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DOE Case Studies: End States for Vadose Zone Environments

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Outline

- Selection of a protective remediation end state for volatile organic contaminants in the vadose zone
  - Application to DOE Hanford Site Soil Vapor Extraction system
  - Guidance document and calculation tools
- Considering end states for inorganic contaminants
  - DOE Hanford Site examples
- Monitoring approaches for remedy decisions based on predicted performance
  - Private site example

Remediation End State Assessment
Volatile Organic Contaminants

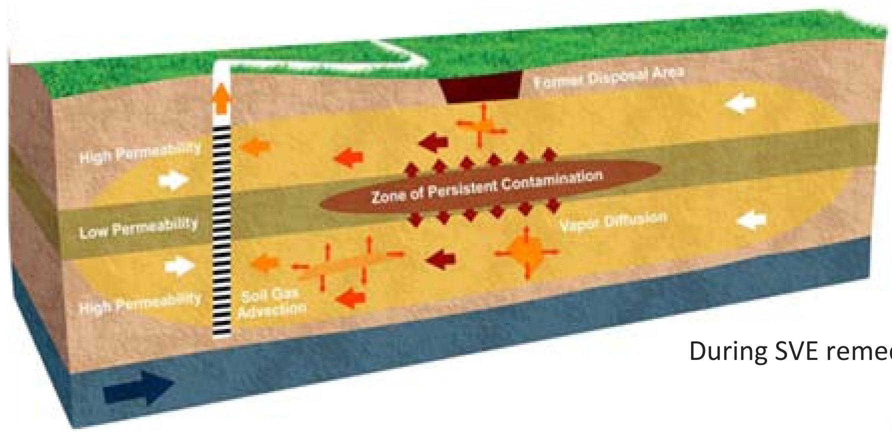
- Measure remedy performance in context of remedy goals
  - Hanford Site Soil Vapor Extraction (SVE) remedy performance was measured as amount of contaminant extracted ***and*** characteristics of contaminants that persist, e.g., how much has the contaminant source been diminished?
- Set remediation end state
  - While SVE cannot remove all of the contamination, it can reach a state where contaminants no longer threaten groundwater (the defined receptor).
- Provide basis for remediation decision
  - Methods for SVE performance evaluation and quantifying impact to groundwater were developed and published to provide technical basis selecting an end state.

