

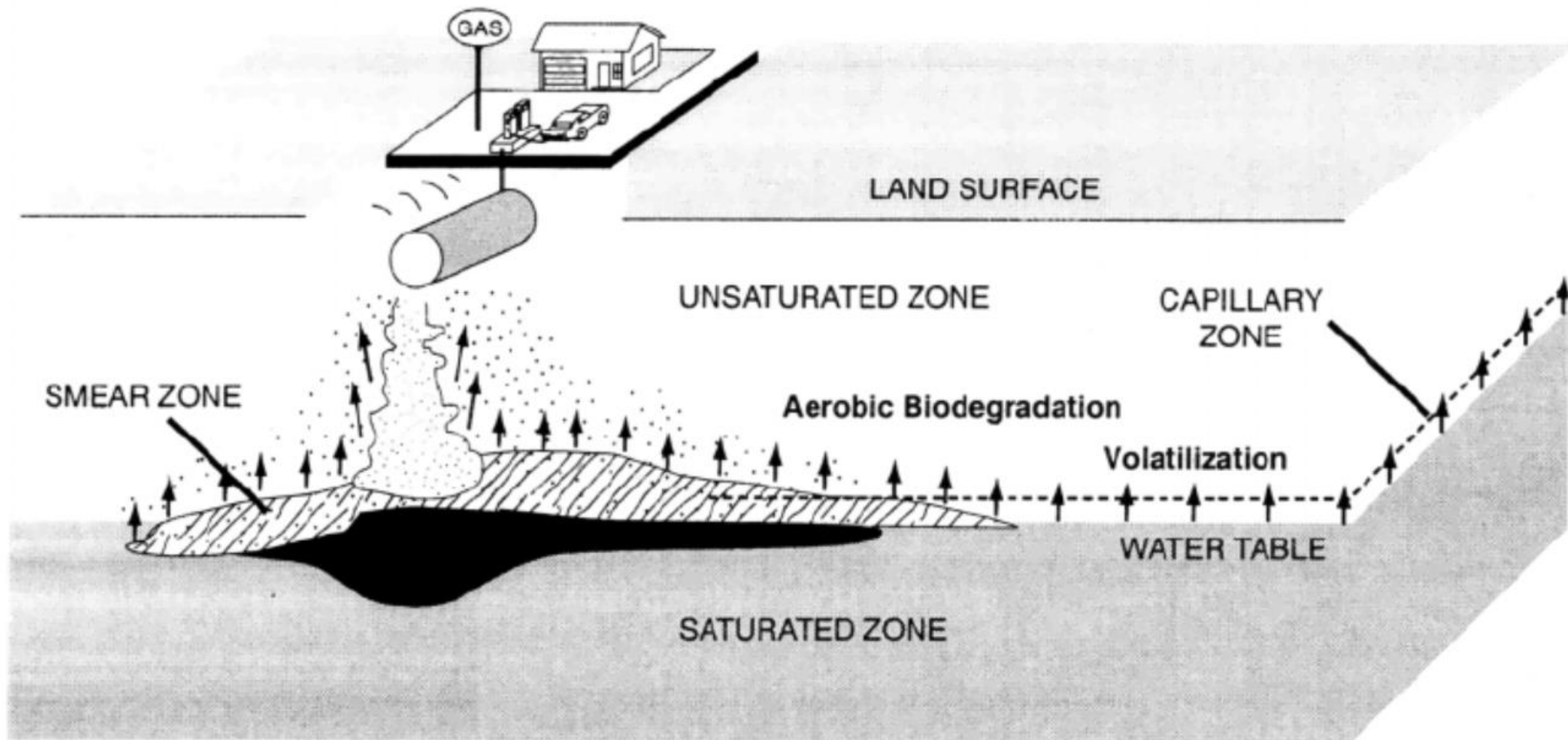
# **Quantification of aerobic biodegradation and volatilization rates of gasoline hydrocarbons near the water table under natural attenuation conditions**

