MOVEMENT AND FATE OF SOLUTES IN A PLUME OF SEWAGE-CONTAMINATED GROUND WATER, CAPE COD, MASSACHUSETTS: U.S. GEOLOGICAL SURVEY TOXIC WASTE GROUND-WATER CONTAMINATION PROGRAM

U.S. GEOLOGICAL SURVEY
Open-File Report 84-475

Papers presented at the Toxic Waste Technical Meeting
Tucson, Arizona, March 20-22, 1984

≋ **USGS**
science for a changing world

Table 6. Inorganic analyses for samples from 1983 field season.
[-- is for no data]

Well No.	pH (lab)	pH (field)	Sp. Cond (lab) (μmhos/cm)	Sp. Cond (field) (μmhos/cm)	Temp (field) (C°)	Br (mg/L)	Cl (mg/L)	F (mg/L)	NH_4^+ + organic N (mg/L) [1]	NO_3^- (mg/L) [1]
FSW 166-67	6.2	5.8	96	100	9.5	0.05	16.0	0.03	0.4	0.92
167-55	6.1	6.0	49	48	9.0	0.03	7.4	0.01	0.3	<0.06
173-69	5.7	5.9	69	122	10.0	0.05	20.0	0.04	1.1	2.2
182-69	5.9	5.7	85	80	9.0	0.05	12.0	0.03	0.5	1.6
194-57	6.0	5.6	151	145	11.5	0.05	14.0	0.07	1.9	1.7
214-60	5.8	5.6	96	83	13.5	0.05	11.0	0.03	0.9	2.3
230-48	5.6	5.4	123	115	10.5	0.05	6.3	0.11	1.0	3.4
231-57	6.0	--	160	145	12.0	--	--	--	1.5	6.4
232-58	6.3	5.9	160	153	12.0	0.05	4.8	0.2	0.8	4.6
234-99	5.6	6.4	126	122	12.5	0.05	13.0	0.04	0.5	2.2
235-94	5.5	--	87	81	11.0	0.03	7.9	0.03	0.4	1.3
236-106	5.4	4.9	140	126	10.0	0.05	14.0	0.05	0.7	1.1
237-88	6.6	6.4	142	128	14.0	0.05	11.0	0.10	6.0	2.6
238-106	6.1	5.2	110	95	10.0	0.05	10.0	0.04	0.8	2.0
239-64	6.8	6.6	220	190	13.0	0.08	11.0	0.20	10.0	<0.06
240-95	5.9	5.8	55	57	10.0	--	9.5	--	0.20	0.07

[1] Milligrams per liter as nitrogen.

Table 6. Continued. Inorganic analyses for samples from 1983 field season.
[-- is for no data]

Well No.	pH (lab)	pH (field)	Sp. Cond (lab) (μmhos/cm)	Sp. Cond (field) (μmhos/cm)	Temp (field) (C°)	Br (mg/L)	Cl (mg/L)	F (mg/L)	NH_4^+ + organic N (mg/L) [1]	NO_3^- (mg/L) [1]
FSW										
241-98	5.9	5.8	68	62	10.0	--	6.9	--	0.20	0.06
242-77	5.6	5.4	57	51	10.0	0.04	7.9	0.06	0.5	0.21
243-45	5.7	6.2	57	38	9.0	0.03	7.4	0.06	0.5	0.29
244-90	6.9	6.6	235	230	11.0	0.30	13.0	0.20	15.0	<0.06
245-25	4.7	4.7	224	200	10.0	0.05	28.0	0.06	0.7	1.2
246-35	6.0	5.6	158	152	12.0	0.05	14.0	0.06	0.6	5.0
247-70	5.5	5.4	119	120	--	0.06	20.0	0.13	1.00	1.4
254-216	6.5	6.9	80	59	10.0	0.02	6.8	0.08	0.2	<0.06
254-168	6.4	6.4	121	115	10.0	0.02	11.0	0.10	0.2	<0.06
254-140	6.7	6.3	163	175	10.5	0.11	15.0	0.09	0.2	0.31
254-107	6.7	6.2	250	235	10.5	0.12	16.0	0.15	1.0	1.0
254-72	6.9	6.7	255	225	11.0	0.46	13.0	0.21	12.0	0.08
254-54	6.7	6.3	241	220	10.5	0.04	7.5	0.11	10.0	0.57
254-26	5.8	4.9	79	70	10.0	0.04	11.0	0.04	0.4	0.80
262-159	7.1	6.7	152	125	10.0	0.04	4.0	0.12	0.3	0.32
262-85	6.5	5.9	262	255	11.0	0.14	22.0	0.13	0.2	0.32
262-69	5.9	5.7	213	200	11.0	0.05	16.0	0.10	4.0	2.9

[1] Milligrams per liter as nitrogen.

