

Decision Support Tool for Vadose Zone Remediation of Volatile Contaminants

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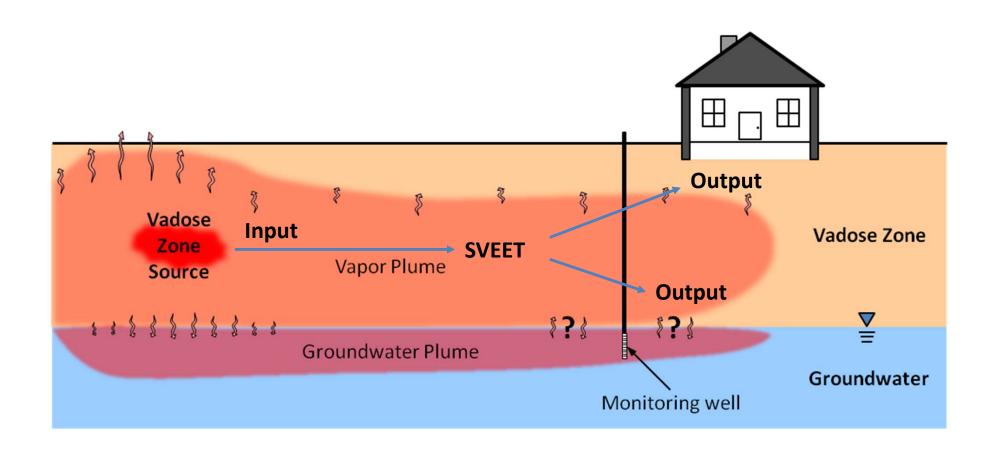
Introduction



- Remedy monitoring is applied to assess remedy performance, but may be insufficient to support a decision to terminate a remedy such as Soil Vapor Extraction.
- ▶ Decision tools are needed for define the end state for SVE because contaminant transport needs to be considered.

Technology/Methodology Description

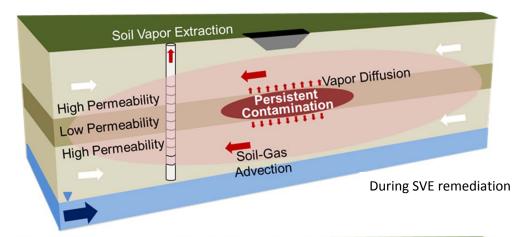


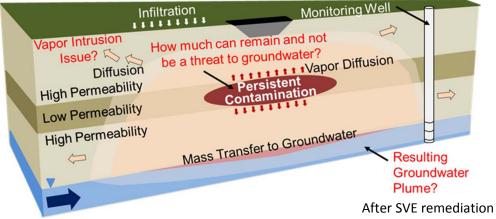


Vadose Zone Contamination



- 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?
 - Where is the persistent source?
 - How strong is the source (contaminant mass discharge/concentration)?
 - What is the contaminant transport toward points of concern?
- At some sites: Is SVE needed?





Key Reference Documents



- Soil Vapor Extraction System Optimization, Transition, and Closure Guidance
 - http://bioprocess.pnnl.gov/SVEET_Request.htm
- Vapor Intrusion Estimation Tool For Unsaturated-Zone Contaminant Sources
 - http://bioprocess.pnnl.gov/VIETUS_Request.htm
- Estimating the Impact of Vadose Zone Sources on Groundwater to Support Performance Assessment of Soil Vapor Extraction. Ground Water Monitoring and Remediation