Matthew A. Lahvis, Arthur L. Baehr, and Ronald J. Baker

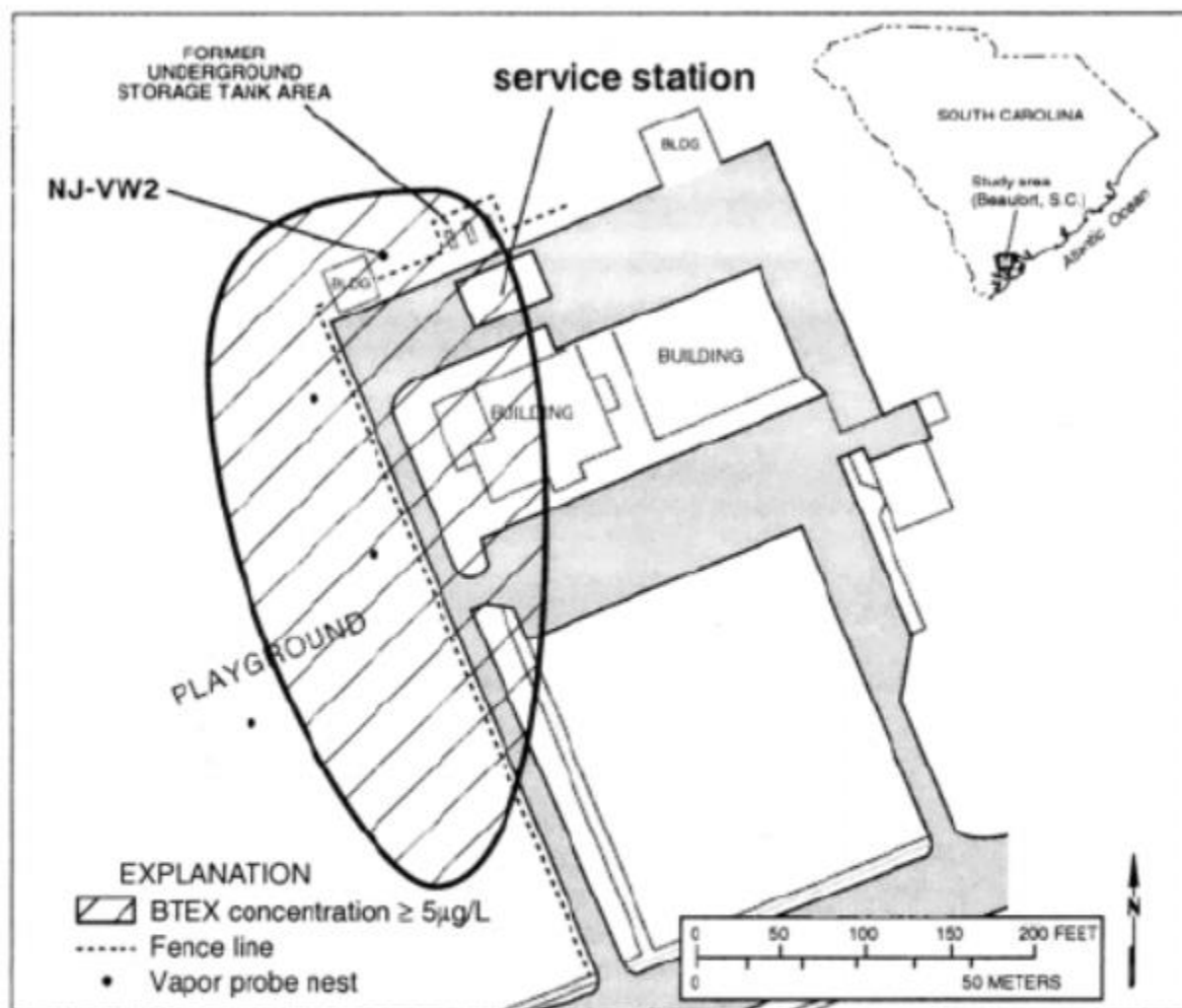
Water Resources Division, U.S. Geological Survey, West Trenton, New Jersey

**Abstract.** Aerobic biodegradation and volatilization near the water table constitute a coupled pathway that contributes significantly to the natural attenuation of hydrocarbons at gasoline spill sites. Rates of hydrocarbon biodegradation and volatilization were quantified by analyzing vapor transport in the unsaturated zone at a gasoline spill site in Beaufort, South Carolina. Aerobic biodegradation rates decreased with distance above the water table, ranging from 0.20 to 1.5  $\text{g m}^{-3} \text{d}^{-1}$  for toluene, from 0.24 to 0.38  $\text{g m}^{-3} \text{d}^{-1}$  for xylene, from 0.09 to 0.24  $\text{g m}^{-3} \text{d}^{-1}$  for cyclohexene, from 0.05 to 0.22  $\text{g m}^{-3} \text{d}^{-1}$  for ethylbenzene, and from 0.02 to 0.08  $\text{g m}^{-3} \text{d}^{-1}$  for benzene. Rates were highest in the capillary zone, where 68% of the total hydrocarbon mass that volatilized from the water table was estimated to have been biodegraded. Hydrocarbons were nearly completely degraded within 1 m above the water table.

