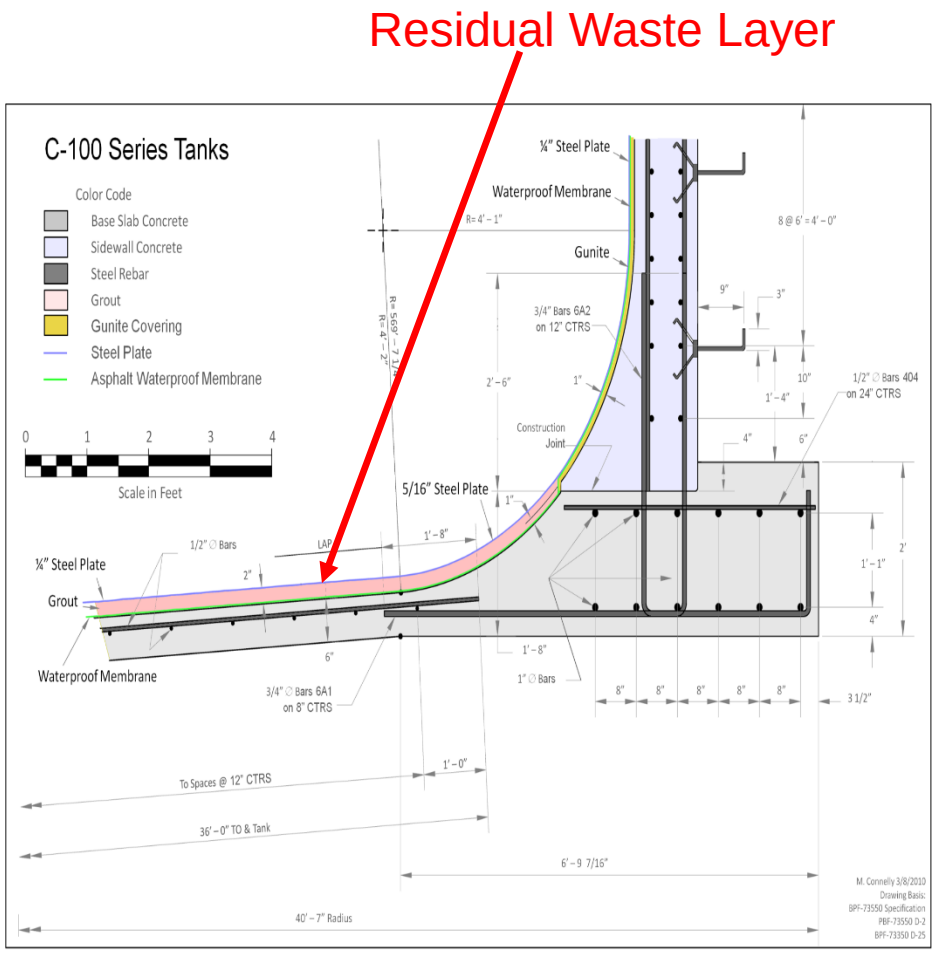


Transport through the SZ is modeled using Aquifer pathway in GoldSim

- Longitudinal dispersion is considered
- Finite difference solution method employed

Distribution of Residual Waste for a Retrieved Tank

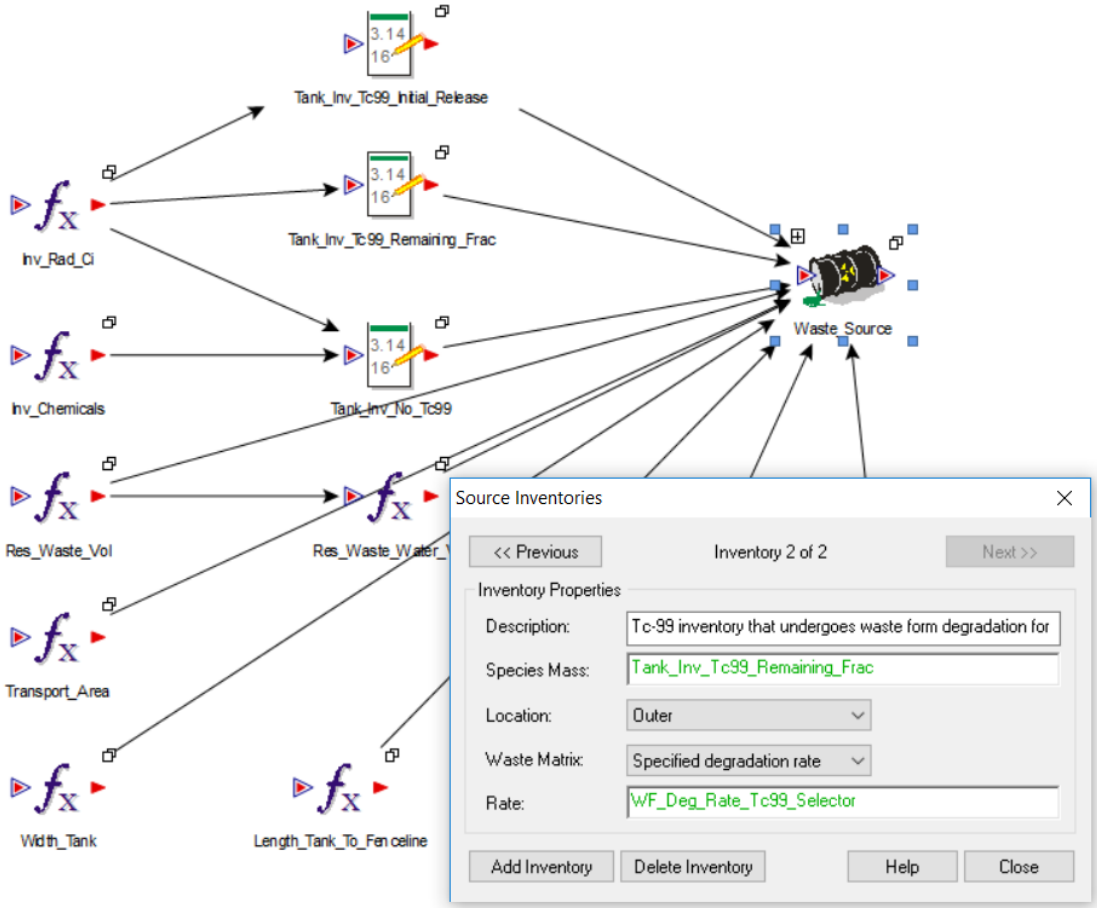


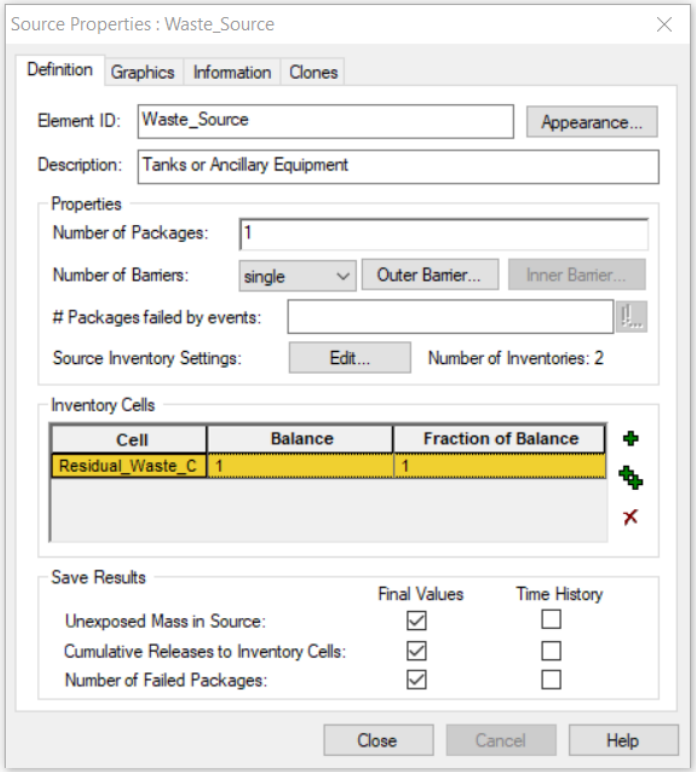


Computer-Aided Modeling Result Showing Distribution of Residual Waste for a Retrieved Tank.