Table 6. Continued. Inorganic analyses for samples from 1983 field season.
[-- is for no data]

Well No.	pH (lab)	pH (field)	Sp. Cond (lab) (μmhos/cm)	Sp. Cond (field) (μmhos/cm)	Temp (field) (C°)	Br (mg/L)	Cl (mg/L)	F (mg/L)	NH_4^+ + organic N (mg/L) [1]	NO_3^- (mg/L) [1]
FSW 262-41	5.3	5.0	90	90	10.0	0.05	10.0	0.04	0.2	1.4
267-155	6.6	6.7	117	122	9.0	0.03	8.8	0.10	0.2	0.19
267-136	6.9	6.0	97	95	9.0	0.05	11.0	0.05	0.3	1.8
267-111	6.3	5.9	125	120	9.0	0.05	11.0	0.06	0.4	3.7
267-88	5.8	5.5	200	195	9.0	0.05	20.0	0.07	11.0	3.5
271-165	7.1	6.9	117	125	9.0	0.03	10.0	0.36	0.20	<0.06
271-141	6.8	6.9	139	132	9.0	0.04	14.0	0.08	0.50	0.56
271-85	5.8	5.0	164	150	10.0	0.07	21.0	0.06	0.30	0.98
271-41	5.4	5.2	55	55	10.0	0.03	9.5	0.01	0.30	0.07
279-86	5.6	--	79	76	11.0	0.06	10.0	0.04	0.20	0.42
279-61	5.6	--	84	73	11.0	0.04	11.0	0.03	0.20	0.25
282-123	6.3	5.9	155	143	9.0	0.05	16.0	0.08	0.30	0.28
282-94	6.6	5.7	219	208	9.0	0.08	20.0	0.09	0.60	0.78
282-70	6.3	5.4	223	215	10.0	0.08	24.0	0.09	0.60	1.36
282-49	6.3	6.0	97	100	9.0	0.05	22.0	0.04	0.40	<0.06
288-97	6.8	6.3	145	142	9.0	0.05	10.0	0.08	3.70	3.8

[1] Milligrams per liter as nitrogen.

Table 6. Continued. Inorganic analyses for samples from 1983 field season.
[-- is for no data]

Well No.	pH (lab)	pH (field)	Sp. Cond (lab) (μmhos/cm)	Sp. Cond (field) (μmhos/cm)	Temp (field) (C°)	Br (mg/L)	Cl (mg/L)	F (mg/L)	NH_4^+ + organic N (mg/L) [1]	NO_3^- (mg/L) [1]
FSW										
290-91	6.8	5.9	91	90	10.0	0.05	8.5	0.04	0.50	2.1
294-89	6.4	6.0	154	139	9.5	0.05	16.0	0.05	0.40	1.4
299-20	6.2	5.2	83	76	10.0	0.18	8.4	0.28	0.30	3.1
300-30	7.1	6.5	422	410	11.5	0.01	19.0	0.04	8.50	14.0
300-10	5.6	5.2	141	138	13.0	0.04	33.0	0.06	0.20	0.26
347-67	6.7	6.3	322	302	10.0	0.06	30.0	0.26	3.8	<0.06
SDW										
305-32	5.7	6.2	126	122	9.5	0.13	9.0	0.23	0.4	3.8
313-60	6.1	--	105	100	10.0	0.02	8.4	0.04	0.2	0.90

[1]Milligrams per liter as nitrogen.