EXAMPLE: DOE Hanford Site Soil Vapor Extraction

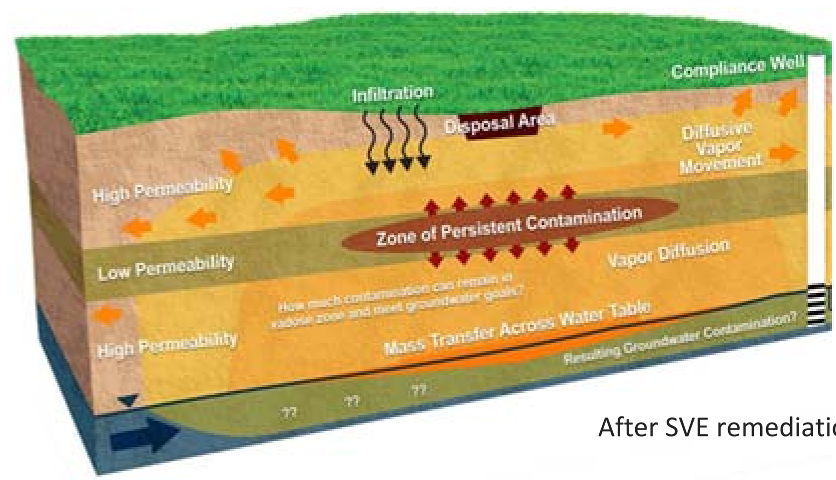
Truex et al. 2012. PNNL-21326

Carroll et al. 2012. *J. Contam. Hydrol.*

Carroll et al. 2012 *GWMR*

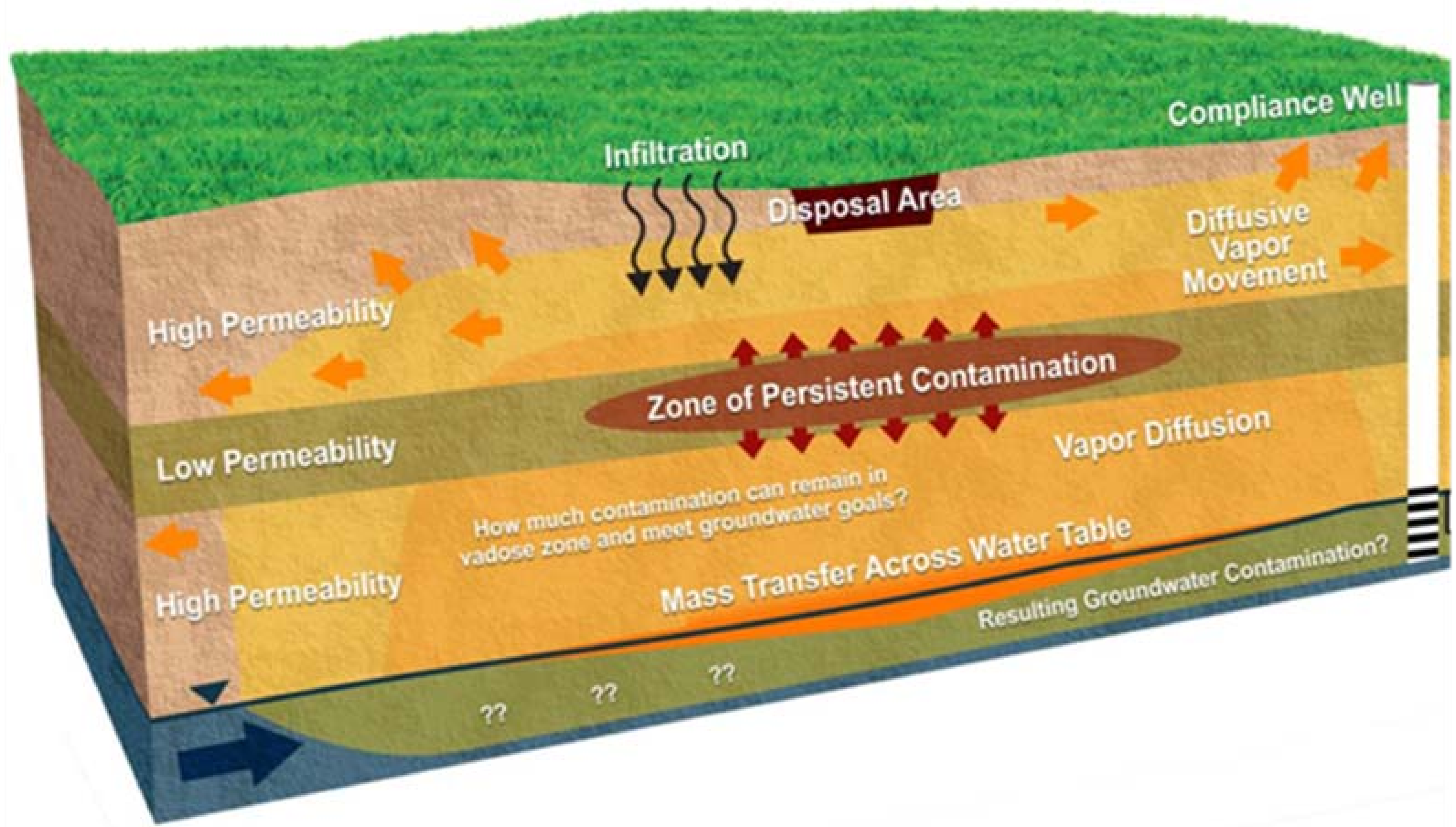


During SVE remediation



After SVE remediation

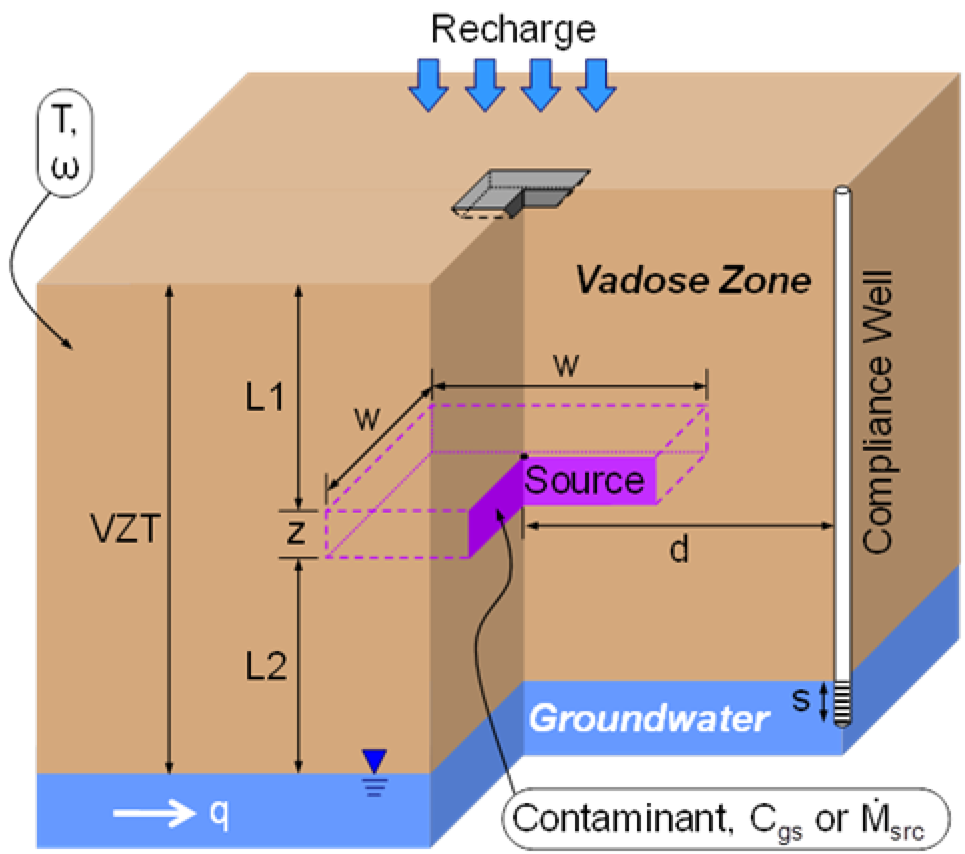
Impact of Remaining Vadose Zone Contaminants?



Brusseau et al. 2012 *Vadose Zone J.* (submitted)

Generalized Conceptual Model for End State Assessment

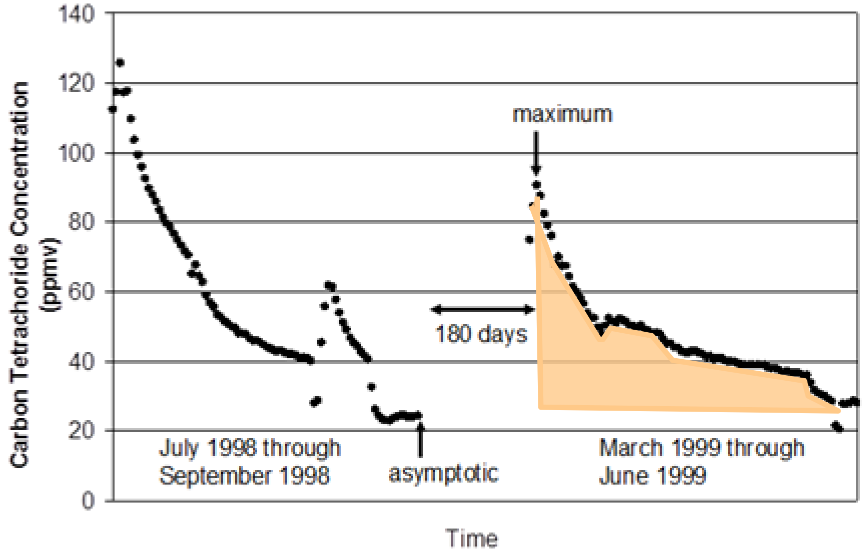
- At an end state, contaminants remaining in the subsurface must not pose a risk.
- SVE effectively removes contaminant vapors, but typically cannot remove all of the contaminant mass – diminishing returns.
- Do contaminants that remain after a period of SVE operation pose a risk?
  - How strong is the source (contaminant discharge rate)?
  - Where is the persistent source?

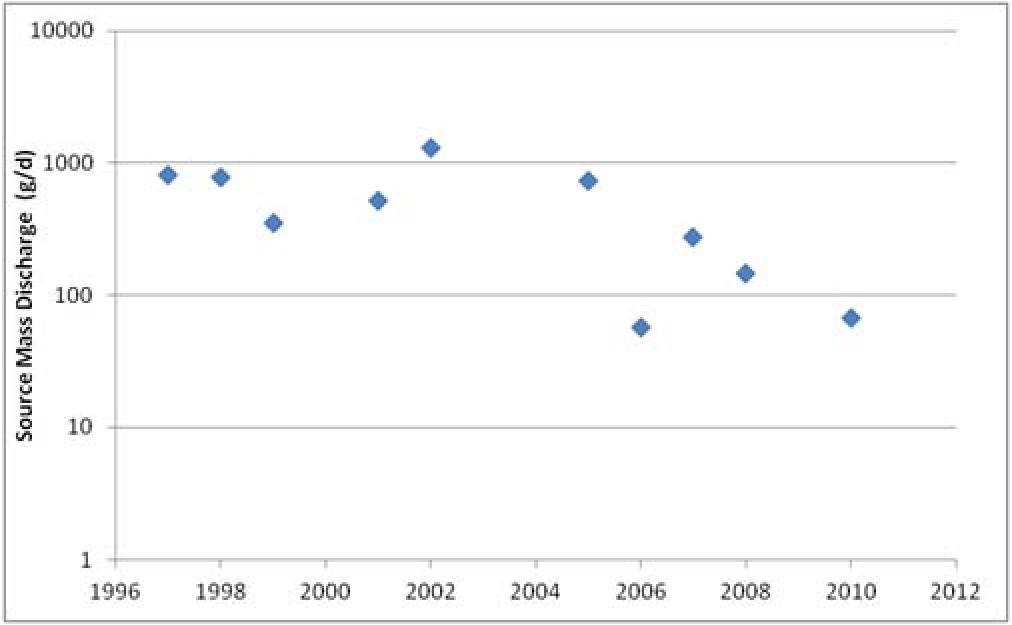


Truex et al. 2012. PNNL-21843
Carroll et al. 2012. *J Contam. Hydrol*.
Oostrom et al. 2010 *GWMR*
Brusseau et al. 2010 *GWMR*
Truex et al. 2009. *GWMR*