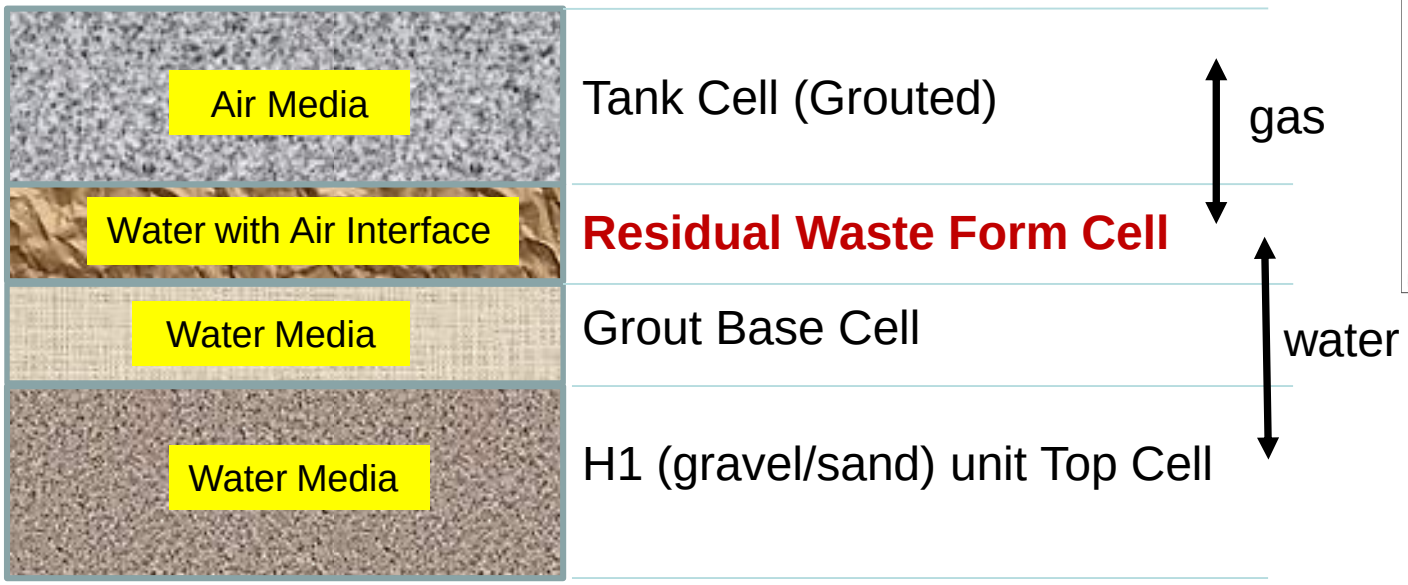
Source Term For a Given Tank

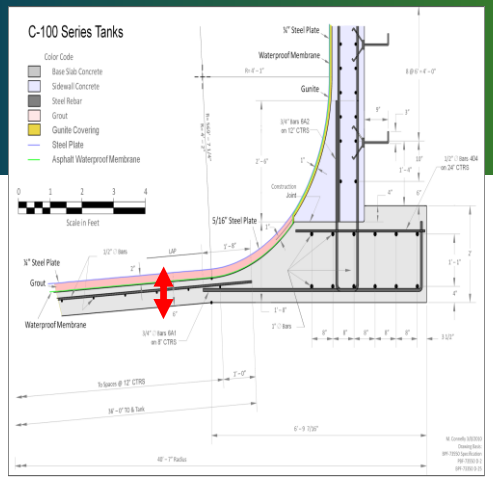
A specialized GoldSim element called Source is used to model the inventory release from waste matrix to the cell pathway (e.g. Tc-99)