SVEET Tool

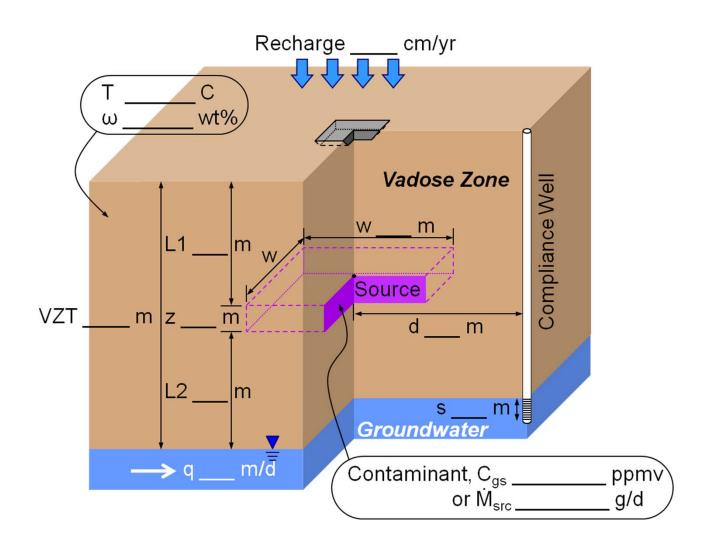


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4	Α	В	С	D	Е	F	G	Н	1	J		K	L
21	SVE E	Indstate Tool (SVEET)			Version 1.0.	0 [Parameter	Permissible R	ango	Ko	y Values	
22	Describe	ed in: Soil Vapor Extraction System Option	ransition, and Closui	re Guidance	2012-Sep-2	4	Name	Providence and the second	ange	N.C	51/30/40/30/30/30		
23								Τ	10 - 30 1 - 9 a			20 1, 5, 9 ^a	
24	User Inp	out						R	0.4 - 7.5°			0.4	
25		Scenario Name:	10_20	Case A	Case B	Case C	1	VZT	10 - 60		10	0, 30, 60	
26		Contaminant:	100	СТ	TCE	TCE		L1	varies c			-	
27	Т	Temperature:	[°C]	19.6	20	20		Z	varies ⁰			8 — 8	Allow ω down to
30	ω	Avg. Moisture Content:		8	1	1		W	10 - 50 °				Sr = 0.05? FALSE
31	R	Avg. Recharge:		0.5	0.5	0.5		q d	0.005 - 0.3 10 [†] , 25, 50, 75			5, 0.03, 0.3 , 50, 75, 100	
32	VZT	Vadose Zone Thickness:	[m]	60	30	30	11	s	5 - 30	, 100	10, 20	5	
33			0.000	40	1000	0.0	+lt	Cos	1 - 2000			159	
	L1	Depth to Top of Source:	[m]		21	21	+	Msrc	0.1 - 5000	ĺ.	from STO	OMP simulations	
34	Z	Source Thickness:	[m]	10	5	5	₩		San factor	tor holow	at 3 mpn	ins elapsed time	
35	w (= I)	Source Width (= Length):	[m]	50	15	15		See footnotes below.					
36	q	GW Darcy Velocity:	-	0.3	0.165	0.165	Ш			0.000	harge		
37	d	Distance to Compliance Well:	[m]	25	50	50		(T)		4	· 4	>	
38	S	Compl. Well Screen Length:	[m]	5	10	10		(Τ, ω)					
39		Source Strength Input Type:	-	Gas Concentration	Gas Concentration	Mass Discharge		<u></u>		1			П
40	Cas	Source Gas Concentration:	[ppmv]	159	50								
41	M _{src}	Source Mass Discharge:	[g/day]			10		1	1		V	adose Zo	ne Ne
42	IVISIC	Courte Mass Discharge.	[g/ddy]			10	6						<u> </u>
									L1	1	W		Compliance
		ted Input		0.407	0.407	0.407			W/				<u>a</u>
46	STR	Source Thickness Ratio*:	[]	0.167	0.167	0.167					Soul	rce /	Ε
48	SA	Areal Footprint of Source*:	[m²]	2500	225	225		VZT	Z		/	d	→ 3
50	RSP	Relative Source Position*:	[]	4.00	5.25	5.25			1			•	
52	L2	Distance – Source to GW:	[m]	10.00	4.00	4.00							
53	Н	Henry's Law Constant**:	[]	0.890	0.263	0.263			L2				sţ
61											Gro	undwater	218
62	Result -	- Estimated Groundwater Contam	inant Cor	ncentration at Se	lected Complian	ce Well		•	+ ₹				
65	Cw	Final Groundwater Conc'n:	[µg/L]	16	15	31		─	> q		(Cont	aminant, C	C _{gs} or M _{src})
66	- vv		11-31										
67		* See below for permissible ranges of i	ntermediat	e calculated values									
68		** See the 'HLC' worksheet for details of			alculation of H								
69		oce the file worksheet for details of	and tempe	rature-dependent ce	acaidion or it.								
	 	a Tho	pro modele	scenarios actually	uso residual setura	tion (S) not	C TL	o rongo fe- l	1 io variable (···i	h a me:		ange of 0 F	10 m) boogus-
70	Parameter Name	Range Key Values gravi	netric moist	ure content. Howeve	r, for user convenien	ce gravimetric			1 is variable (wit of the permissibl				
71	STR	0.1 - 0.5 0.1, 0.25, 0.5 moist	ure content	is used as the input	parameter. The key	values for S _r	and	d VZT.	·				
72	SA	100 - 2300 100, 400, 300, 2300		nd 0.55, which corres and 8.879, respective					is variable (with the permissible r				
73	RSP L2	0.1 - 10 0.1, 1, 10 moist	ure content	range is truncated a	at 1 wt% and extend	ed to 9 wt%,	e Th	e range for	w is a function	of the			
74	H	contaminant-		at orabove 8.879 wt% of the estimation					of the source ar th must be less t		nusl to	20 m to uso	1 = 10
75		specific 0.09 THE	med for site	s with recharge betwe	en 2.5 and 7.5 cm/yr.	See Section		e source wid	ur must be less t	nan or e	quai (0	ZV III IU USE	u – 10.
76		4.2.2	1 of the	PNNL report entitle	d Soil Vapor Extra	ction System							
77		Optin	nzauon, ira	namon, and Closure G	uluarice for further dis	cussion.							
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14	← → →	Notice SVEET HLC											