Quantifying the persistent source strength

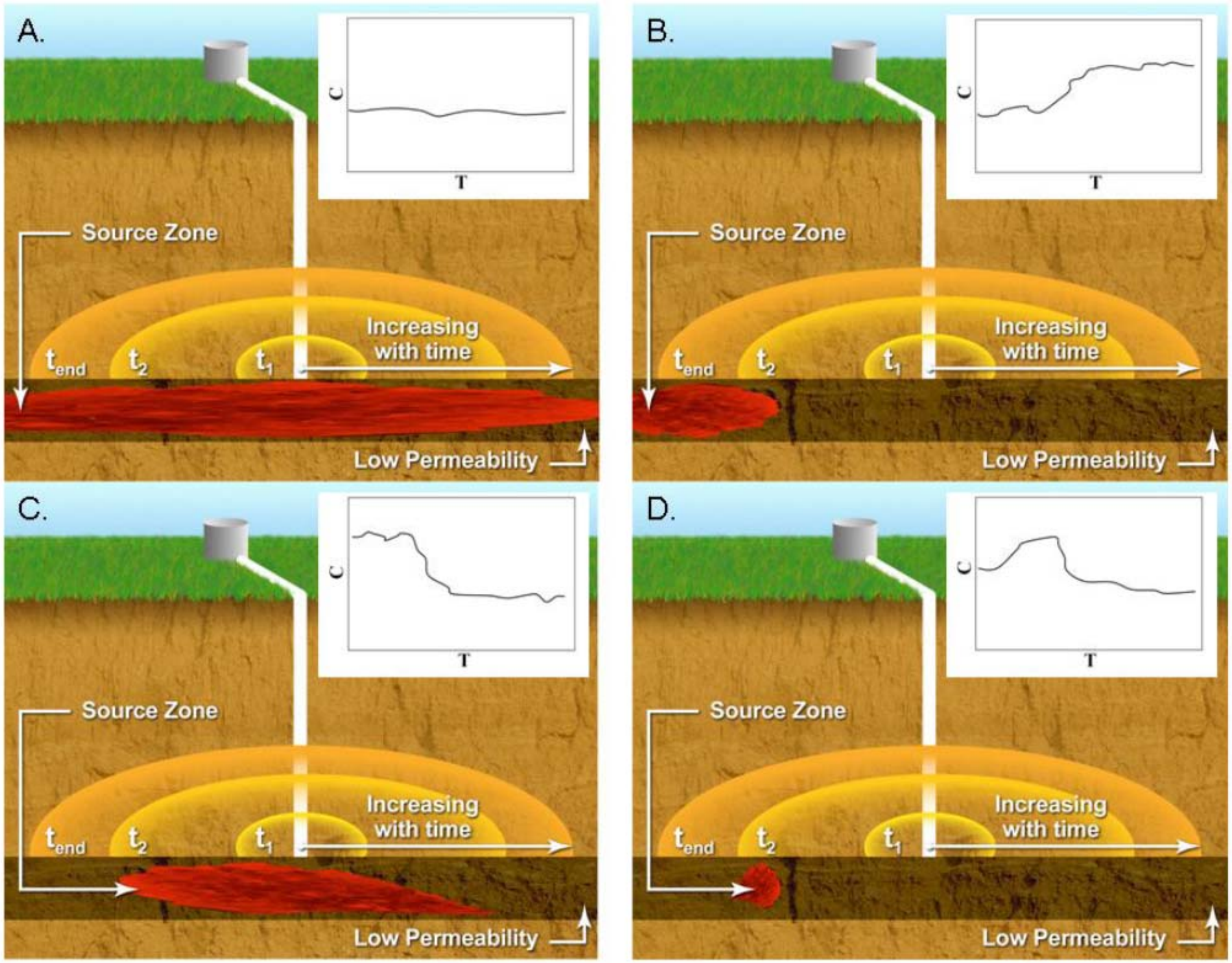
- Data from the SVE system can be used to quantify source strength as contaminant mass discharge.
- Operations are cycled between on and off. While the system is off, concentrations “rebound” due to contamination discharging from source areas.
- Rebound analysis estimates source strength if SVE is terminated. Can use this information to evaluate whether this source poses a risk.

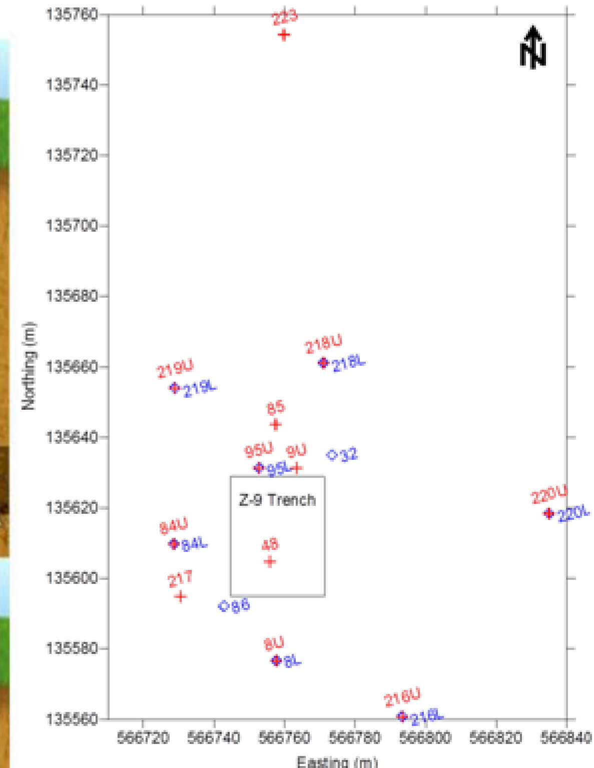




Brusseau et al. 2010. *GWMR*

Determining Source Location: Hanford Field Test

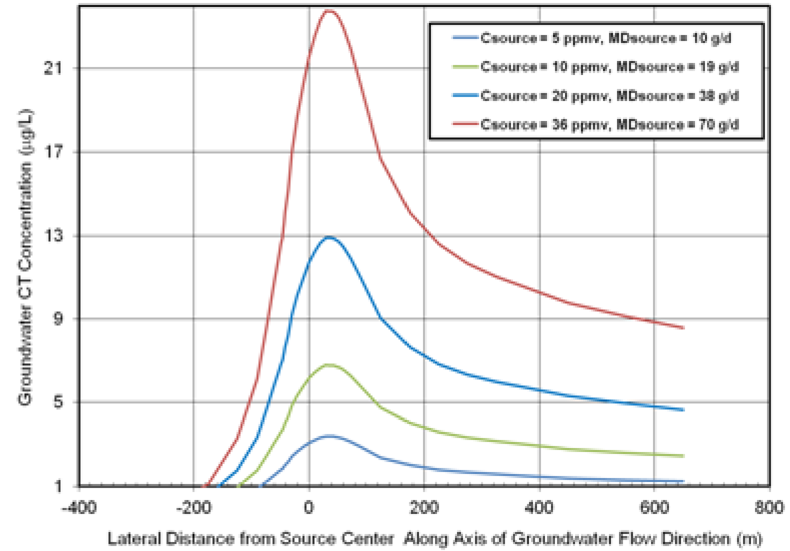


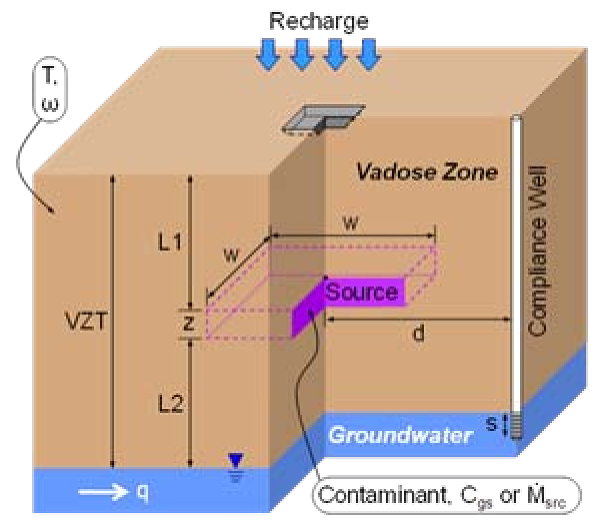


Truex et al. 2012. PNNL-21326
Carroll et al. 2012. *J. Contam. Hydrol*.
Brusseau ESTCP 201125