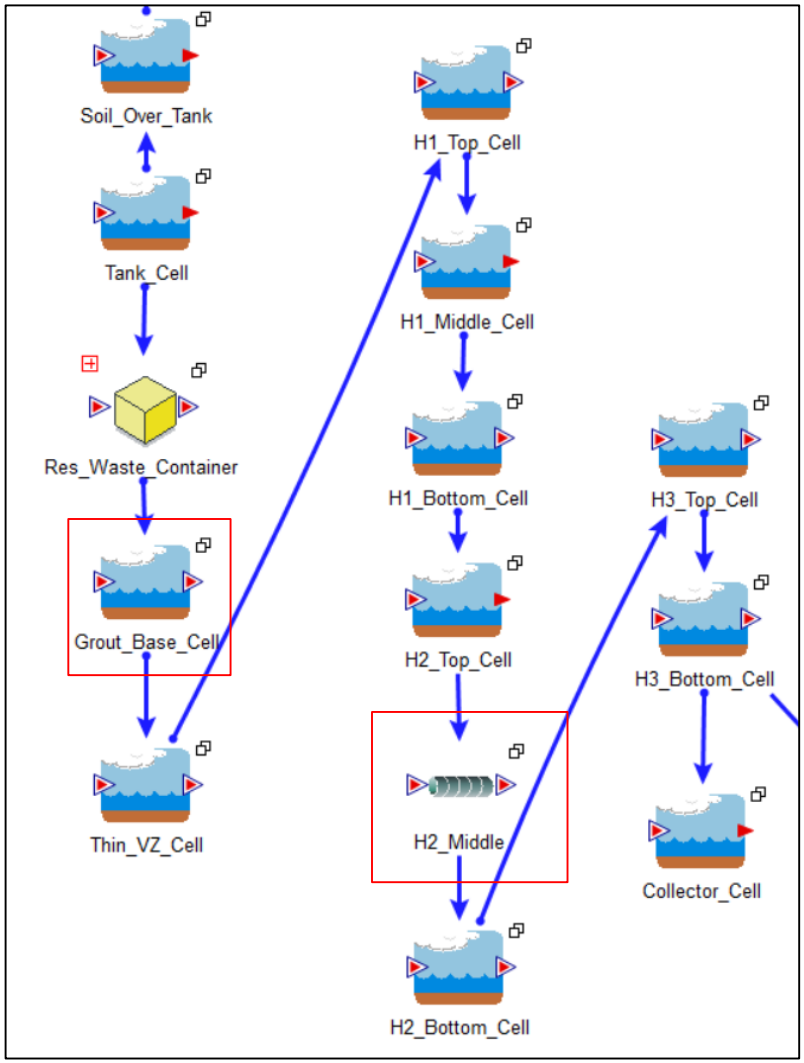
Residual Waste Release

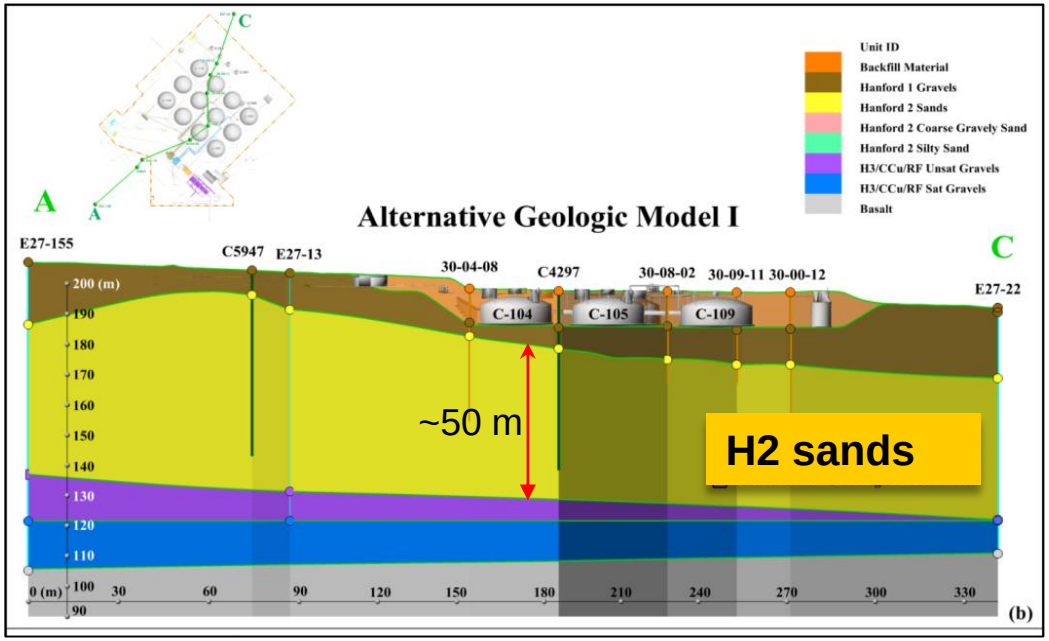




- Residual waste is assumed fully saturated with a porosity of 40%
- Thickness of waste layer is assumed zero for diffusion calculation
- Shortest diffusive path out of tank considered
  - Across the base pad (2" grout + 6" concrete)
  - No credit taken for steel liner
- Vadose zone underneath the source is modeled (as part of System Model); the 3-D F&T model abstracted flow-field provides appropriate boundary conditions for diffusive flux calculations out of the base of the tanks
- The mass flux from the source term is provided to the 3-D F&T model for modeling transport through the VZ and SZ (in addition to the System Model)

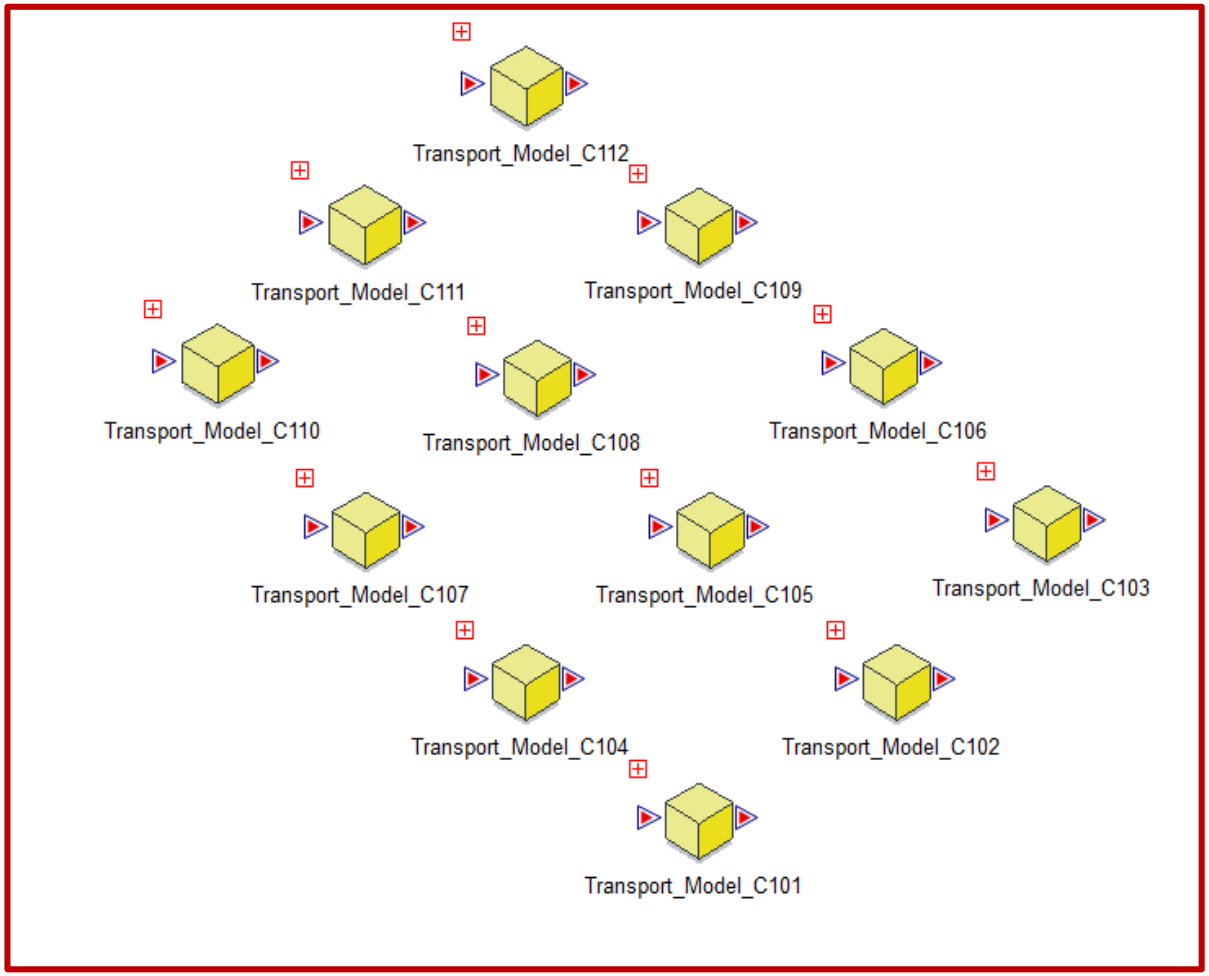
Cell-Net for Vadose Zone





Application of Cloning in GoldSim

- Due to similarity in tank configuration and source release processes, cloning of containers was undertaken
- All 100-Series tanks were cloned separate from the 200-Series tanks due to size and location differences
- Representative vadose zone columns are different under 100-Series and 200-Series tanks
- Differences among tanks were inventory and residual waste volume



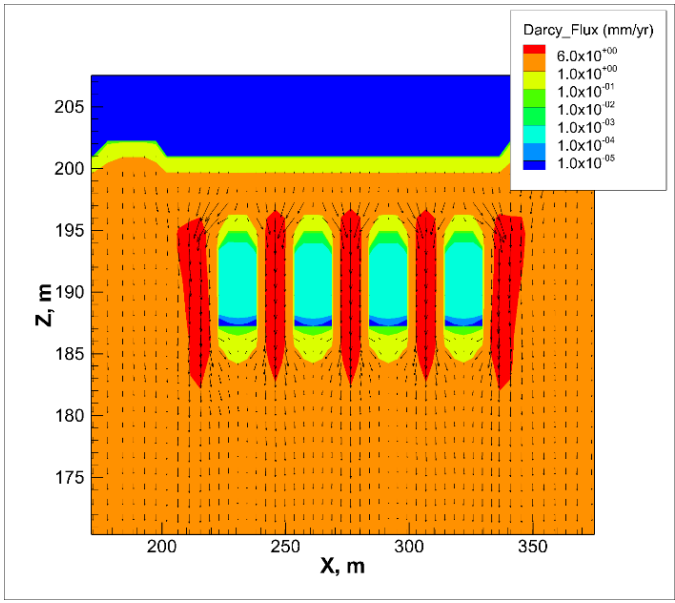
Flow-Field Abstraction Approach

The Contaminant Transport module in GoldSim requires Flow-Field information to be provided