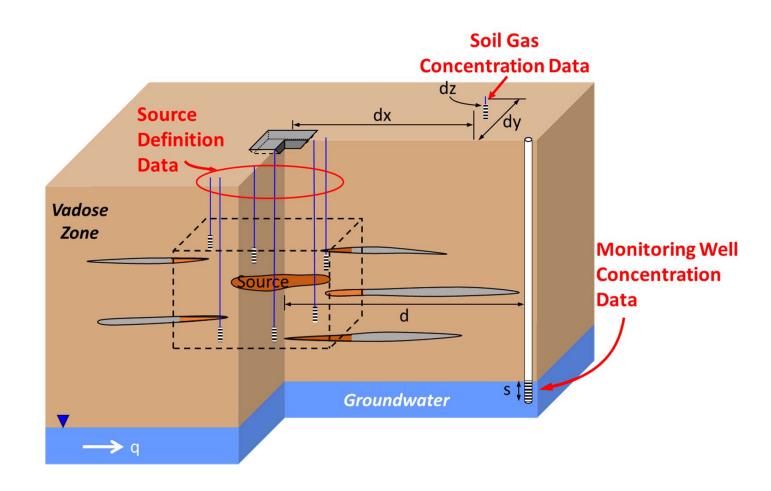
Calculation Approach





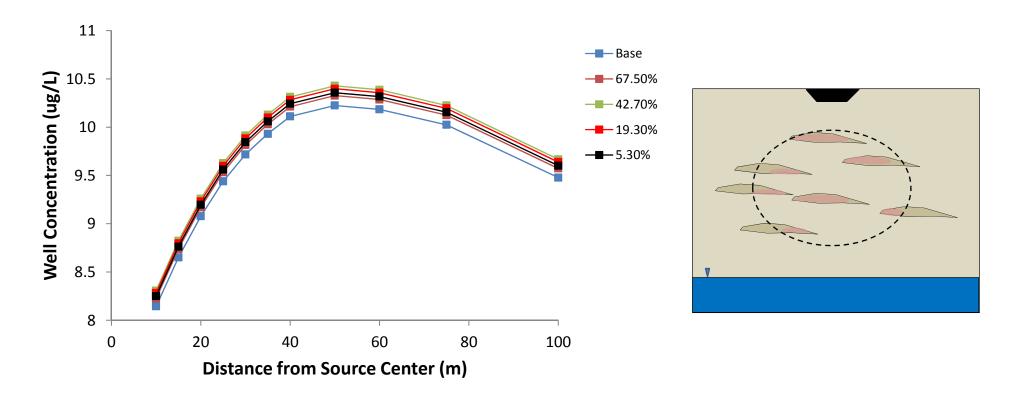
Relationship of Source and Output





Technical Basis



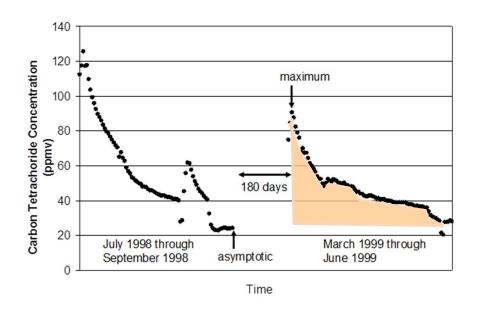


The presence of discrete source zones (versus a uniformly distributed source) within the same portion of the vadose zone only has a small effect on simulated groundwater well concentrations, even to a small effective source volume (Truex et al. 2013).

SVE Data – Source Strength

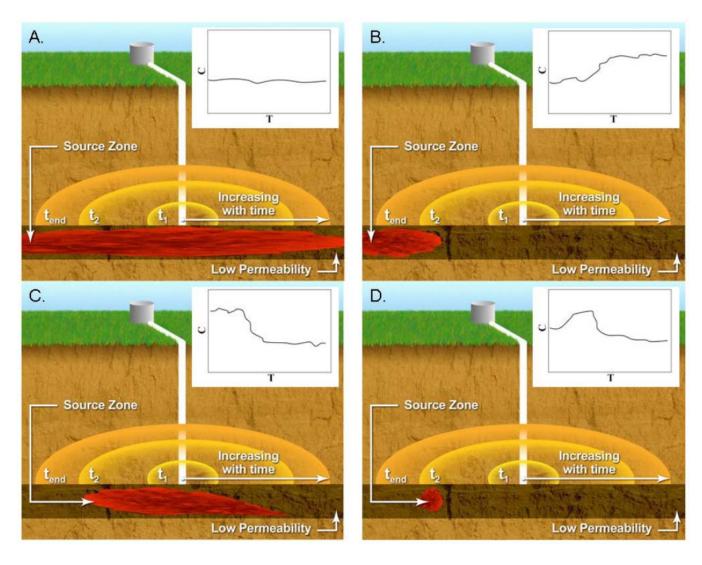


- Data from the SVE system can be used to quantify source strength as contaminant mass discharge.
- Rebound analysis estimates source strength if SVE is terminated. Can use this information to evaluate whether this source poses a risk.