Hanford SVE System Results: Impact to Groundwater

- At the Hanford Site, groundwater is contaminated by sources other than the vadose zone and is being treated by Pump-and-Treat.
- The SVE system needs to have reduced vadose zone contamination such that groundwater remediation goals can be met within timeframe of groundwater remedy
- Used a process to assess future impact if SVE is terminated and provided a metric in the vadose zone for the end state – incorporated into Record of Decision





Truex et al. 2012. PNNL-21326

SVE Guidance and Calculation Tool

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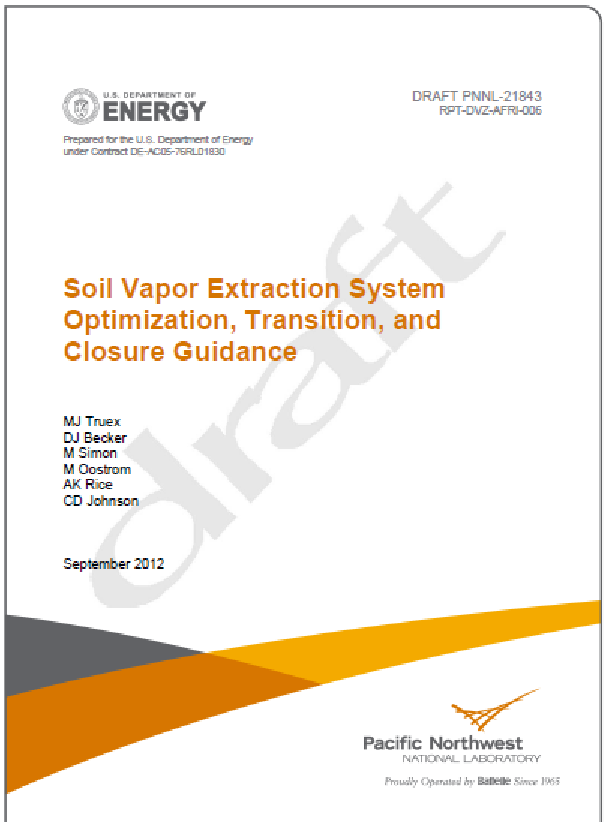
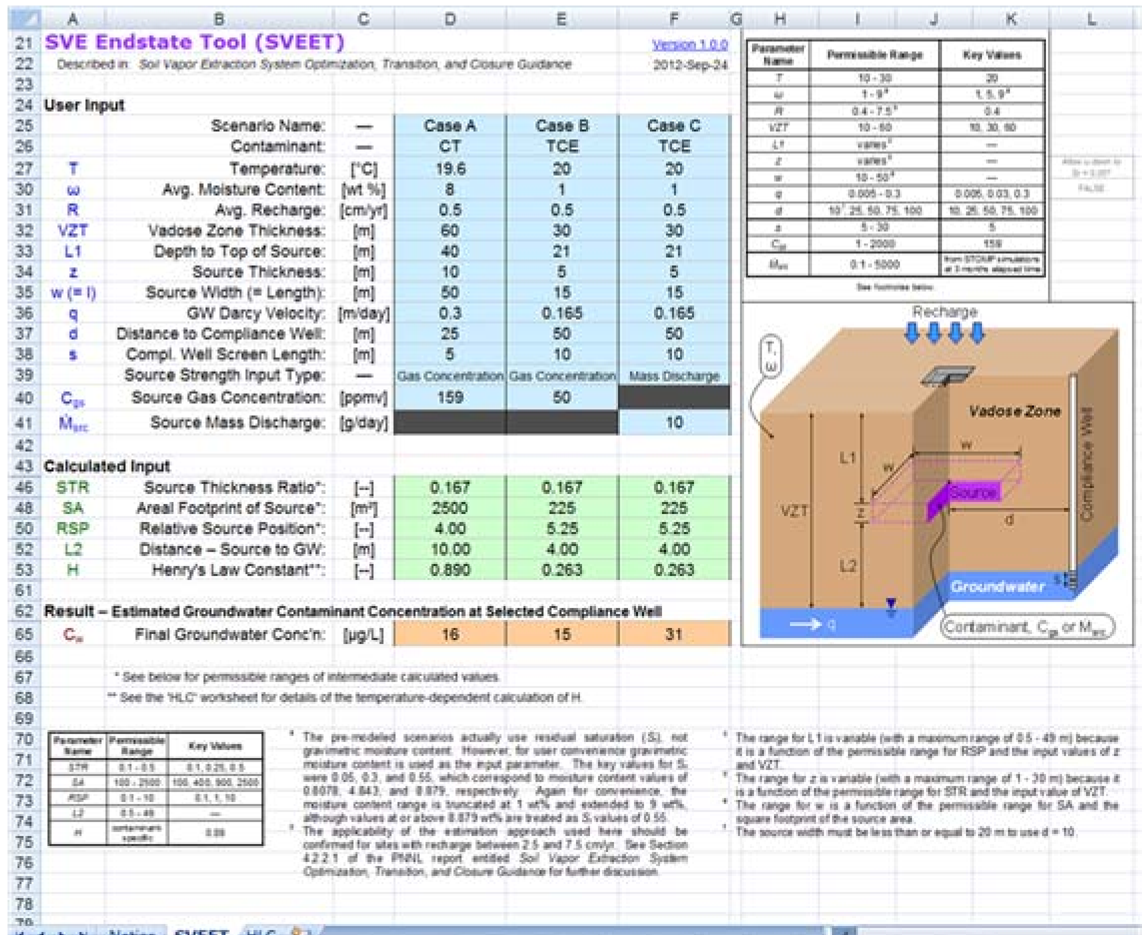
- A systems-based approach to SVE performance assessment and estimating closure conditions
  - New tools in guidance document consider risk to groundwater
  - Development related to vapor intrusion issues continuing through DoD ESTCP projects (e.g., 201125)





SVE Endstate Tool (SVEET) Version 1.0.0

Described in: *Soil Vapor Extraction System Optimization, Transition, and Closure Guidance* 2012-Sep-24

	A	B	C	D	E	F
24	**User Input**					
25		Scenario Name:	—	Case A	Case B	Case C
26		Contaminant:	—	CT	TCE	TCE
27	T	Temperature:	[°C]	19.6	20	20
30	ω	Avg. Moisture Content:	[wt %]	8	1	1
31	R	Avg. Recharge:	[cm/yr]	0.5	0.5	0.5
32	VZT	Vadose Zone Thickness:	[m]	60	30	30
33	L1	Depth to Top of Source:	[m]	40	21	21
34	z	Source Thickness:	[m]	10	5	5
35	w (= l)	Source Width (= Length):	[m]	50	15	15
36	q	GW Darcy Velocity:	[m/day]	0.3	0.165	0.165
37	d	Distance to Compliance Well:	[m]	25	50	50
38	s	Compl. Well Screen Length:	[m]	5	10	10
39		Source Strength Input Type:	—	Gas Concentration	Gas Concentration	Mass Discharge
40	C_{gs}	Source Gas Concentration:	[ppmv]	159	50	
41	$\dot{M}_{src}$	Source Mass Discharge:	[g/day]			10
43	**Calculated Input**					
46	STR	Source Thickness Ratio*:	[–]	0.167	0.167	0.167
48	SA	Areal Footprint of Source*:	[m²]	2500	225	225
50	RSP	Relative Source Position*:	[–]	4.00	5.25	5.25
52	L2	Distance – Source to GW:	[m]	10.00	4.00	4.00
53	H	Henry's Law Constant**:	[–]	0.890	0.263	0.263
62	**Result – Estimated Groundwater Contaminant Concentration at Selected Compliance Well**					
65	C_w	Final Groundwater Conc'n:	[μg/L]	16	15	31

* See below for permissible ranges of intermediate calculated values.
** See the "HLC" worksheet for details of the temperature-dependent calculation of H.