Table 6. Continued. Inorganic analyses for samples from 1983 field season.
[-- is for no data]

Well No.	NO_2^- (mg/L)[2]	NH_4^+ (mg/L)[2]	Total-N (mg/L)[2]	Diss O_2[1] (mg/L)	Diss P[3] (mg/L)	SO_4 (mg/L)	Alkalinity (meq/L)	Al (µg/L)	B (µg/L)	Ba (µg/L)
FSW										
166-67	<0.06	<0.10	1.09	0.8	0.01	5.6	0.16	19.0	50.0	15.0
167-65	<0.06	<0.10	<0.25	10.8	0.01	3.6	0.19	<10.0	20.0	11.0
173-69	<0.06	<0.10	2.04	--	0.01	4.2	0.22	20.0	50.0	22.0
182-69	<0.06	<0.10	1.54	--	0.02	3.8	0.12	10.0	30.0	10.0
194-57	<0.06	1.6	3.42	4.4	0.02	16.0	0.44	19.0	140.0	44.0
214-60	<0.06	0.11	2.40	--	0.01	8.2	0.15	11.0	90.0	20.0
230-48	<0.06	<0.10	4.30	--	0.29	21.0	0.15	38.0	50.0	10.0
231-57	<0.06	<0.10	--	--	0.50	--	0.26	31.0	60.0	10.0
232-58	<0.06	<0.10	4.79	--	0.74	24.0	0.25	33.0	60.0	9.0
234-99	<0.06	<0.10	2.10	--	0.02	14.0	0.14	17.0	40.0	18.0
235-94	<0.06	<0.10	1.12	--	0.01	16.0	0.08	13.0	30.0	15.0
236-106	<0.06	<0.10	1.48	--	0.01	24.0	0.10	16.0	140.0	18.0
237-88	<0.06	3.8	8.20	--	0.05	6.5	0.51	12.0	50.0	13.0
238-106	<0.06	<0.10	1.90	--	0.03	17.1	0.15	18.0	30.0	12.0
239-64	<0.06	7.0	12.0	0.0	0.11	15.0	1.35	13.0	320.0	16.0
240-95	--	<10.0	--	--	0.01	6.0	8.00	<10.0	<10.0	15.0

[1] Dissolved oxygen data collected in 1979 (LeBlanc, 1982).
[2] Milligrams per liter as nitrogen.
[3] Milligrams per liter as phosphorus.

Table 6. Continued. Inorganic analyses for samples from 1983 field season.
[-- is for no data]

Well No.	NO_2^- (mg/L)[2]	NH_4^+ (mg/L)[2]	Total-N (mg/L)[2]	Diss O_2[1] (mg/L)	Diss P[3] (mg/L)	SO_4 (mg/L)	Alkalinity (meq/L)	Al (μg/L)	B (μg/L)	Ba (μg/L)
FSW										
241-98	--	<0.10	--	--	0.02	10.0	11.0	<10.0	20.0	--
242-77	<0.06	<0.10	0.40	--	0.04	6.0	0.09	11.0	30.0	11.0
243-45	<0.06	<0.10	0.40	--	0.02	8.1	0.09	19.0	20.0	9.7
244-90	<0.06	10.7	15.0	--	0.11	16.0	1.29	16.0	160.0	19.0
245-25	<0.06	<0.10	1.45	--	0.02	9.4	0.06	426.0	40.0	117.0
246-35	<0.06	<0.10	6.5	--	0.36	16.0	0.22	30.0	130.0	40.0
247-70	<0.06	0.60	--	2.6	0.02	5.8	0.26	33.0	40.0	49.0
254-216	<0.06	<0.10	0.30	0.1	0.09	13.0	0.34	20.0	20.0	10.0
254-168	<0.06	<0.10	<0.25	0.0	0.05	17.0	0.45	21.0	20.0	12.0
254-140	<0.06	<0.10	0.50	--	0.08	14.0	0.94	51.0	30.0	11.0
254-107	<0.06	<0.10	2.09	0.0	0.04	23.0	1.32	30.0	290.0	13.0
254-72	<0.06	9.10	12.0	0.0	0.07	11.0	1.57	31.0	250.0	17.0
254-54	<0.06	7.6	10.0	0.0	0.03	16.0	1.10	15.0	240.0	23.0
254-26	<0.06	0.15	1.31	8.1	0.01	7.4	0.11	54.0	40.0	33.0
262-159	<0.06	<0.10	3.80	--	0.12	22.0	0.82	--	30.0	14.0

[1]Dissolved oxygen data collected in 1979 (LeBlanc, 1982).
[2]Milligrams per liter as nitrogen.
[3]Milligrams per liter as phosphorus.