SVE Data - Source Location



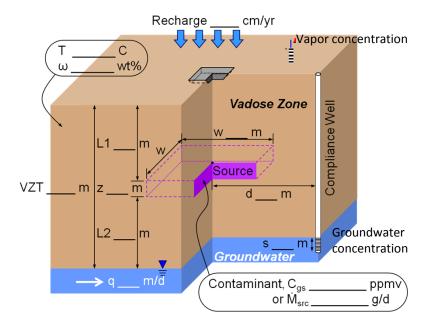


Carroll et al. 2012, 2013; Truex et al. 2012; Mainhagu et al. 2014; Brusseau 2015

Transport Calculations



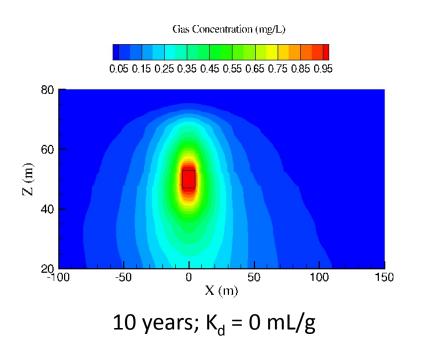
- Approach uses a limited set of parameters based on examining the effect of parameters on long-term vapor and groundwater concentrations
- Approach uses 3D multiphase transport because this was shown to be important to estimating transport for volatile contaminants.
- Spreadsheet tool assesses results of pre-modeled scenario results
 - Interpolates to give results relevant to site-specific conditions
 - Enables sensitivity analyses to be rapidly conducted