Incorporating End State Considerations in Remedy Selection

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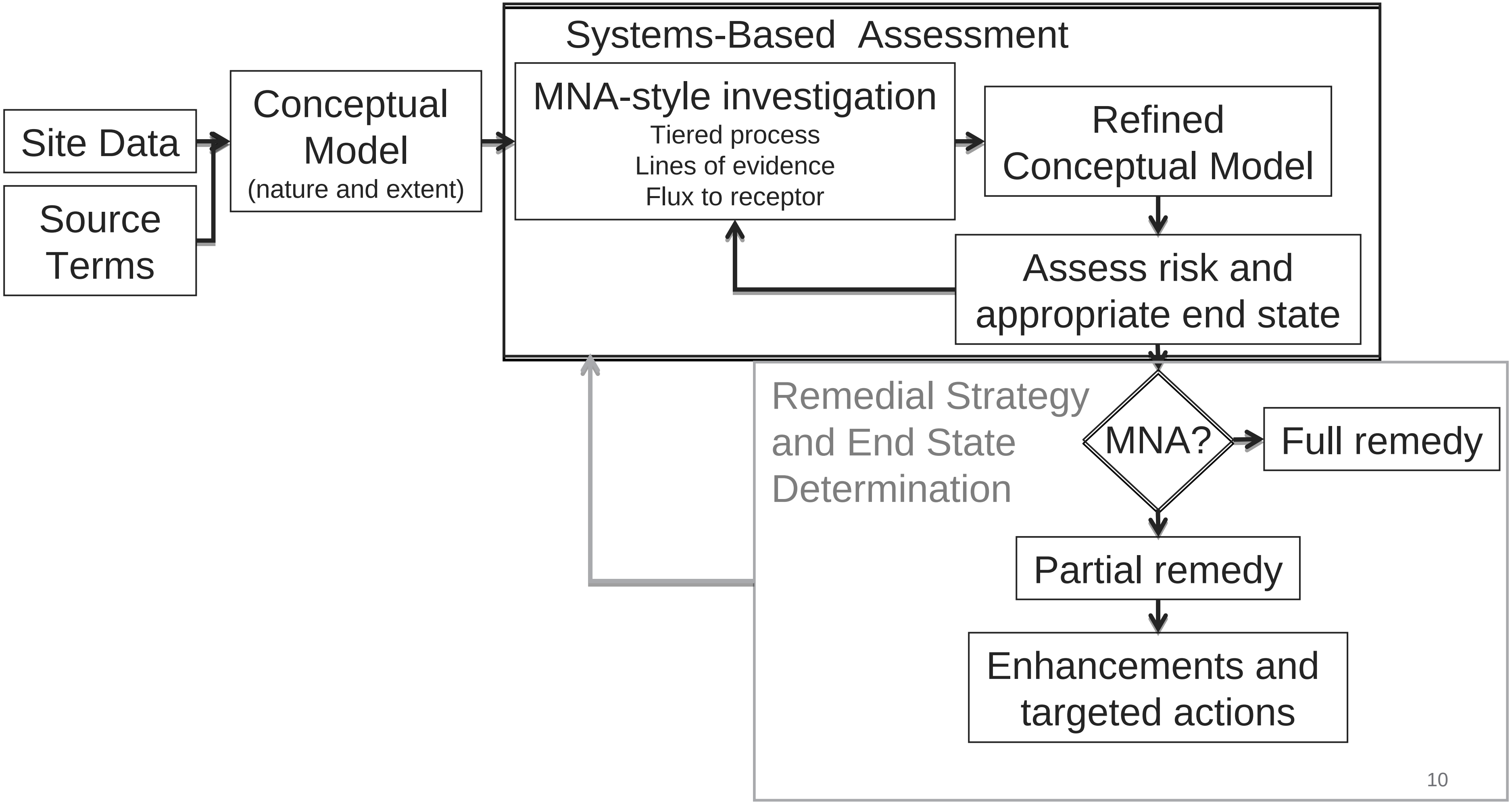

Applications

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- Vadose Zone Example – apply a systems based, MNA-style approach
  - Significant natural attenuation processes in the vadose zone need to be considered
  - We have time in many cases due to slow movement to groundwater
- Hanford 300 Area Example
  - Complex system with interactions between the vadose zone, groundwater and Columbia River

Coupled Vadose Zone/Groundwater System Non-Volatile, Inorganic Contaminants

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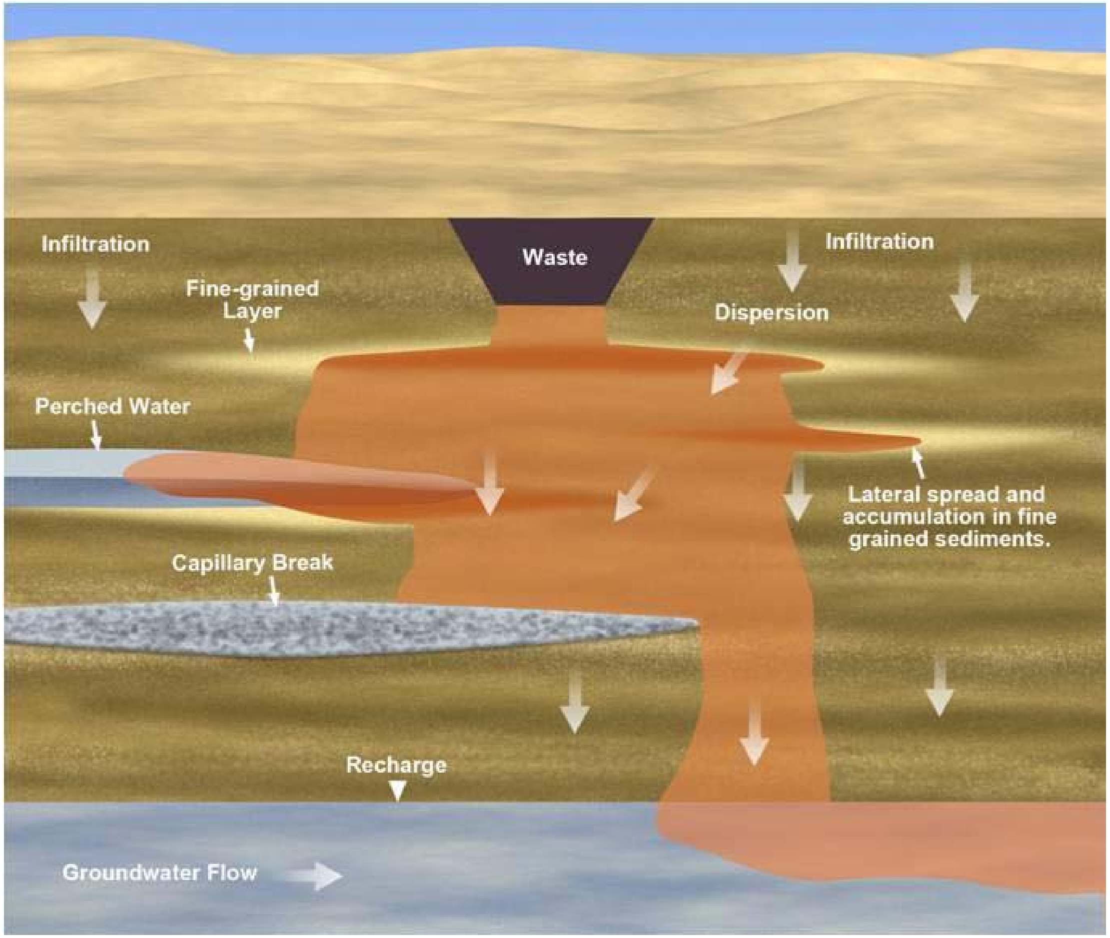

Dresel et al. 2011. *Environ. Sci. Technol*.