Table 6. Continued. Inorganic analyses for samples from 1983 field season.
[-- is for no data]

Well No.	NO$_2^-$ (mg/L)[2]	NH$_4^+$ (mg/L)[2]	Total-N (mg/L)[2]	Diss O$_2$[1] (mg/L)	Diss P (mg/L)[3]	SO$_4$ (mg/L)	Alkalinity (meq/L)	Al (µg/L)	B (µg/L)	Ba (µg/L)
FSW										
262-85	<0.06	<0.10	0.50	0.0	0.04	23.0	1.26	10.0	380.0	16.5
262-69	<0.06	2.1	5.81	0.0	0.02	23.0	0.57	10.0	360.0	22.0
262-41	<0.06	<0.10	--	8.0	0.01	9.2	0.17	72.0	30.0	64.0
267-155	<0.06	<0.10	--	--	0.38	15.0	0.58	66.0	30.0	13.0
267-136	<0.06	<0.10	1.81	8.2	0.06	7.5	0.30	18.0	20.0	10.9
267-111	<0.06	<0.10	--	0.0	0.05	12.0	0.31	<10.0	40.0	12.0
267-88	<0.06	7.6	--	0.0	0.05	25.0	0.22	8.6	160.0	24.3
271-165	<0.06	<0.10	--	--	0.11	12.0	0.58	13.0	20.0	12.7
271-141	<0.06	<0.10	--	--	0.01	11.0	0.53	23.0	20.0	12.2
271-85	<0.06	<0.10	--	--	0.08	14.0	0.36	14.0	150.0	13.7
271-41	<0.06	<0.10	--	--	0.01	5.8	0.08	39.0	20.0	17.2
279-86	<0.06	<0.10	--	4.3	0.01	12.0	0.12	13.0	50.0	16.6
279-61	<0.06	<0.10	--	7.3	0.01	12.0	0.14	13.0	40.0	16.5
282-123	<0.06	<0.10	--	0.8	0.01	12.0	0.58	101.0	20.0	10.7
282-94	<0.06	<0.10	--	0.1	0.03	27.0	0.72	112.0	270.0	15.2
282-70	<0.06	<0.10	--	0.2	0.03	29.0	0.33	25.0	380.0	21.4
282-49	<0.06	<0.10	--	11.4	0.01	3.9	0.09	19.0	30.0	11.7

[1] Dissolved oxygen data collected in 1979 (LeBlanc, 1982).
[2] Milligrams per liter as nitrogen.
[3] Milligrams per liter as phosphorus.

Table 6. Continued. Inorganic analyses for samples from 1983 field season.
[-- is for no data]

Well No.	NO_2^- (mg/L)[2]	NH_4^+ (mg/L)[2]	Total-N (mg/L)[2]	Diss O_2[1] (mg/L)	Diss P[3] (mg/L)	SO_4 (mg/L)	Alkalinity (meq/L)	Al (µg/L)	B (µg/L)	Ba (µg/L)
FSW										
288-97	<0.06	2.3	--	0.0	0.05	10.0	0.47	<10.0	210.0	--
290-91	<0.06	<0.10	--	0.3	0.05	6.6	--	<10.0	30.0	12.0
294-89	<0.06	<0.10	--	0.4	0.06	9.9	0.54	669.0	40.0	17.0
299-20	<0.06	<0.10	--	--	0.01	7.6	0.09	28.0	30.0	39.0
300-30	<0.06	5.3	22.0	0.0	1.20	31.0	1.77	<10.0	530.0	12.0
300-10	<0.06	<0.10	--	5.9	0.03	5.1	0.07	67.0	40.0	52.0
347-67	<0.06	2.1	4.60	0.0	1.70	26.0	1.52	18.0	220.0	20.0
SDW										
305-32	<0.06	<0.10	--	--	0.23	19.0	0.14	220.0	70.0	11.0
313-60	<0.06	<0.10	--	10.0	0.02	22.0	0.14	22.0	30.0	20.0

[1] Dissolved oxygen data collected in 1979 (LeBlanc, 1982).
[2] Milligrams per liter as nitrogen.
[3] Milligrams per liter as phosphorus.