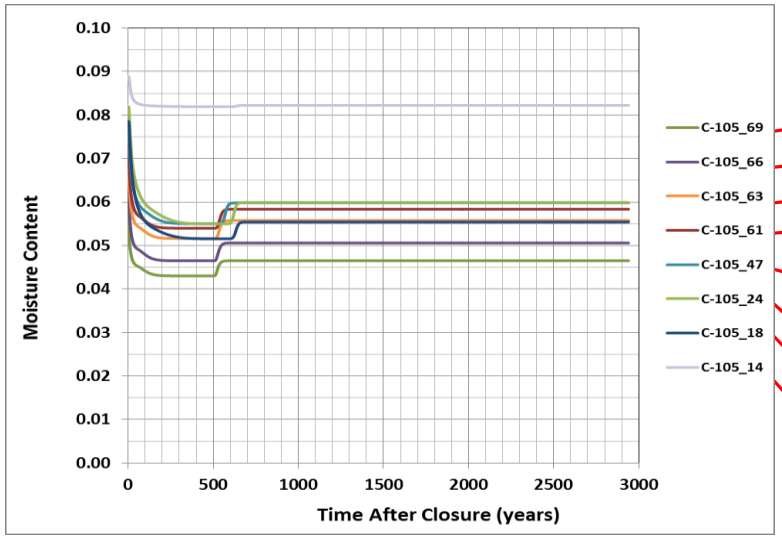
- **Darcy flux**
- **Moisture content**

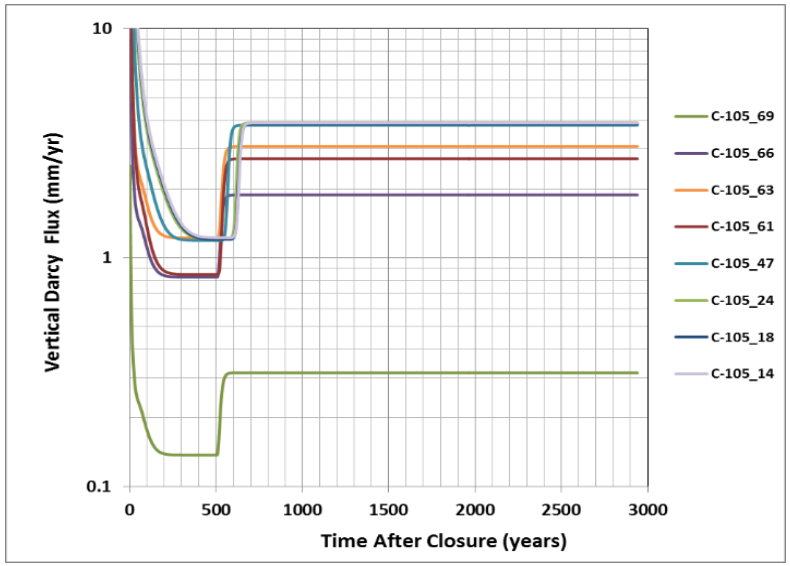
- **Flow-field abstracted from 3-D Flow & Transport (F&T) model results**

- **Some aspects considered in developing an abstraction model for WMA C PA are:**
  - **Spatial and temporal variability in recharge**
  - **Spatial variability in flow underneath the tank**
  - **Variable thickness of hydrostratigraphic units (HSUs)**
  - **Variable distances from tanks to the 100 m boundary**



Flow Field for 100-Series Tanks

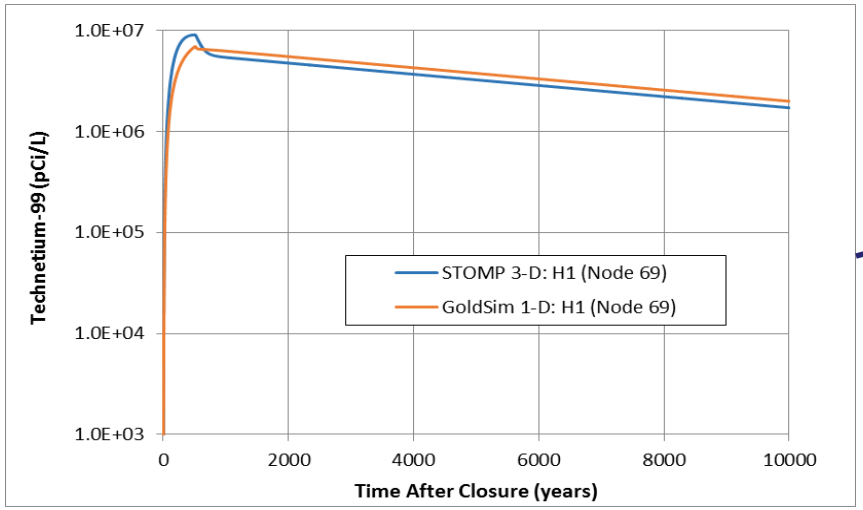


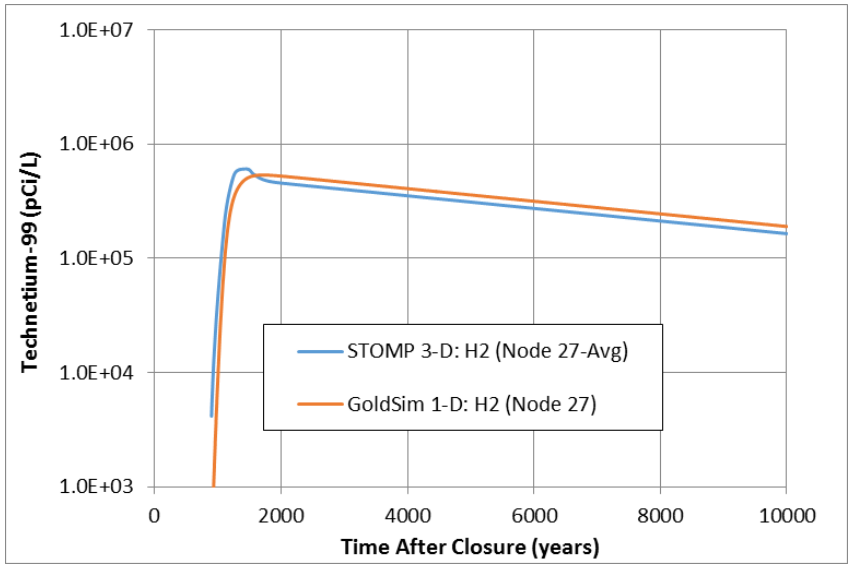


HSU	STOMP			GoldSim
Hydrostratigraphy Below C-105	STOMP Node Elevation (m)	STOMP Node Numbers	STOMP Vertical Discretization (m)	GoldSim Vertical Discretization (m)
H1 Gravelly Sand	185.75	69	1.00	2 m
	184.75	68	1.00	
	183.75	67	1.00	3.5 m
	182.625	66	1.25	
	181.375	65	1.25	
	180.125	64	1.25	3.75 m
	178.875	63	1.25	
	177.625	62	1.25	
H2 Sand	176.375	61	1.25	3.75 m
	175.125	60	1.25	
	173.875	59	1.25	
	172.625	58	1.25	2 m (over 40 m thickness)
	171.375	57	1.25	
	170.125	56	1.25	
	168.875	55	1.25	
	167.625	54	1.25	
	166.375	53	1.25	
	165.125	52	1.25	
	163.875	51	1.25	
	162.625	50	1.25	
	161.375	49	1.25	
	160.125	48	1.25	
	158.875	47	1.25	
	157.625	46	1.25	
	156.375	45	1.25	
	155.125	44	1.25	
	153.875	43	1.25	
	152.625	42	1.25	
	151.375	41	1.25	
	150.125	40	1.25	
	148.875	39	1.25	
	147.625	38	1.25	
	146.375	37	1.25	
	145.125	36	1.25	
	143.875	35	1.25	
	142.625	34	1.25	
	141.375	33	1.25	
	140.125	32	1.25	
	138.875	31	1.25	
	137.625	30	1.25	
	136.375	29	1.25	
	135.125	28	1.25	
	133.875	27	1.25	
	132.75	26	1.00	5 m
	131.75	25	1.00	
	130.75	24	1.00	
	129.75	23	1.00	
	128.75	22	1.00	
H3 Gravelly Sand	127.75	21	1.00	7 m
	126.75	20	1.00	
	125.75	19	1.00	
	124.75	18	1.00	
	123.75	17	1.00	
	122.75	16	1.00	
	121.75	15	1.00	
	120.875	14	0.75	1.25 m
	120.25	13	0.50	
Aquifer	119.75	12	0.50	12 m
	119.25	11	0.50	
	118.625	10	0.75	
	117.75	9	1.00	
	116.625	8	1.25	
	115.25	7	1.50	
	113.75	6	1.50	
	112	5	2.00	
	109.5	4	3.00	
Inactive	106	3	4.00	
	102	2	4.00	
	97.5	1	5.00	