Vadose Zone Remedy Framework - Inorganics

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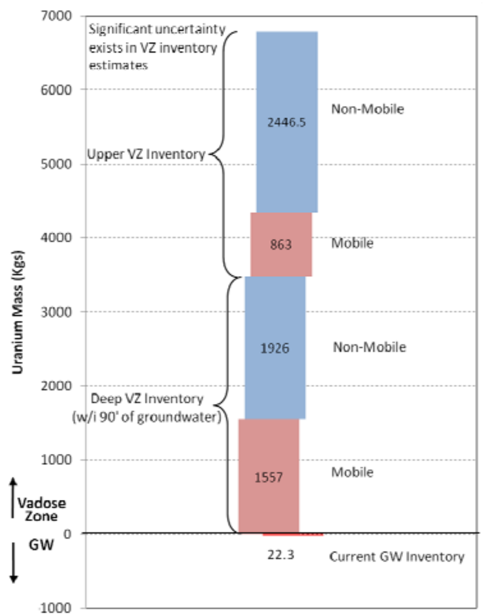
- Evaluate Threat to Groundwater
  - Vadose zone contaminants are not a direct exposure threat. They are a potential risk to groundwater but must transport through the vadose zone to impact groundwater
- Use MNA Approach
  - Transport of contaminants in the vadose zone is significantly attenuated by hydraulic processes and dispersion in addition to potential geochemical attenuation. Thus, natural attenuation can likely be a significant part mitigating risk
- Enhance Natural Processes
  - When natural attenuation is only part of the remedy, the MNA analysis can identify enhancements to attenuation processes that reduce flux to groundwater

EXAMPLE: US DOE Hanford Site

Waste discharges into the thick Hanford vadose zone varied in volume and chemical properties. Significant inventory remains in the vadose zone due to geochemical processes and vadose zone water flow characteristics that contribute to natural attenuation of the impact to groundwater.

Truex and Carroll. 2012. PNNL-21815



Uranium solubility reactions limit mass of mobile uranium

Vadose Zone Hydraulic Attenuation

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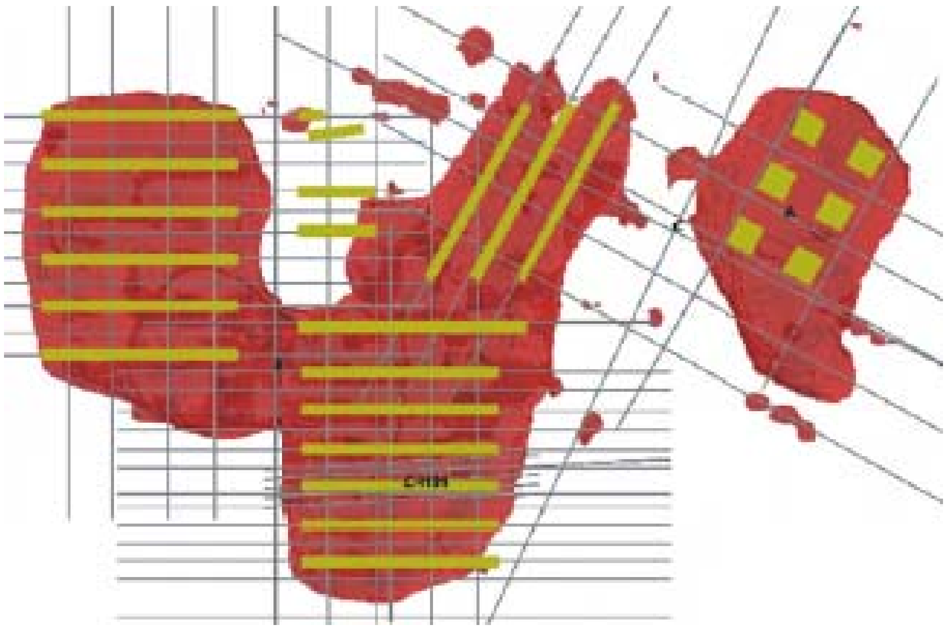
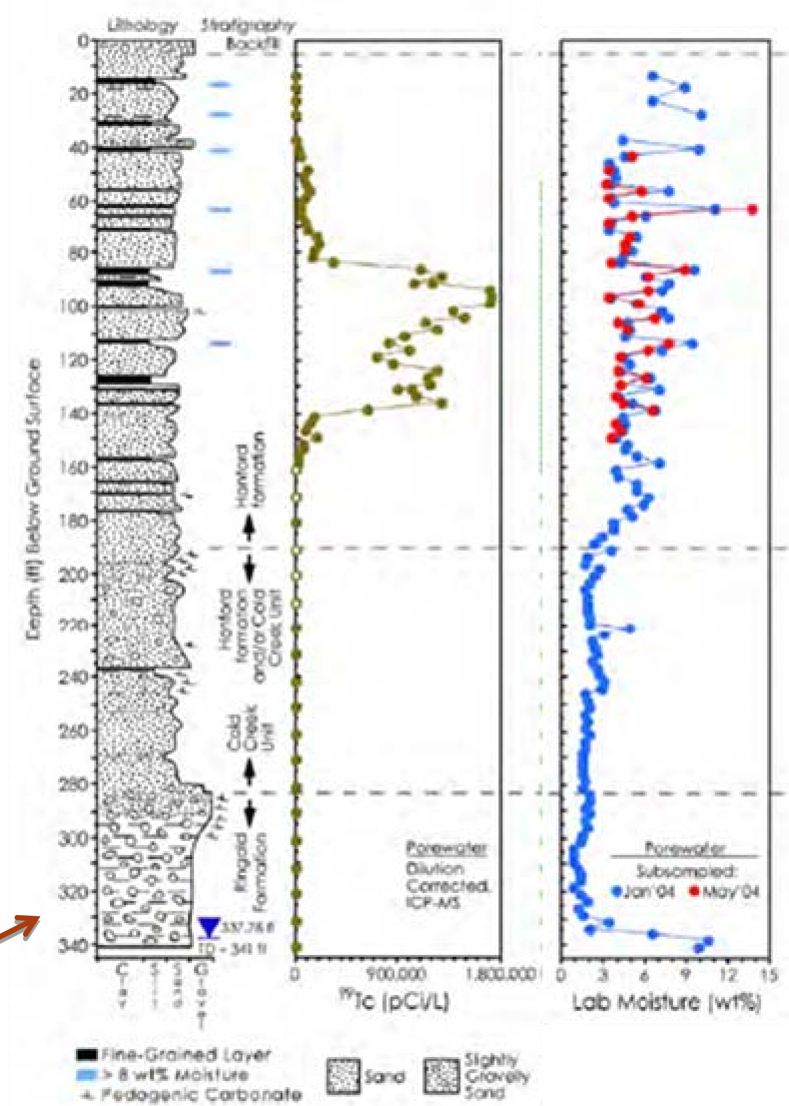


