Use of Mass Flux to Guide Decision Making in Plume Management

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GROUP 1

Background

10-acre former bulk fuel terminal, which operated between 1952 and 1990 with numerous documented fuel releases

- Historical LNAPL covered approx. 5 acres and extended off site beneath RR and highway onto downgradient property

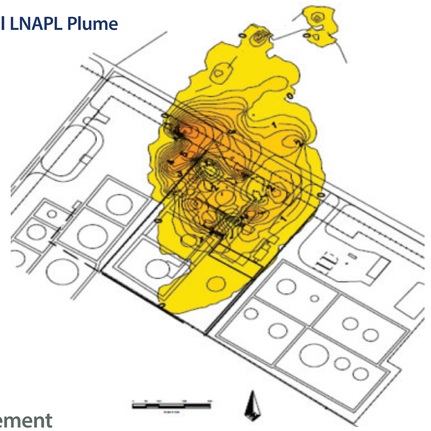
On-site electrical resistive soil heating: 2007-2012

- Mobile LNAPL eliminated and 880K lbs hydrocarbon destroyed

Setting: Southern Appalachian Piedmont

- Thick saprolite cover (60-100 ft) over crystalline igneous bedrock
- Vertically integrated aquifer system, no stratification above bedrock

Historical LNAPL Plume



Problem Statement

Remediation targeted upper aquifer and did not address deep saprolite or bedrock zones on site

A large dissolved phase plume, which extends off-site, remains with VOC concentrations in excess of applicable regulatory standards

Several CoCs found at concentrations of 3 to 4 orders of magnitude above state standards in on-site wells — TBA greatest in bedrock zone

Inadequate understanding of local hydraulics

- Well network did not allow accurate assessment of contaminant transport characteristics to predict off-site risks
- No bedrock wells on site and only 2 off site
- Vertical gradients and overall groundwater flow regime not well understood

Methods / Field Activities

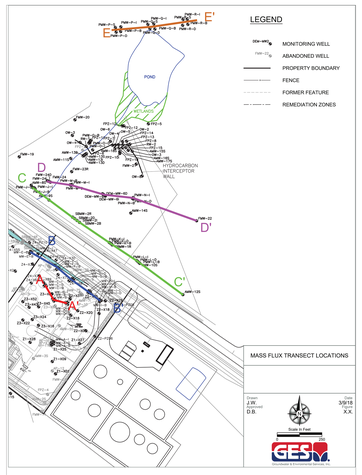
Electrical conductivity and MASW to resolve top of rock surface

Install 18 nested well clusters - 9 on site and 9 off site

- Screened in 4 hydraulic zones — water table (avg. 6-30), intermediate (avg. 38-47), deep saprolite (avg. 65-75), and bedrock (avg. 92-108)

Constructed 5 mass flux transects perpendicular to groundwater flow direction

- Farthest downgradient transect (E — E') eliminated from further consideration due to all non-detect results for dissolved CoCs
- 62 total "cells" in 16 well clusters used for mass flux evaluation
- 58 slug tests completed to determine hydraulic conductivity — see Table
- All 62 cells sampled on a biannual basis



Slug Test Data Summary

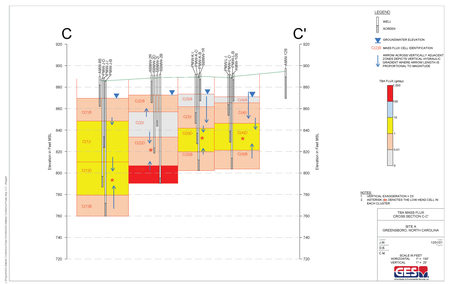
Zone	# wells tested	Avg K (cm/sec)
Water Table	10	0.000569
Intermediate	14	0.001244
Deep	16	0.002117
Bedrock	18	0.009615

Mass Flux Calculation (Farhat, Newell, and Nichols, 2011)

$$w = \sum_{i=1}^{i=n} C_i q_i A_i CF$$

Where:
w = total mass flux across selected transect (g/day)
C_i = concentration of constituent in selected cell i (mg/L)
A_i = area of cell i (ft^2)

CF = conversion factor = 80.3 (ft/cm)/ (sec/day) (L/ft^3) (g/mg)
q_i = Darcy velocity through cell i



TBA Flux by Cell - Transect A: 572.60 g/day

	A (1)	A (2)	A (3)
shallow			
interm.			
deep	28.49	225.54	18.31 *
bedrock	*	298.46 *	

91.5% of transect flux in 2 cells

Transect B: 536.85 g/day

	B (1)	B (2)	B (3)	B (4)	B (5)
		*	*		
	*	2.32	533.67		*
				*	

99.4% of transect flux in 1 cell - 2.5% of transect area

Transect C: 1,060.30 g/day

	C (1)	C (2)	C (3)	C (4)
	*	*	8.32*	2.14*
		1041.16		

98.2% of transect flux in 1 cell - 9.3% of transect area

Transect D: 146.49 g/day

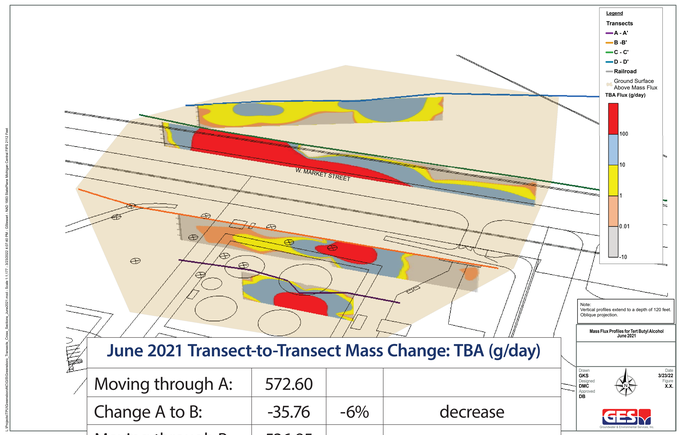
	D (1)	D (2)	D (3)	D (4)
	2.08		14.81	
		37.66	82.68	*
	*	3.15*	*	3.06
	NA		NA	

Legend:
< 0.01 g
0.01 - 1 g
1 - 10 g
10 - 100 g
> 100.0 g
NA not analyzed

* denotes low head zone per cluster

Results

Resolution of vertical gradients and regional groundwater flow
Bedrock is low head zone on site, gradient is upward from bedrock aquifer off site
No fractures or discrete flow pathways identified in bedrock zone
Delineation of CoCs nearly complete in 3D



June 2021 Transect-to-Transect Mass Change: TBA (g/day)

Moving through A:	572.60		
Change A to B:	-35.76	-6%	decrease
Moving through B	536.85		
Change B to C:	523.46	98%	increase
Moving through C:	1060.30		
Change C to D:	-913.81	-86%	decrease
Moving through D:	146.49	leaving system	

Conclusions/Findings

The mass flux evaluation offers exceptional insight into groundwater dynamics and contaminant fate and transport for the site:

- Flux calculations show 91% of TBA moves through 5.5% of total cross-sectional area (4 of 62 cells)
- <15% of total TBA mass flux coincides with low head hydraulic zones

Comparison of total mass moving through successive transects indicates:

- Residual mass remains beneath highway and RR corridor
- Mass reduction downgradient of highway implies robust MNA activity:
  93% reduction of MTBE & 98% of TBA from transect C to D and 100% from D to E

The ongoing evaluation of mass discharge provides a more complete understanding of the site and will underpin the development of a long-term risk management strategy