# LAHVIS ET AL.: GASOLINE HYDROCARBONS NEAR THE WATER TABLE



**Figure 1.** Conceptualization of natural attenuation remediation at a petroleum product spill site.



**Figure 2.** Site map showing location of source area and vapor well NJ-VW2 and distribution of benzene, toluene, ethylbenzene, and xylenes (BTEX) in groundwater at gasoline spill site, Beaufort, South Carolina, March 11, 1994.

**Table 1.** Measured Gaseous- and Aqueous-Phase Concentrations of Carbon Dioxide, Oxygen, and Hydrocarbons at Vapor Well NJ-VW2, Gasoline Spill Site, Beaufort, South Carolina, June 20, 1995

Distance Above Water Table, cm	Carbon Dioxide	Oxygen	Cyclo-Hexene	Benzene	Toluene	Ethyl-Benzene	Xylenes	BTEX	C <sub>6</sub> -C <sub>9</sub> Aliphatic Compounds	C <sub>6</sub> -C <sub>9</sub> Aromatic Compounds	THC
	<i>Gaseous-Phase Concentration (G<sub>k</sub>)</i>										
332	0.540	277	...	...	...	...	...	...	...	...	...
256	142	173	...	...	...	...	...	...	...	...	...
225	186	136	...	...	0.00	...	0.00	0.00	...	0.00	0.00
165	236	112	...	...	0.000780	...	0.000614	0.00139	...	0.00139	0.00139
134	261	73.9	...	...	0.00297	...	0.000600	0.00357	...	0.00357	0.00357
104	270	65.5	0.00	0.00	0.00393	0.00	0.00100	0.00493	0.00	0.00529	0.00529
73	308	28.0	0.00317	0.00230	0.216	0.00288	0.00690	0.228	0.0145	0.243	0.258
43	330	33.0	0.102	0.0167	0.623	0.0592	0.287	0.986	0.490	1.31	1.80
12	304	21.0	2.29	0.145	5.41	0.592	3.12	9.87	6.81	11.3	18.1
	<i>Aqueous-Phase Concentration (C<sub>k</sub>)</i>										
-24	259	0.0	1.17	1.40	25.6	3.62	22.2	52.8	2.20	64.9	67.1
-62	205	0.0	...	16.0	26.2	5.70	25.2	73.1	...	...	...

All concentrations are in milligrams per liter; BTEX is benzene, toluene, ethylbenzene, and xylenes; and THC is total hydrocarbon (C<sub>6</sub>-C<sub>9</sub>, aliphatic, and aromatic compounds).

**Table 9.** Mass Fluxes ( $J_k$ ) from Groundwater to the Unsaturated Zone at Vapor Well NJ-VW2, Gasoline Spill Site, Beaufort, South Carolina, June 20, 1995