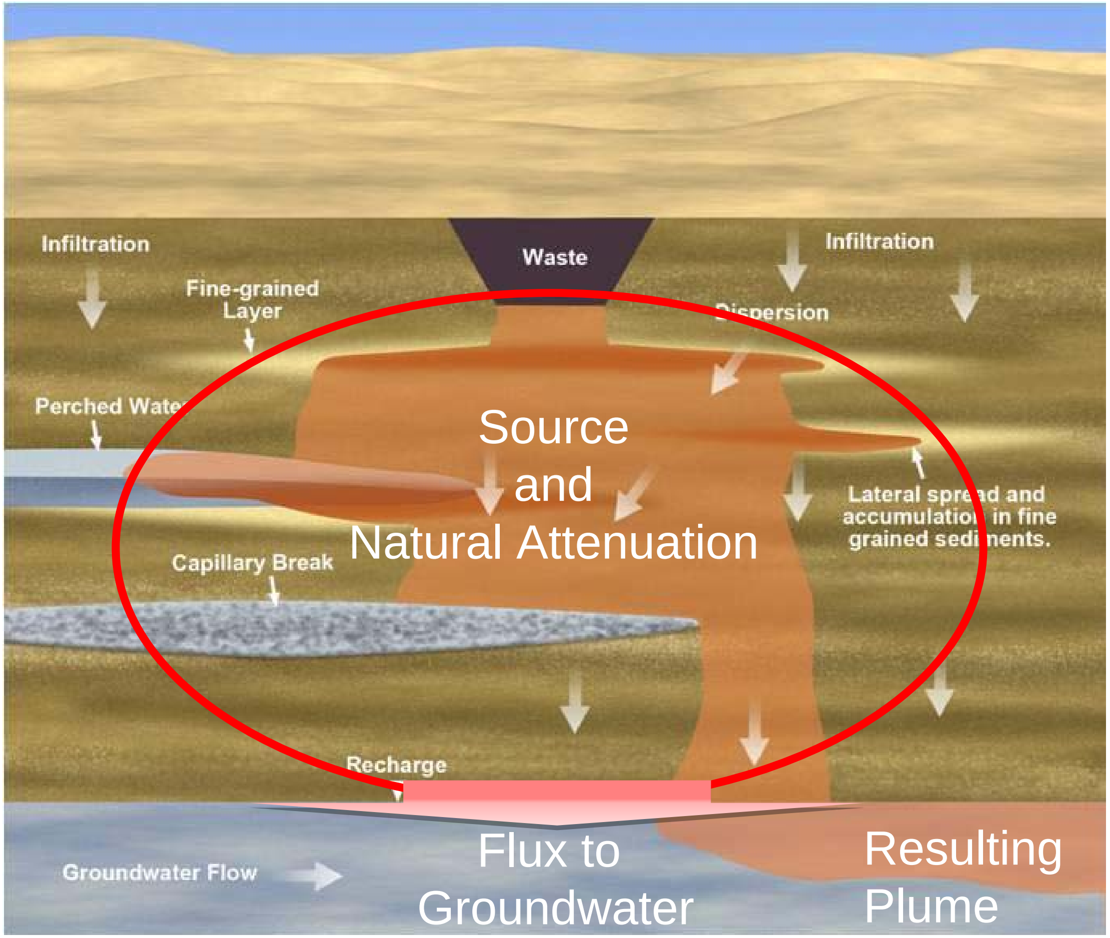
Electrical resistivity survey shows lateral spreading of waste (red color) disposed in cribs and trenches (gold color). Lateral spreading slows downward movement



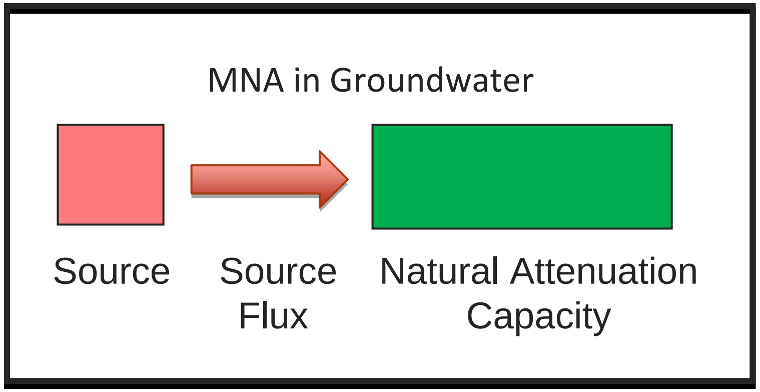
Borehole data shows relative contaminant and water movement

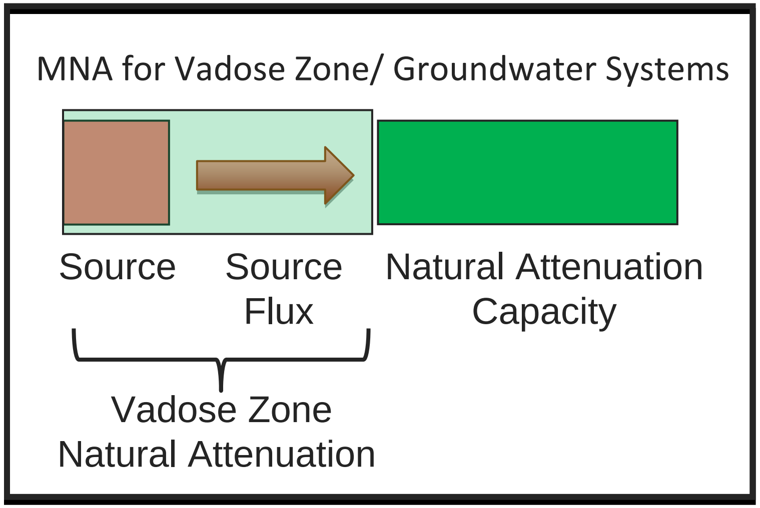
Jansik et al. 2012. *Vadose Zone J.* (submitted)

Coupled Vadose Zone/Groundwater System



Adapted from Dresel et al. 2011. *Environ. Sci. Technol.*





Truex and Carroll. 2012. PNNL-21815

Applications

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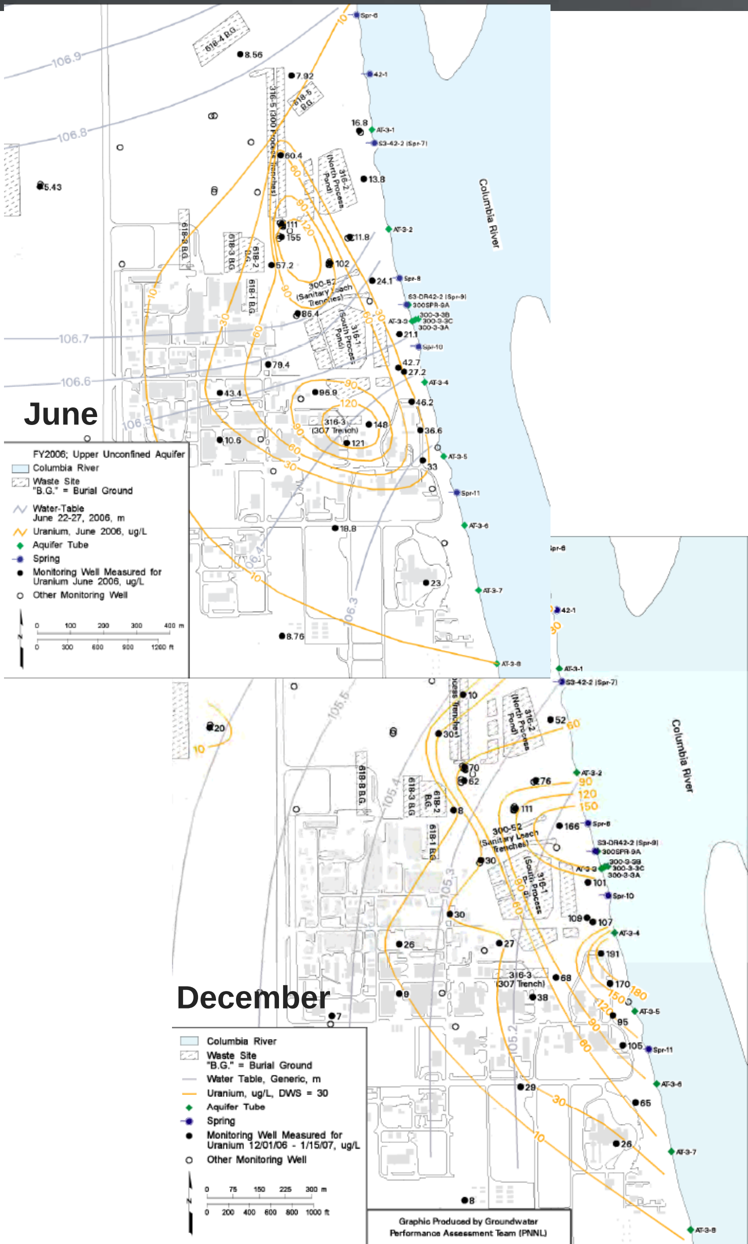
- Hanford 300 Area Example
  - Uranium waste solutions discharged to surface
  - Uranium plume adjacent to Columbia River
- Remedy History
  - Initial remedial investigation/feasibility study led to excavation of waste trenches and MNA for the groundwater plume
    - Key assumption – uranium source could be removed with excavation
  - Monitoring showed that plume did not decline as expected
  - Remedial investigation and re-evaluation of conceptual model
    - Uranium source present in lower vadose zone contacted by seasonal water table rise