Node used in Flow Field abstraction

Transport: Comparison with 3-D F&T Model





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	165.125	52	1.25	
	163.875	51	1.25	
	162.625	50	1.25	
	161.375	49	1.25	
	160.125	48	1.25	
	158.875	47	1.25	
	157.625	46	1.25	
	156.375	45	1.25	
	155.125	44	1.25	
	153.875	43	1.25	
	152.625	42	1.25	
	151.375	41	1.25	
	150.125	40	1.25	
	148.875	39	1.25	
	147.625	38	1.25	
	146.375	37	1.25	
	145.125	36	1.25	
	143.875	35	1.25	
	142.625	34	1.25	
	141.375	33	1.25	
	140.125	32	1.25	
	138.875	31	1.25	
	137.625	30	1.25	
	136.375	29	1.25	
	135.125	28	1.25	
	[illegible]	27	1.25	
	132.75	26	1.00	5 m
	131.75	25	1.00	
	130.75	24	1.00	
	129.75	23	1.00	
	128.75	22	1.00	
H3 Gravelly Sand	127.75	21	1.00	7 m
	126.75	20	1.00	
	125.75	19	1.00	
	124.75	18	1.00	
	123.75	17	1.00	
	122.75	16	1.00	
	121.75	15	1.00	
	120.875	14	0.75	1.25 m
	120.25	13	0.50	
Aquifer	119.75	12	0.50	12 m
	119.25	11	0.50	
	118.625	10	0.75	
	117.75	9	1.00	
	116.625	8	1.25	
	115.25	7	1.50	
	113.75	6	1.50	
	112	5	2.00	
	109.5	4	3.00	
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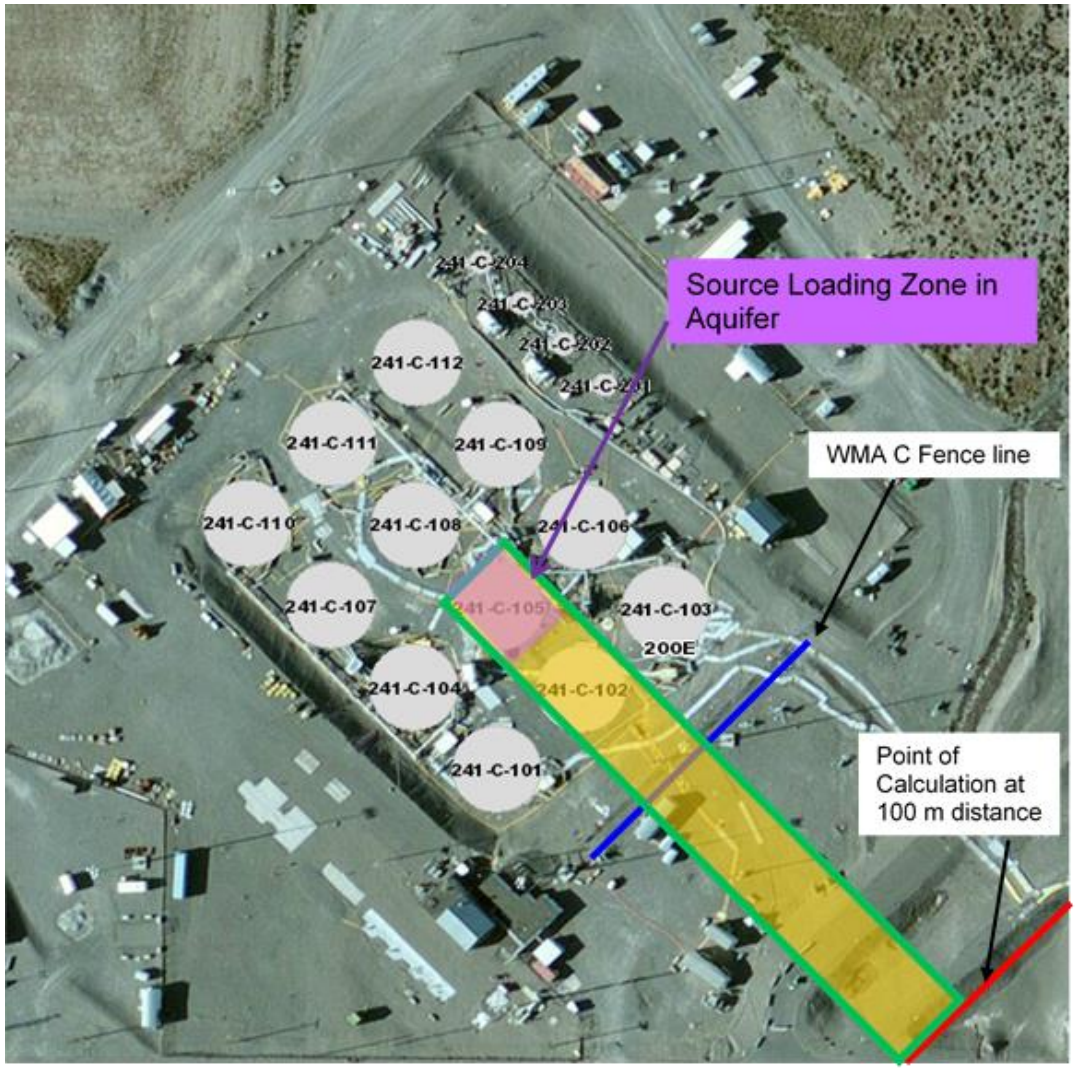
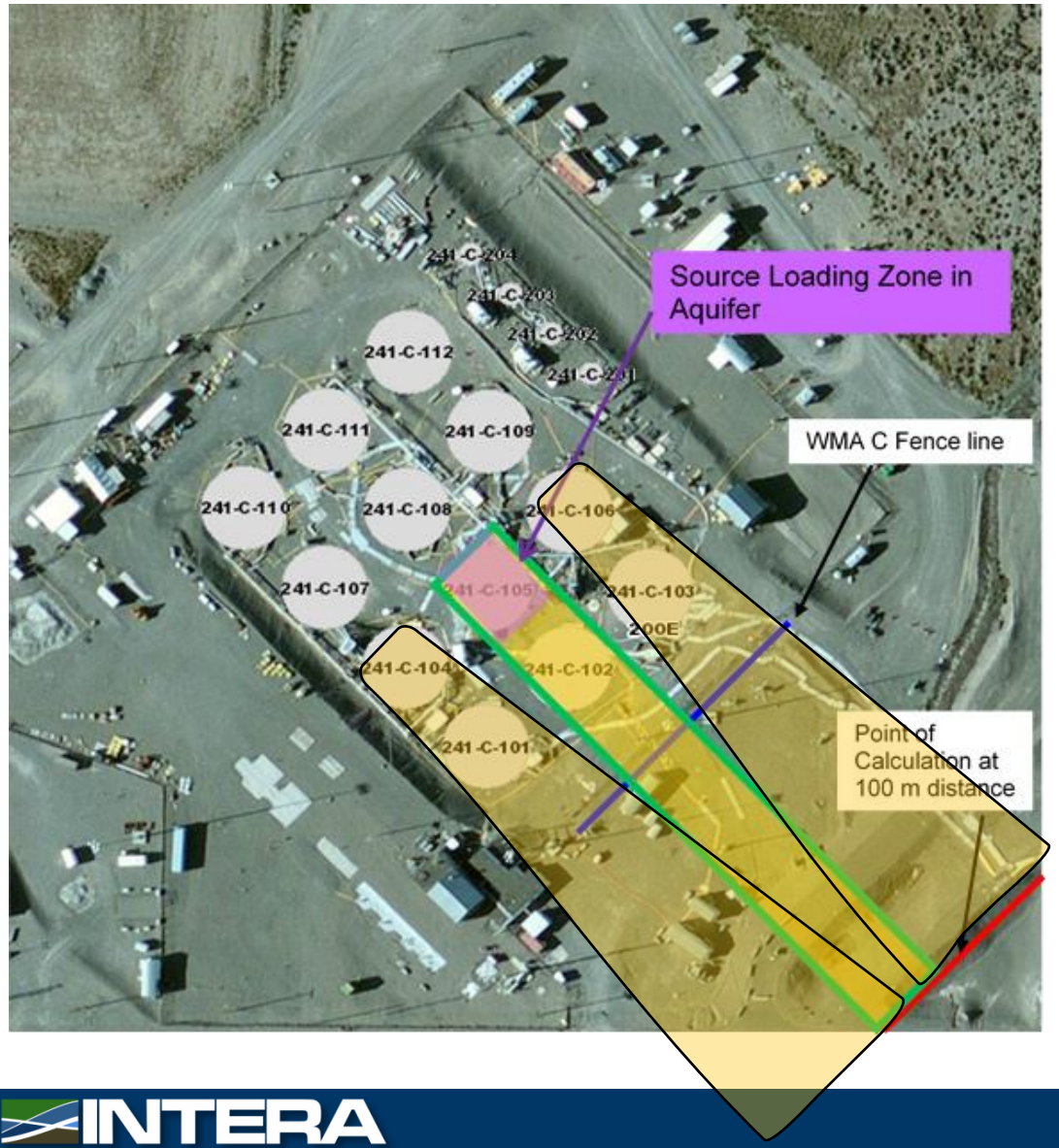
Node used in Flow-Field abstraction