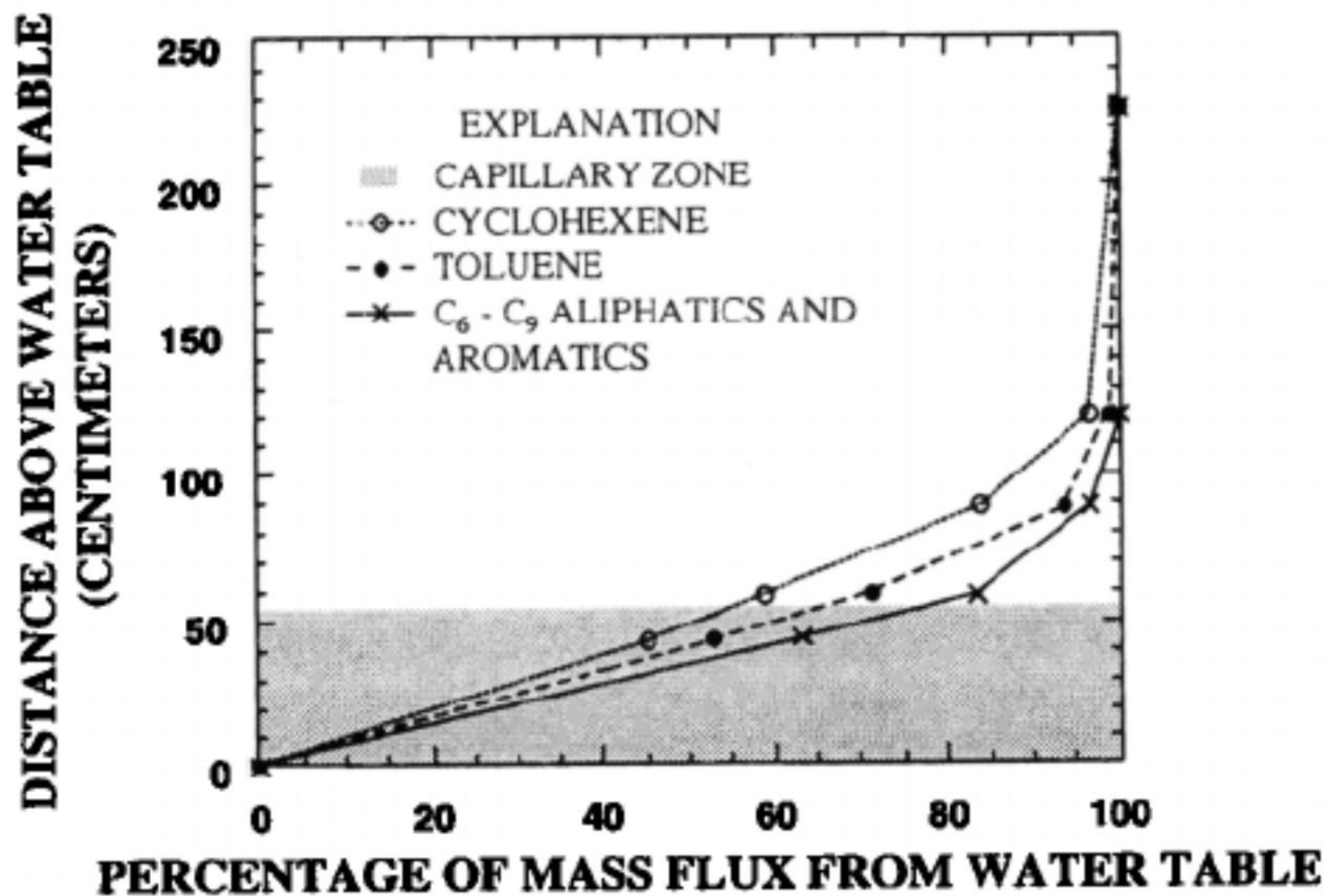
Distance Above Water Table, cm	Carbon Dioxide	Oxygen	Cyclo-Hexene	Benzene	Toluene	Ethyl-Benzene	Xylenes	BTEX	C <sub>6</sub> -C <sub>9</sub> Aliphatic Compounds	C <sub>6</sub> -C <sub>9</sub> Aromatic Compounds	THC
119	-13.0	13.7	...	...	-0.0118*	...	...	-0.0115*	...	-0.0123*	-0.0131*
88	-9.73	10.7	-0.00505†	-0.00103†	-0.0583	-0.00285†	-0.0138†	-0.0603	-0.0230†	-0.0772	-0.0815
58	-6.11	7.45	-0.0252	-0.00488	-0.149	-0.0142	-0.0667	-0.228	-0.127	-0.416	-0.400
43	-3.75	5.34	-0.0543	-0.00736	-0.198	-0.0233	-0.117	-0.335	-0.223	-0.276	-0.661
0	-3.75‡	5.34‡	-0.0543‡	-0.00736‡	-0.198‡	-0.0233‡	-0.117‡	-0.335‡	-0.223‡	-0.276‡	-0.661‡

Mass fluxes are in  $\text{g m}^{-2} \text{d}^{-1}$ . Negative value indicates upward transport.

\*Mass flux computed at a distance 108 cm above water table.

†Mass flux computed at a distance 77 cm above water table.

‡Mass flux extrapolated downward to the water table by assuming that reaction rates remain constant from the base of model domain ( $z = 43$ ) to the water table ( $z = 0$ ).



**Figure 10.** Distribution of mass loss in the unsaturated zone resulting from aerobic biodegradation reactions at gasoline spill site, Beaufort, South Carolina, June 20, 1995.