Applications

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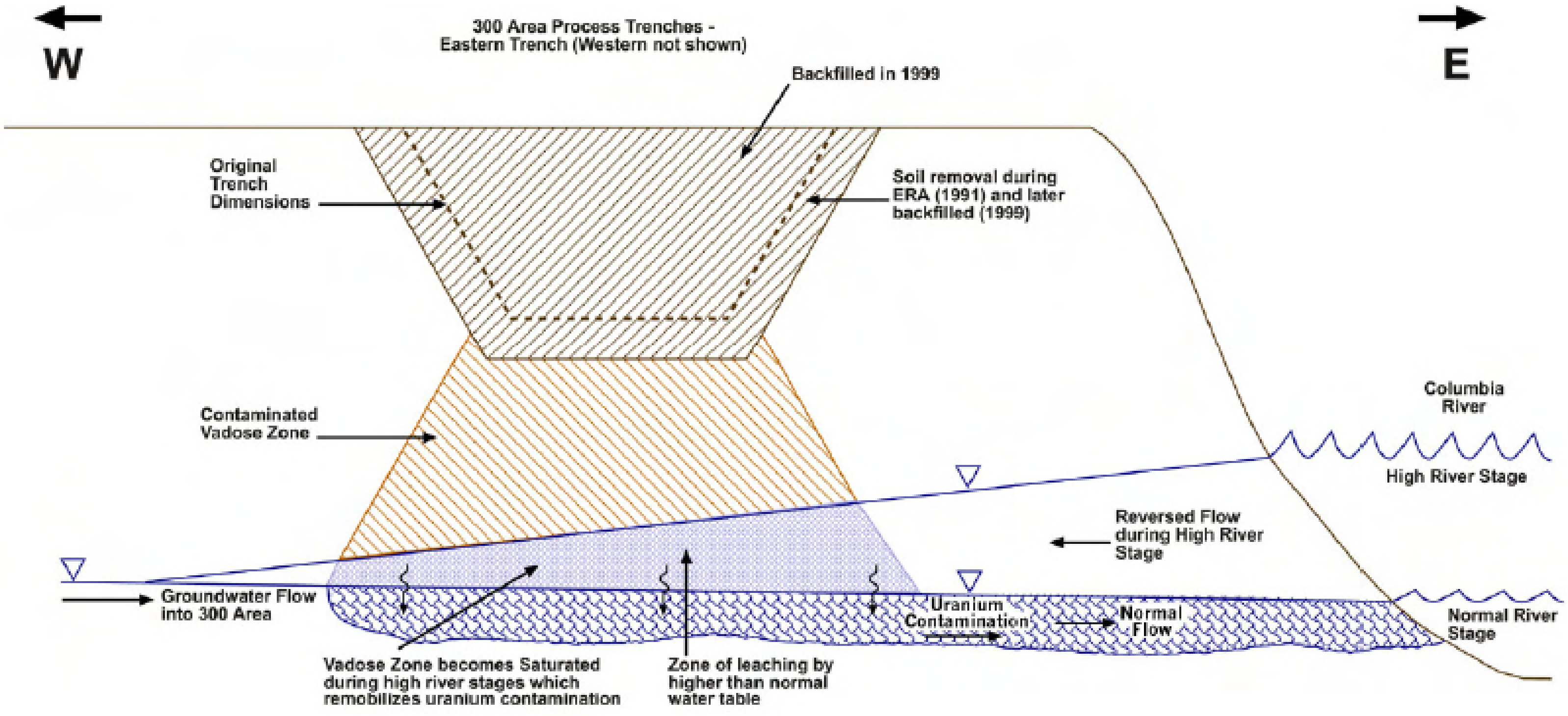
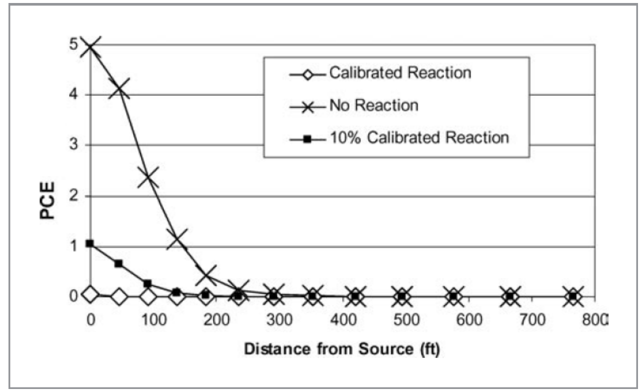
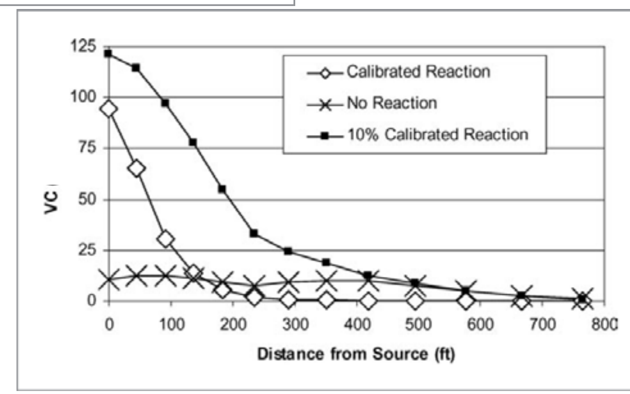
- Current Situation
  - Remedy evaluation shows few viable source treatment options (large, complex site)
    - Consider active remedies
    - Assess end state in light of new conceptual model information and transient site conditions

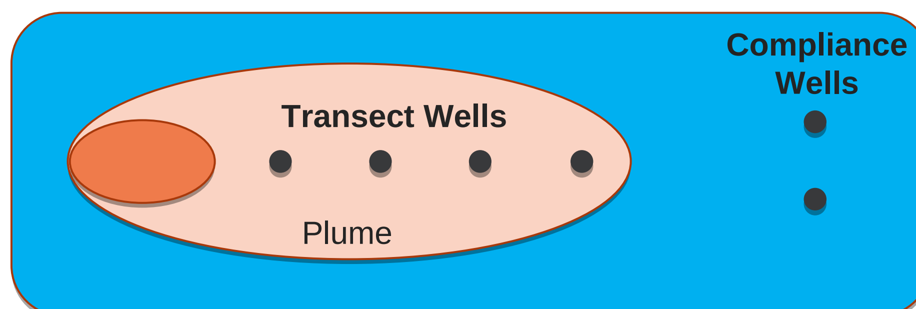


Monitoring Approach for Remedy Decisions Based on Predicted Performance

- Model predictions for three scenarios
  - Base case natural attenuation
  - 10% natural attenuation
  - No attenuation
- Monitoring approach developed to compare observed concentration response to prediction scenarios
  - Evaluation at transect locations as early indication of performance
  - Enables monitoring of transient conditions







Truex et al. 2007. *Remediation Journal*.

Conclusions

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- Examples of end state determination based on quantifying the subsurface and contaminant “system” and applying analyses to estimate potential future risk from contaminant conditions.
  - Very similar to MNA approaches
  - Enable remedy decisions and provide means to verify performance
  - Incorporate mass flux/discharge concepts

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