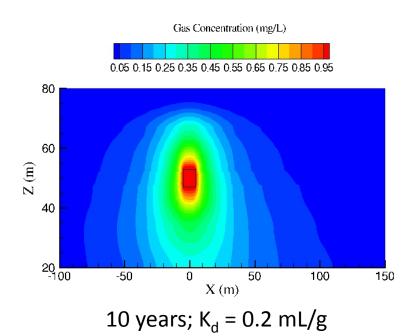


Technical Basis for Parameters



- Because VOC transport was simulated until steady state conditions were obtained, the effects of sorption could be neglected (Carroll et al., 2012)
- Sorption may delay the impact to groundwater, but has minimal impact on the overall long-term contaminant distribution if the source strength remains constant





Pre-Modeled Scenarios



- STOMP (Subsurface Transport Over Multiple Phases) was used (White and Oostrom, 2006)
- Fully-implicit, integrated finite difference model
- Applicable governing equations are the component mass-conservation equations for water, organic compounds, and air
- Simulations were conducted for Base Case (bold) and 971 other cases
- Groundwater concentrations at wells located 10, 25, 50, 75, and 100 m downstream are computed.

Name	Symbol	Simulated Values
gravimetric moisture content (%)	ω	1 , 3, 5, 7, 9
vadose zone thickness (m)	VZT	10, 20, 30, 45, 60
source thickness ratio (-)	STR	0.1 , 0.25, 0.5
relative source position (-)	RSP	0.1, 0.5, 1 , 5, 10
source area (m²)	SA	100 , 400, 900, 2500
groundwater Darcy velocity (m/d)	q	0.05, 0.0175, 0.03, 0.165, 0.3
source gas concentration (mg/L)	C_{qs}	1 , 2, 10, 20
Henry's Law coefficient	Ĥ	0.1, 0.5, 0.89 , 1.0
compliance well screen length (m)	S	5 , 10, 20
recharge rate (cm/yr)	R	0.4, 0.8, 2, 4, 7.5

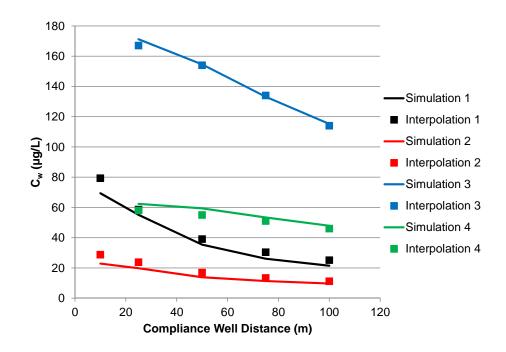
(Oostrom et al., 2014)





Comparison of STOMP simulations and interpolations (Oostrom et al. 2014)

Parameter	Test Case 1	Test Case 2	Test Case 3	Test Case 4	
ω	3%	3%	7%	7%	
STR	0.175	0.175	0.375	0.375	
VZT	20	20	45	45	
SA	250 m ²	250 m ²	1700 m ²	1700 m ²	
q	0.0175 m/d	0.165 m/d	0.0175 m/d	0.165 m/d	
RSP	0.55	0.55	5.5	5.5	



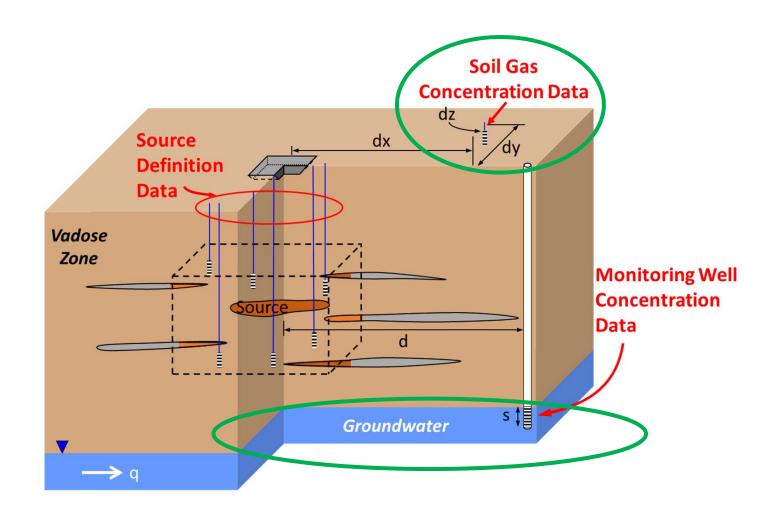
Tool Updates



- Provide soil gas concentrations at two depths across the whole model domain
- Provide groundwater concentration at any location along the plume centerline
- Expand the range of parameters in the pre-modeled scenarios
 - Enable the tool to be applied at more sites