Implementation of Aquifer Pathway



- Implemented using Aquifer Pathway
- Transport in the aquifer is performed by collecting the flux from the base of vadose zone (for each source) and distributing the mass in the aquifer over the “source zone length”

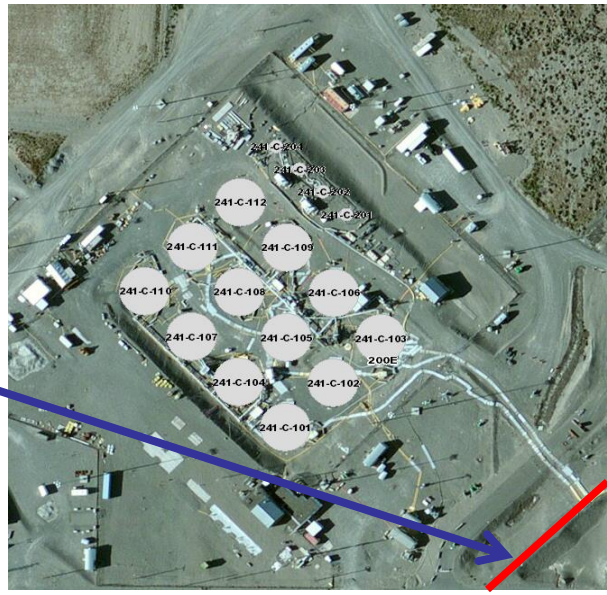
Implementation of Aquifer Pathway



Effect of commingling from lateral dispersion from parallel flow paths are accounted

- Using Plume function

Comparison in Saturated Zone at 100 m

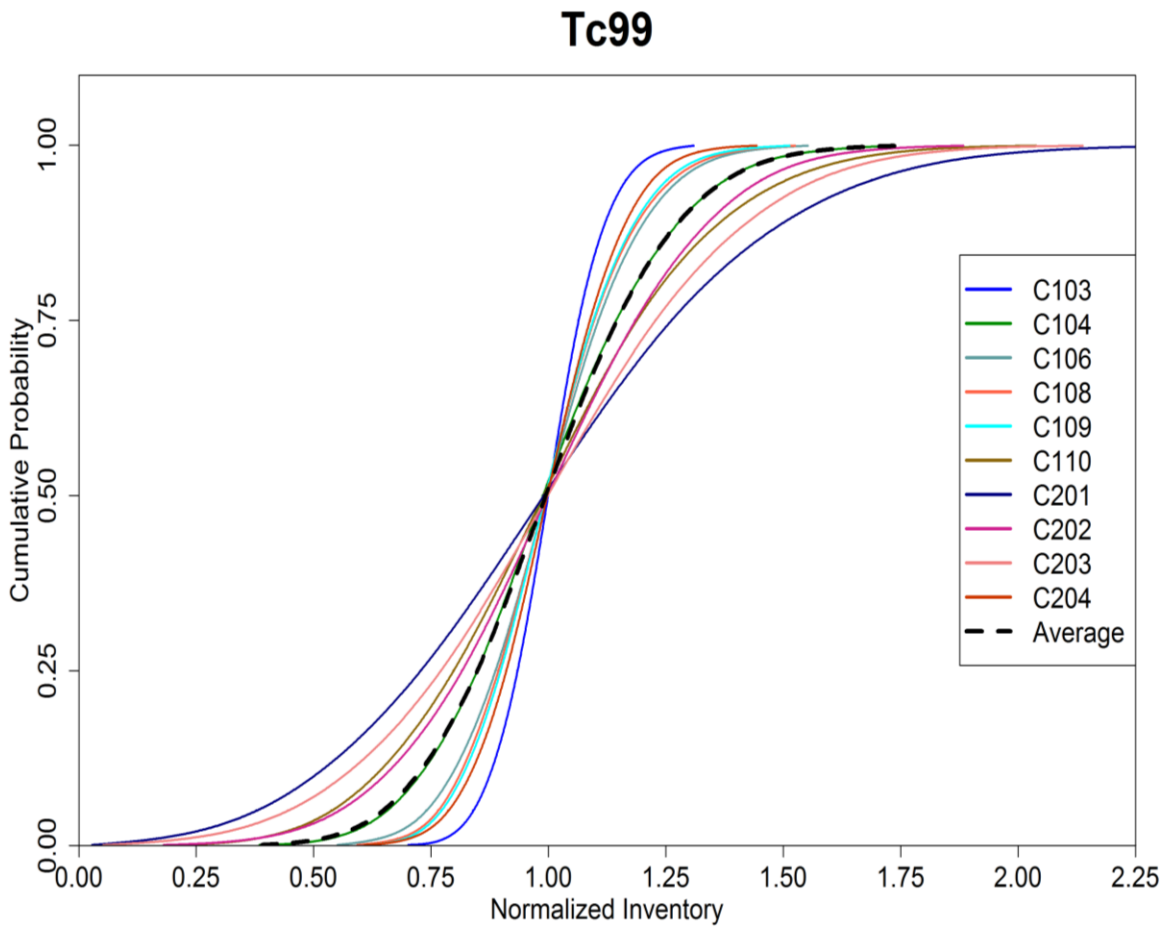


Uncertainty Analysis

- Uncertainty analysis was conducted to evaluate the impact of parameter uncertainty on total dose.
- Parameter uncertainty developed for:
  - recharge rates
  - residual inventory
  - waste release and source-term parameters
  - vadose zone flow and transport parameters
  - saturated zone flow and transport parameters
  - atmospheric transport parameters