Table 6. Continued. Inorganic analyses for samples from 1983 field season.
[-- is for no data]

Well No.	Be (µg/L)	Ca (mg/L)	Cd (µg/L)	Co (µg/L)	Cu (µg/L)	Fe (µg/L)	K (mg/L)	Li (µg/L)	Mg (mg/L)	Mn (µg/L)	Mo (µg/L)
FSW											
166–67	<0.5	2.4	<1.0	<3.0	<10.0	1393.0	0.7	<4.0	2.4	35.0	<10.0
167–65	<0.5	1.0	<1.0	<3.0	<10.0	1295.0	0.6	4.0	1.0	35.0	<10.0
173–69	<0.5	4.2	<1.0	<3.0	<10.0	378.0	0.9	<4.0	3.4	13.0	<10.0
182–69	<0.5	2.6	<1.0	<3.0	<10.0	423.0	0.6	5.0	2.0	15.0	<10.0
194–57	<0.5	2.9	<1.0	<3.0	<10.0	25.0	2.0	4.0	2.0	457.0	<10.0
214–60	<0.5	1.9	<1.0	<3.0	13.0	39.0	1.0	<4.0	1.9	14.0	<10.0
230–48	<0.5	8.7	<1.0	29.0	<10.0	14.0	3.1	5.0	2.7	435.0	<10.0
231–57	<0.5	13.0	2.8	6.6	<10.0	325.0	3.5	<4.0	3.2	411.0	<10.0
232–58	<0.5	12.0	<1.0	5.0	<10.0	116.0	4.5	<4.0	3.5	248.0	<10.0
234–99	<0.5	4.9	<1.0	<3.0	<10.0	15.0	1.8	<4.0	3.4	10.0	<10.0
235–94	<0.5	2.7	<1.0	<3.0	<10.0	10.0	0.7	<4.0	2.5	3.0	<10.0
236–106	<0.5	3.1	<1.0	<3.0	<10.0	29.0	0.8	<4.0	2.3	141.0	<10.0
237–88	<0.5	0.4	<1.0	<3.0	<10.0	21.0	2.6	<4.0	0.3	12.0	<10.0
238–106	<0.5	5.1	<1.0	<3.0	<10.0	37.0	1.0	<4.0	4.2	5.0	<10.0
239–64	<0.5	1.5	<1.0	<3.0	<10.0	24.0	4.5	<4.0	1.3	723.0	12.0
240–95	<0.5	1.4	<1.0	<3.0	<10.0	9.0			5.0	1.5	2.0	<10.0

Table 6. Continued. Inorganic analyses for samples from 1983 field season.
[-- is for no data]

Well No.	Be (µg/L)	Ca (mg/L)	Cd (µg/L)	Co (µg/L)	Cu (µg/L)	Fe (µg/L)	K (mg/L)	Li (µg/L)	Mg (mg/L)	Mn (µg/L)	Mo (µg/L)
FSW											
241-98	--	--	--	--	--	--	--	--	--	--	--
242-77	<0.5	1.0	<1.0	<3.0	<10.0	4.0	0.4	7.0	1.2	2.8	<10.0
243-45	<0.5	1.4	<1.0	<3.0	<10.0	15.0	0.7	8.0	2.0	5.0	<10.0
244-90	<0.5	1.6	<1.0	<3.0	<10.0	38.0	5.4	9.0	1.2	50.0	<10.0
245-25	<0.5	4.5	<1.0	<3.0	<10.0	17.0	2.0	8.0	1.6	374.0	<10.0
246-35	<0.5	5.5	<1.0	<3.0	85.0	12.0	3.1	7.0	2.9	387.0	<10.0
247-70	<0.5	3.4	<1.0	<3.0	<10.0	1.4	1.3	6.0	2.3	840.7	<10.0
254-216	<0.5	3.4	<1.0	<3.0	<10.0	3320.0	1.1	8.0	1.9	63.0	<10.0
254-168	<0.5	6.7	<1.0	<3.0	<10.0	2934.0	1.0	10.0	3.2	31.0	<10.0
254-140	<0.5	9.6	<1.0	<3.0	<10.0	7657.0	1.8	9.0	3.9	335.0	<10.0
254-107	<0.5	12.0	<1.0	<3.0	<10.0	216.0	1.9	7.0	6.4	18.0	<10.0
254-72	<0.5	1.8	<1.0	<3.0	<10.0	870.0	5.4	6.0	1.6	372.0	<10.0
254-54	<0.5	1.4	<1.0	<3.0	<10.0	57.0	8.1	9.0	1.8	53.0	<10.0
254-26	<0.5	1.6	<1.0	<3.0	<10.0	29.0	1.0	9.0	1.4	28.0	<10.0
262-159	<0.5	11.0	<1.0	<3.0	<10.0	1656.0	2.6	12.0	3.9	158.0	<10.0
262-85	0.9	10.2	<1.0	<3.0	<10.0	55.0	1.2	7.6	5.3	10.0	<10.0
262-69	<0.5	1.3	<1.0	<3.0	<10.0	34.0	2.4	5.1	1.3	20.0	<10.0