Tool Updates

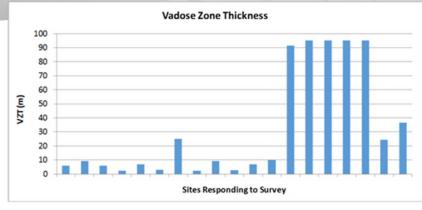


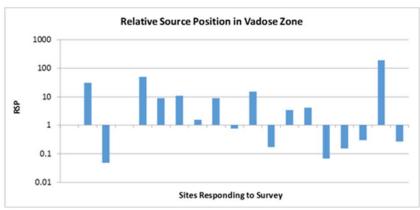


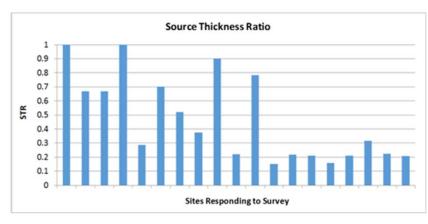
Survey to Expand Applicability

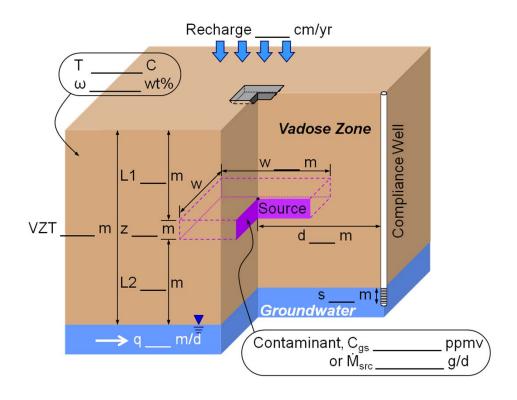


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Parameter Expansion

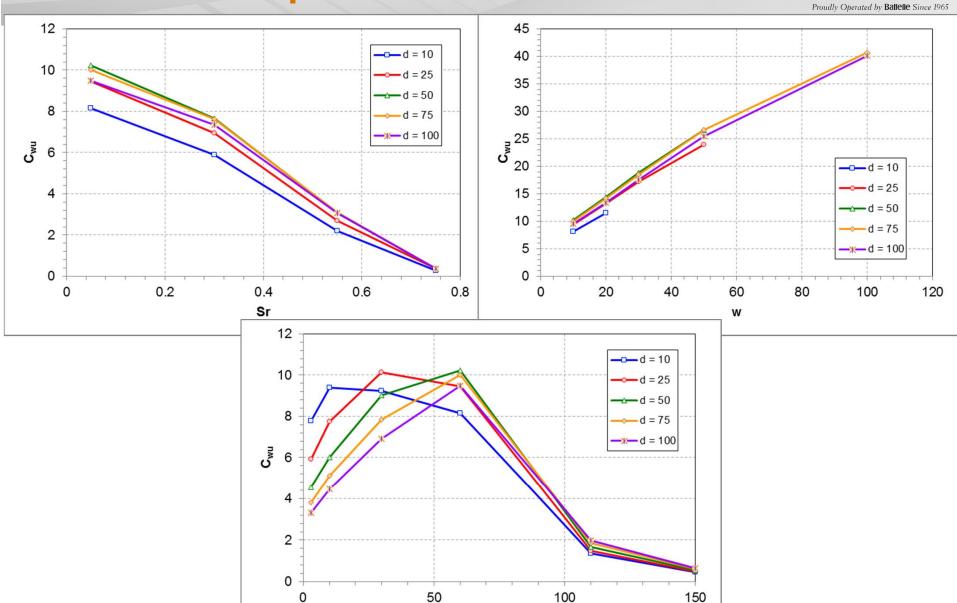


Parameter	Evaluation Points as the Basis for Interpolation						
Residual Moisture Saturation		0.05	0.3	0.55	0.75		
Source Thickness Ratio		0.1	0.25	0.5	0.75		
Vadose Zone Thickness	3	10	30	60	110	150	
Source Area (m²)		100	400	900	2,500	10,000	