Number of Uncertain Parameters : 130

Uncertainty in Residual Inventory



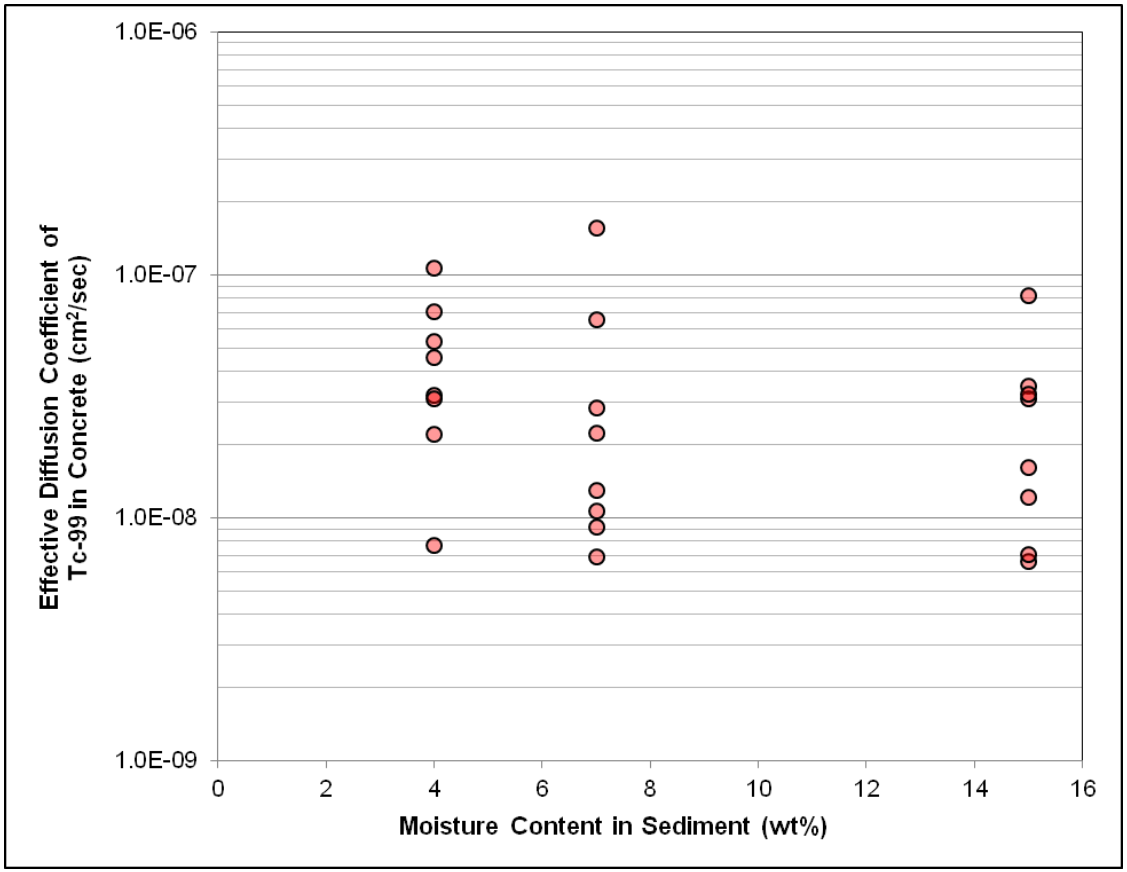
Uncertainty range presented by normalizing to the mean value

- Reflects variability in sampling within a given tank
- Reflects varying types of mineral-waste phases (primarily Al and Fe hydroxides/oxyhydroxide mineral phases)

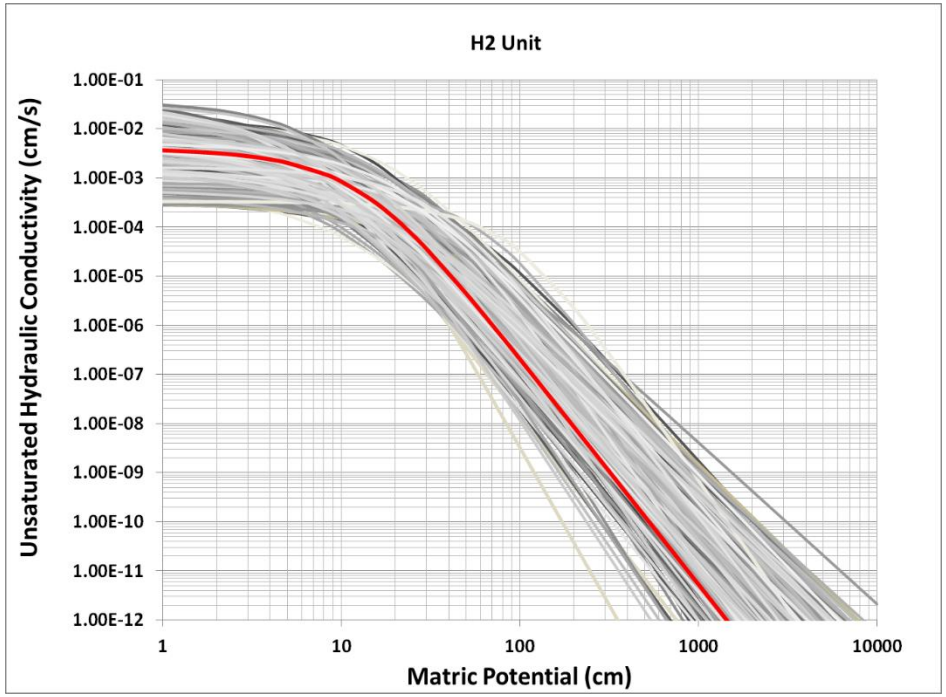
Average CDF varies from 0.4 to 1.75

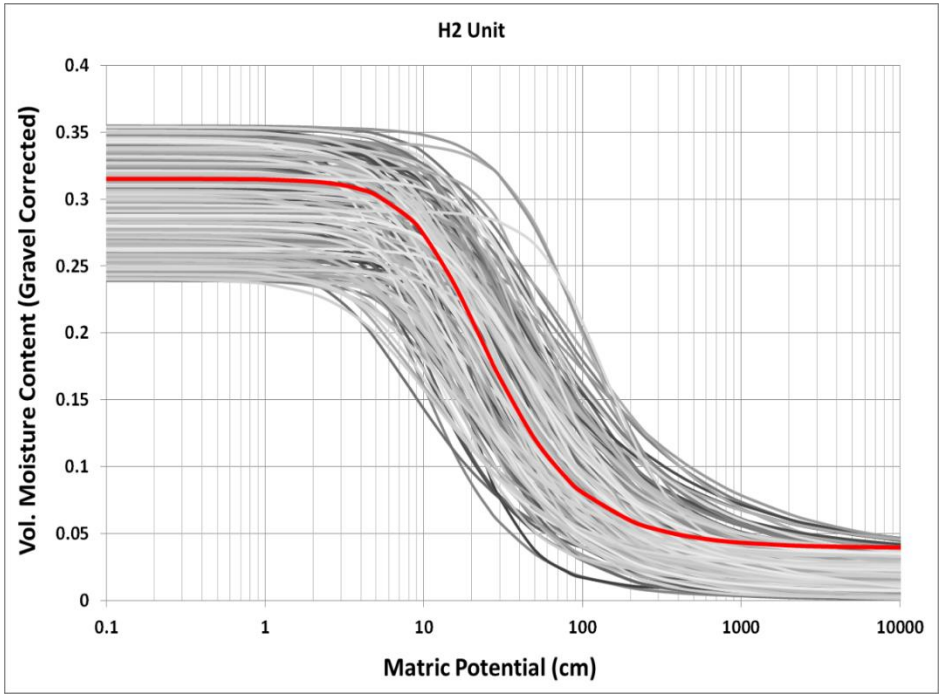
Uncertainty in Concrete Diffusion Coefficient

- Uncertainty in effective diffusion coefficient through the concrete/grout within the tank is based on range of ^{99}Tc diffusion coefficients derived from the sediment-concrete half-cell experiments (PNNL-23841)
- A log-uniform distribution is selected to range from 6E-9 to 2E-7 cm^2/s
  - Median = 3E-8 cm2/s