Table 6. Continued. Inorganic analyses for samples from 1983 field season.
[-- is for no data]

Well No.	Be (µg/L)	Ca (mg/L)	Cd (µg/L)	Co (µg/L)	Cu (µg/L)	Fe (µg/L)	K (mg/L)	Li (µg/L)	Mg (mg/L)	Mn (µg/L)	Mo (µg/L)
FSW											
262-41	<0.5	1.5	<1.0	<3.0	<10.0	9.0	0.7	<4.0	4.0	386.0	<10.0
267-155	0.6	8.0	<1.0	<3.0	<10.0	4.0	1.5	6.6	3.3	308.0	<10.0
267-136	<0.5	5.3	<1.0	<3.0	<10.0	37.0	0.8	8.0	2.2	1.9	<10.0
267-111	<0.5	7.4	<1.0	<3.0	<10.0	22.0	0.8	4.8	3.8	4.9	<10.0
267-88	<0.5	3.3	<1.0	<3.0	<10.0	6.5	3.0	5.8	2.2	17.0	<10.0
271-165	<0.5	7.9	<1.0	<3.0	<10.0	4.1	1.5	7.2	3.0	219.9	<10.0
271-141	<0.5	8.1	<1.0	<3.0	<10.0	147.2	1.2	8.3	3.9	4.0	<10.0
271-85	<0.5	6.6	<1.0	<3.0	<10.0	6.0	1.0	4.0	4.8	3.1	<10.0
271-41	<0.5	1.3	<1.0	<3.0	<10.0	8.0	0.7	7.0	1.2	15.9	<10.0
279-86	<0.5	1.9	<1.0	<3.0	<10.0	6.1	0.5	6.9	1.8	6.7	<10.0
279-61	<0.5	2.0	<1.0	<3.0	<10.0	53.4	0.7	7.4	2.1	5.2	<10.0
282-123	<0.5	9.4	<1.0	4.4	<10.0	146.4	1.2	8.3	4.2	5.7	<10.0
282-94	<0.5	13.2	<1.0	4.9	<10.0	127.8	1.2	5.6	6.4	22.2	<10.0
282-70	0.6	8.5	<1.0	28.8	<10.0	14.3	1.2	<4.0	6.6	27.1	<10.0
282-49	<0.5	0.9	<1.0	<3.0	<10.0	6.0	0.6	5.3	1.1	2.9	<10.0
288-97	<0.5	2.1	<1.0	<3.0	<10.0	7.0	2.2	6.0	1.3	5.0	<10.0

Table 6. Continued. Inorganic analyses for samples from 1983 field season.
[-- is for no data]

Well No.	Be (µg/L)	Ca (mg/L)	Cd (µg/L)	Co (µg/L)	Cu (µg/L)	Fe (µg/L)	K (mg/L)	Li (µg/L)	Mg (mg/L)	Mn (µg/L)	Mo (µg/L)
FSW											
290-91	<0.5	4.1	<1.0	<3.0	<10.0	< 3.0	0.7	5.0	2.0	< 1.0	<10.0
294-89	<0.5	7.8	<1.0	<3.0	<10.0	910.	1.3	9.0	4.2	110	<10.0
299-20	<0.5	5.4	<1.0	<3.0	<10.0	6.0	0.7	8.0	1.3	9.0	<10.0
300-30	<0.5	5.8	<1.0	<3.0	<10.0	< 3.0	5.5	8.0	4.3	8.0	30.0
300-10	<0.5	3.0	<1.0	<3.0	<10.0	< 3.0	1.4	8.0	2.1	32.0	<10.0
347-67	<0.5	17.0	<1.0	7.0	<10.0	101.0	3.4	6.0	9.4	2662.0	<10.0
SDW											
305-32	<0.5	8.4	<1.0	7.0	50.0	29.	2.8	10.0	3.0	100.	<10.0
313-60	<0.5	3.5	<1.0	<3.0	<10.0	12.	1.2	8.0	4.2	9.	<10.0

Table 6. Continued. Inorganic analyses for samples from 1983 field season.
[-- is for no data]