Groundwater Velocity (m/day)		0.005	0.03	0.3	1		
Relative Source Position		0.1	1	10	50		

~5,000 Simulations required to extend parameter ranges to the values in red





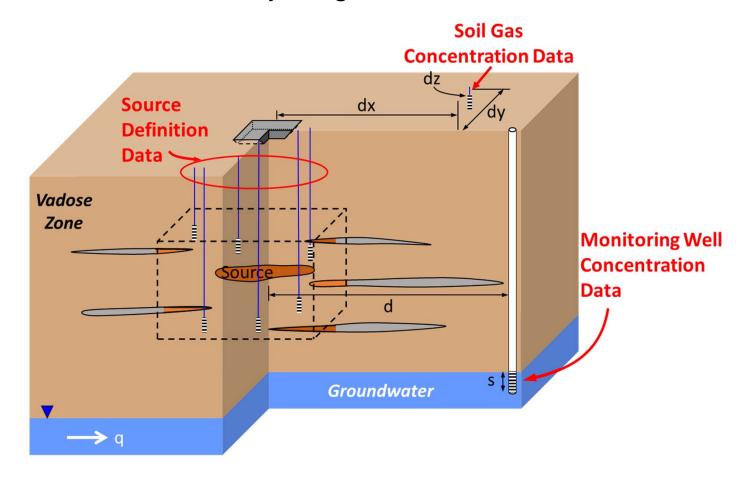


VZT

Ground-Truthing

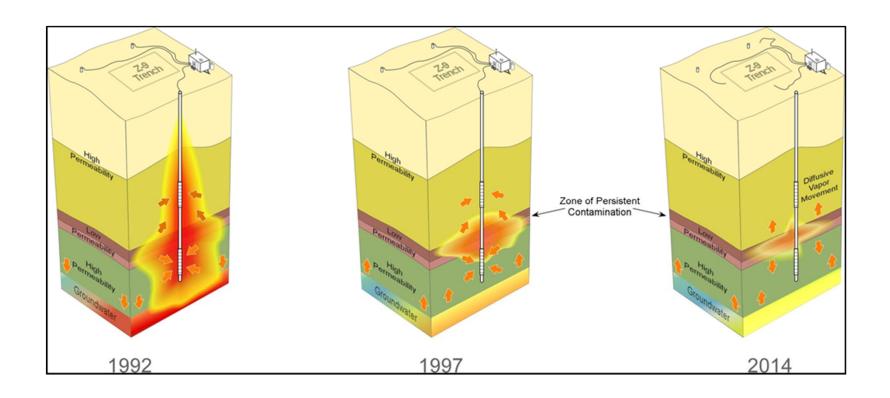


- ► For sites with pseudo steady-state conditions compare model results to measured values at specific locations
 - Consider uncertainty ranges



Case Study: Hanford Site Conceptual Model

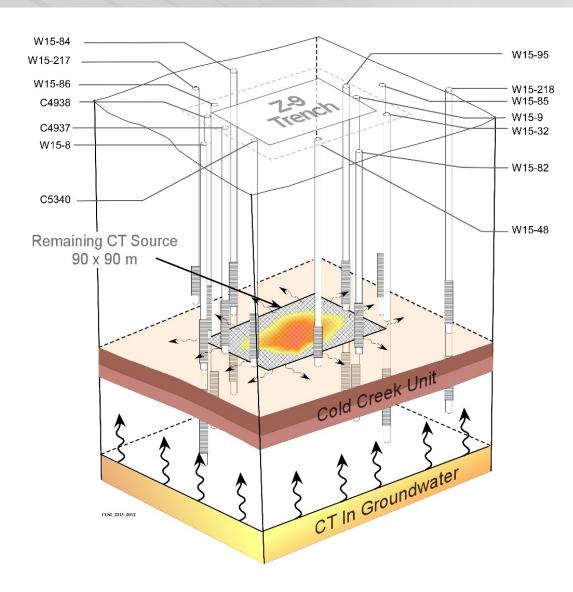




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Case Study: Hanford Site Parameters