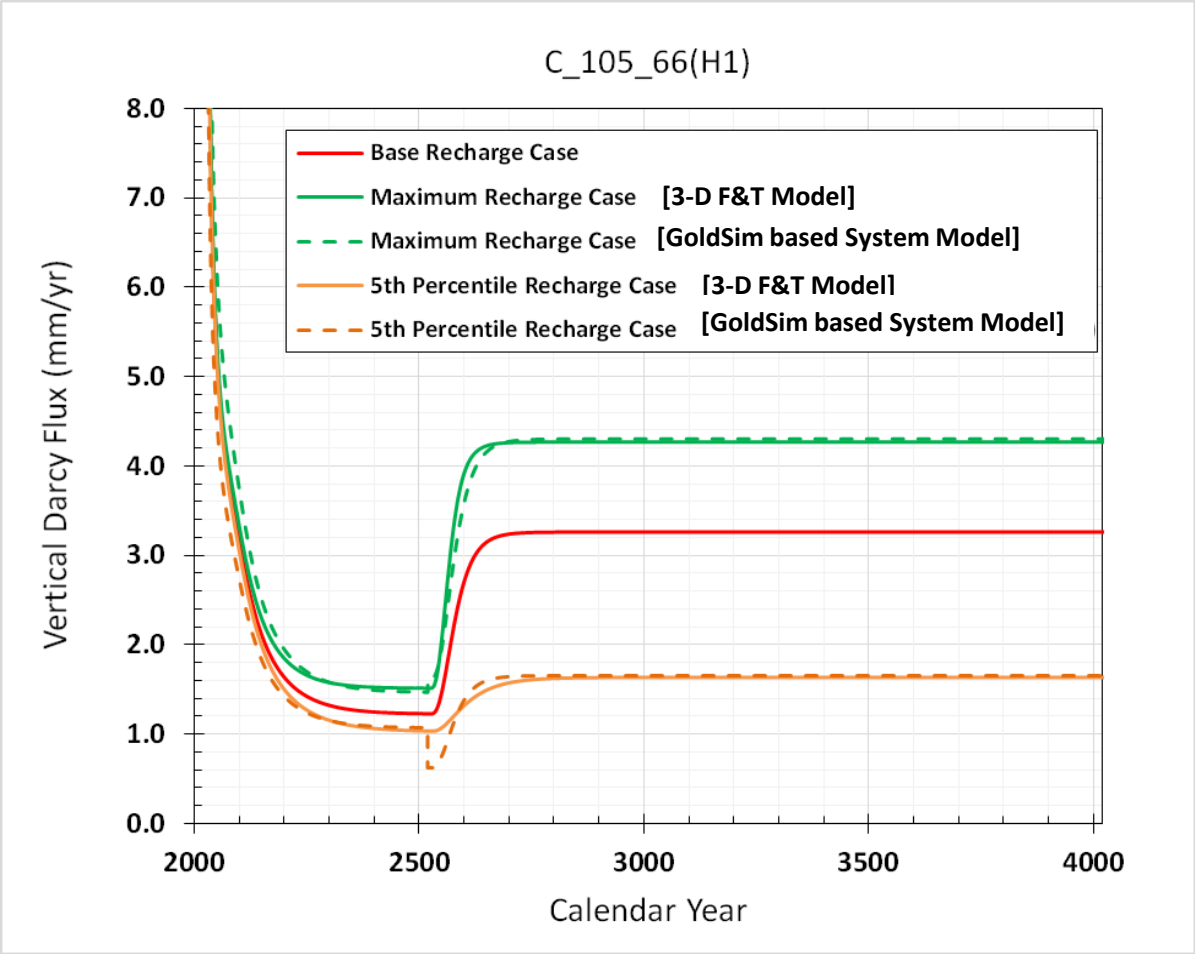
Uncertainty in Hydraulic Properties





Uncertainty in Recharge Rates combined with Uncertainty in Hydraulic Properties are used to develop joint uncertainty distribution in Flow-Field

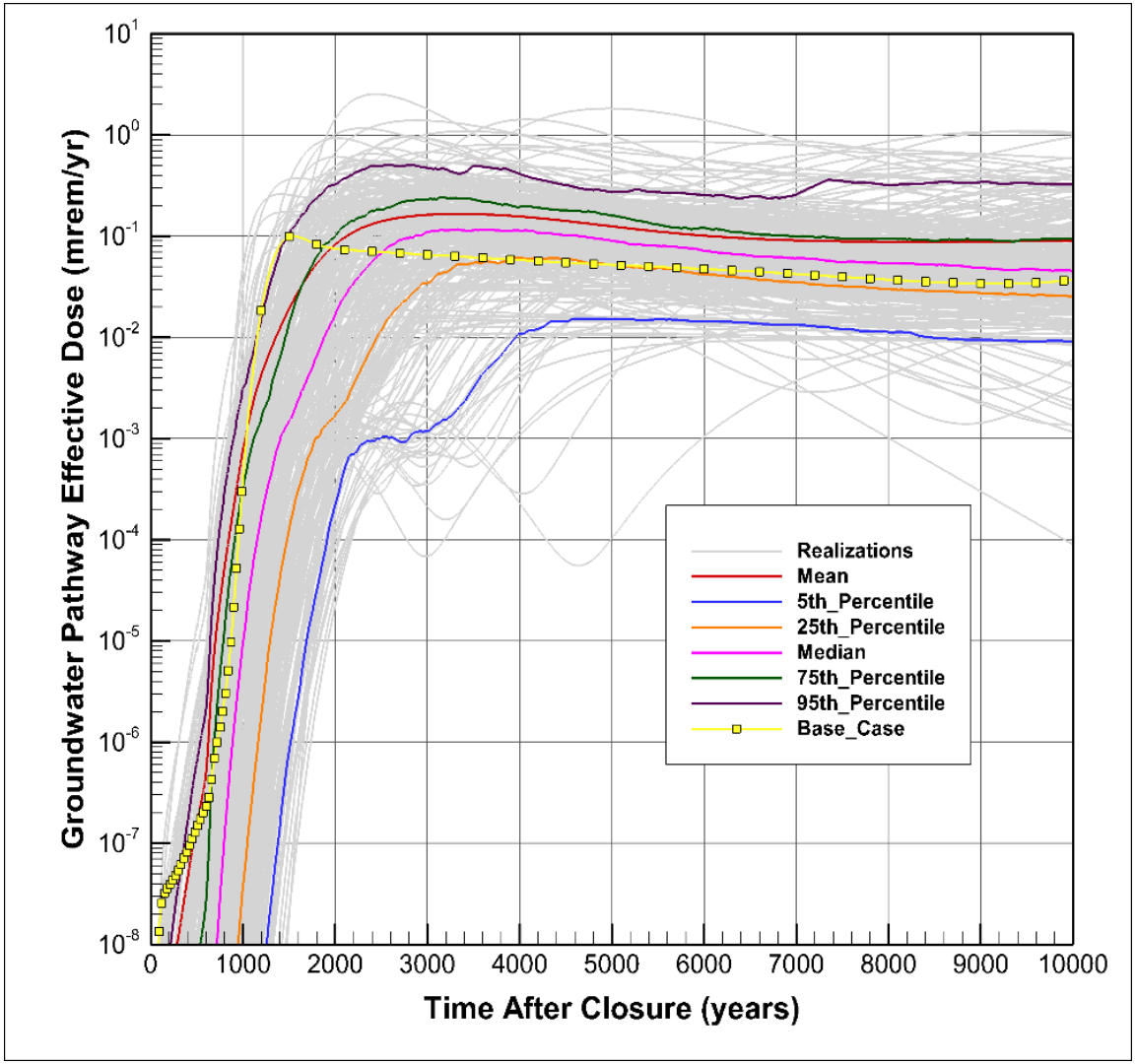
Verification of Flow-Field Abstraction: 5th Percentile Hydraulic Property



Uncertainty Analysis: GW Pathway

- Highest mean (and median) dose occurs around 3,400 years after closure
  - Base case peak dose occurs around 1,500 years
- At late times (>7,000 years) the variance in dose increases marginally
  - Result from increasing importance of uranium isotopes
- Realizations that show earlier peak tend to decline prior to the peak of the mean

GW Pathway: 300 Realizations



Conclusion

- Evaluation of long-term impact of residual radiological contamination left within single-shell tanks is of interest for making closure decisions.
- System-model built using GoldSim is an important tool for evaluating the long-term performance of single-shell tanks following closure.
  - Involves complimentary use of Process model and System-model.
  - Methods and approaches developed for evaluating WMA C Tank farm are being applied to other tanks.