Well No.	Na (mg/L)	Pb (µg/L)	Si (mg/L)	Sr (µg/l)	V (µg/L)	Zn (µg/L)
FSW 166-67	9.7	<10.0	8.1	30.0	<6.0	216.0
167-55	5.5	<10.0	5.6	14.0	<6.0	130.0
173-69	11.0	<10.0	9.5	41.0	<6.0	210.0
182-69	8.5	<10.0	9.1	25.0	<6.0	158.0
194-57	17.0	<10.0	7.2	28.0	<6.0	4.0
214-60	11.0	<10.0	7.5	23.0	<6.0	30.0
230-48	4.7	<10.0	12.0	120.0	<6.0	639.0
231-57	6.4	<10.0	13.0	115.0	<6.0	113.0
232-58	6.6	<10.0	13.0	126.0	<6.0	65.0
234-99	10.0	<10.0	12.0	51.0	<6.0	10.0
235-94	7.2	<10.0	9.0	27.0	<6.0	9.0
236-106	17.0	<10.0	9.4	16.0	<6.0	28.0
237-88	16.0	<10.0	12.0	4.0	<6.0	14.0
238-106	6.2	<10.0	9.3	48.0	<6.0	63.0
239-64	20.0	<10.0	11.0	16.0	<6.0	14.0
240-95	6.2	<10.0	8.4	14.0	<6.0	9.0

Table 6. Continued. Inorganic analyses for samples from 1983 field season.
[-- is for no data]

Well No.	Na (mg/l)	Pb (µg/L)	Si (mg/l)	Sr (µg/L)	V (µg/L)	Zn (µg/L)
FSW						
241-98	--	--	--	--	--	--
242-77	5.5	<10.0	8.0	11.0	<6.0	11.0
243-45	4.3	<10.0	7.4	17.0	<6.0	21.0
244-90	18.0	<10.0	6.3	15.0	<6.0	23.0
245-25	28.0	<10.0	4.6	27.0	<6.0	13.0
246-35	15.0	11.0	11.0	27.0	<6.0	64.0
247-70	11.6	<10.0	7.2	38.9	<6.0	46.6
254-216	7.2	<10.0	19.0	29.0	<6.0	3.0
254-168	9.9	<10.0	19.0	36.0	<6.0	6.0
254-140	14.0	<10.0	17.0	92.0	<6.0	5.0
254-107	26.0	<10.0	8.7	106.0	<6.0	< 3.0
254-72	25.0	<10.0	5.4	24.0	<6.0	4.0
254-54	23.0	<10.0	4.9	18.0	<6.0	6.0
254-26	9.2	<10.0	6.2	21.0	<6.0	3.0
262-159	11.0	<10.0	19.0	66.0	<6.0	11.0
262-85	35.0	<10.0	10.0	91.0	<6.0	6.1
262-69	30.0	<10.0	7.0	18.0	<6.0	22.0

Table 6. Continued. Inorganic analyses for samples from 1983 field season.
[-- is for no data]

Well No.	Na (mg/l)	Pb (µg/L)	Si (mg/l)	Sr (µg/L)	V (µg/L)	Zn (µg/L)
FSW						
262-41	6.6	<10.0	8.4	33.0	<6.0	20.0
267-155	8.4	<10.0	22.0	46.0	<6.0	25.0
267-136	8.8	<10.0	14.9	34.2	<6.0	51.4
269-111	8.8	<10.0	8.9	58.0	<6.0	2.4
267-88	13.0	<10.0	14.6	39.3	<6.0	9.9
271-165	9.4	<10.0	19.5	44.7	<6.0	12.6
271-141	11.2	<10.0	18.3	48.6	<6.0	7.0
271-85	15.2	<10.0	11.0	63.5	<6.0	11.6
271-41	6.0	<10.0	5.8	22.9	<6.0	15.8
279-86	8.9	<10.0	3.1	22.4	<6.0	3.6
279-61	8.7	<10.0	3.9	27.9	<6.0	7.5
282-123	12.1	<10.0	18.3	53.8	<6.0	7.8
282-94	18.2	<10.0	12.4	110.6	<6.0	14.2
282-70	22.8	<10.0	10.6	84.5	<6.0	28.8
282-49	15.8	<10.0	6.9	10.6	<6.0	17.4
288-97	17.0	<10.0	7.8	22.0	<6.0	16.0