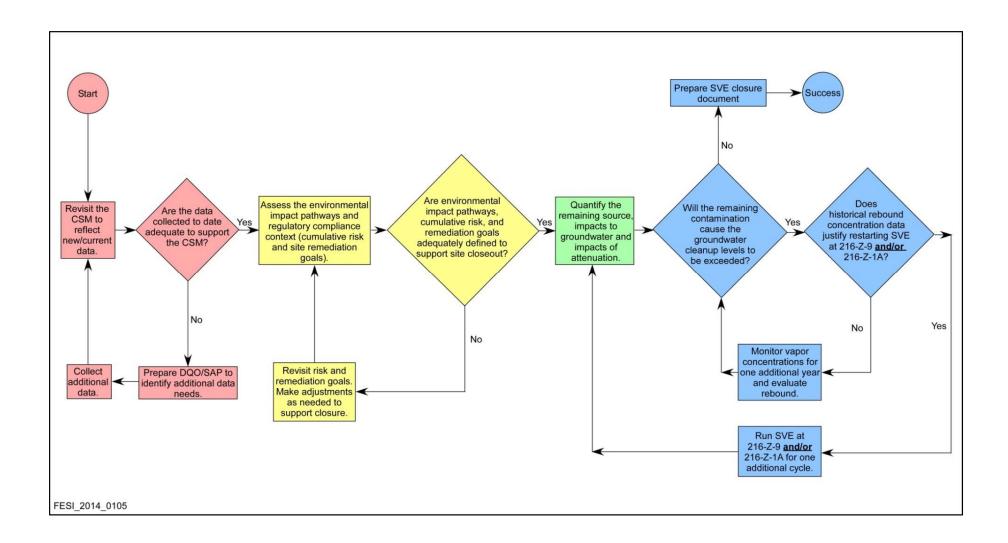




DOE 2014, 2016

Case Study: Decision Logic





DOE 2014, 2016

Case Study: Results



- Site provided SVE data according to the decision logic and obtained approval from regulators to terminate the SVE system
 - Approval was based on site data and transport analysis showing that no additional SVE was needed to meet the groundwater protection objective
 - Vapor intrusion was not an issue for this site

References – Journal Articles



- Brusseau, M.L., K.C. Carroll, M.J. Truex, and D.J. Becker. 2013. "Characterization and Remediation of Chlorinated Volatile Organic Contaminants in the Vadose Zone: An Overview of Issues and Approaches." Vadose Zone J., 12(4): doi:10.2136/vzj2012.0137
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- ▶ DOE. 2016. Endpoint Evaluation for the 200-PW-1 Operable Unit Soil Vapor Extraction System Operations. DOE/RL-2014-48 Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.
- ▶ DOE. 2014. Path Forward for Future 200-PW-1 Operable Unit Soil Vapor Extraction Operations. DOE/RL-2014-18 Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.
- ▶ Johnson, C.D., M.J. Truex, K.C. Carroll, M. Oostrom, and A.K. Rice. 2016. *Vapor Intrusion Estimation Tool For Unsaturated-Zone Contaminant Sources*. PNNL-23381, Revision 1, Pacific Northwest National Laboratory, Richland, WA.
- ▶ Truex, MJ, CD Johnson DJ Becker, MH Lee, and MJ Nimmons. 2015. Performance Assessment for Pump-and-Treat Closure or Transition. PNNL-24696, Pacific Northwest National Laboratory, Richland, WA.
- ► Truex, M.J., D.J. Becker, M.A. Simon, M. Oostrom, A.K. Rice, and C.D. Johnson. 2013. *Soil Vapor Extraction System Optimization, Transition, and Closure Guidance*. PNNL-21843, Pacific Northwest National Laboratory, Richland, WA.
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