Table 6. Continued. Inorganic analyses for samples from 1983 field season.
[-- is for no data]

Well No.	Na (mg/l)	Pb (µg/L)	Si (mg/l)	Sr (µg/L)	V (µg/L)	Zn (µg/L)
FSW						
290-91	9.1	<10.0	13.0	31.0	<6.0	6.0
294-89	15.0	<10.0	18.0	62.0	<6.0	9.0
299-20	6.1	<10.0	6.5	28.0	<6.0	8.0
300-30	59.0	<10.0	18.0	35.0	<6.0	< 3.0
300-10	17.0	<10.0	6.8	34.0	<6.0	< 3.0
347-67	22.0	<10.0	13.0	28.0	<6.0	12.0
SDW						
305-32	6.6	<10.0	13.0	68.0	<6.0	250.0
313-60	7.6	<10.0	9.4	43.0	<6.0	8.0

Table 7. Organic analyses for samples from 1983
field season
[na = not analyzed; nd = not detected]

Well No.	DOC (mg/L)	MBAS (mg/L)	Total volatiles (µg/L) (DCE, TCE, PCE)
FSW			
166-67	1.3	0.04	0.5
167-65	1.0	0.01	na
173-69	1.0	0.52	na
182-69	1.0	0.04	nd
194-57	2.3	0.20	1.1
214-60	1.4	0.09	na
230-48	2.0	0.10	na
231-57	3.0	na	na
232-58	3.2	0.11	0.8
234-99	0.9	0.04	na
235-94	0.9	0.02	na
236-106	1.1	0.04	1.0
237-88	1.1	0.05	0.9
238-106	<1.0	0.03	na
239-64	1.9	0.07	268.4
242-77	0.9	0.02	nd
243-45	0.8	0.01	na
244-90	1.8	0.08	390.6
245-25	1.0	0.04	nd
246-35	2.0	0.09	na
247-70	1.0	0.06	na
254-216	1.0	0.04	1.0
254-168	1.1	0.04	1.3
254-140	1.9	0.16	4.5
254-107	2.3	0.25	93.7
254-72	2.8	0.14	681.7
254-54	3.2	0.18	8.1
254-26	1.2	0.03	nd
262-159	2.0	0.03	na
262-109	4.0	0.10	na
262-85	3.7	0.69	46.7
262-69	2.8	0.48	3.7
262-41	1.0	0.04	na
267-155	2.0	0.04	na
267-136	1.0	0.04	na
267-111	1.0	0.07	na
267-88	1.2	0.09	9.6
271-165	1.0	0.03	nd
271-141	2.0	0.05	nd
271-85	2.0	1.3	nd

Table 7. Continued. Organic analyses for samples from 1983
field season
[na = not analyzed; nd = not detected]

Well No.	DOC (mg/L)	MBAS (mg/L)	Total volatiles (µg/L) (DCE, TCE, PCE)
271-41	1.0	0.05	nd
279-86	1.0	0.05	na
279-61	<1.0	0.04	na
282-123	3.1	0.06	nd
282-94	4.0	2.00	5.9
282-70	4.2	2.00	nd
282-49	1.9	0.05	na
288-97	2.2	0.18	30.8
290-91	1.0	0.06	na
294-89	3.1	0.96	0.5
299-20	2.0	0.05	nd
300-30	3.5	0.27	3.9
300-10	1.0	0.04	na
347-67	4.0	0.21	11.7
SDW			
305-32	3.0	0.13	na
313-60	1.0	0.05	na

Table 8. DOC fractionation analyses for native ground water
   containing 0.02 mg/L MBAS (Well FSW 242-77) and for a
   ground water containing 2.0 mg/L MBAS (well FSW 282-70)

DOC fraction	FSW 242-77 (mg/L organic carbon)	FSW 282-70 (mg/L organic carbon)
Hydrophobic		
Acids	0.1	0.3
Bases	0.0	0.1
Neutrals	0.0	2.8
Hydrophilic		
Acids	0.1	0.0
Bases	0.3	0.3
Neutrals	0.4	0.6
Total organic carbon	0.9	4.2

Table 9. Organic analyses by purge/trap and gas chroma-
tography/mass spectrometry for samples from the
1983 field season
[nd = none detected]

Well No.	Compound	Concentration (μg/L)
FSW		
166-67	Trichloroethene	0.3
	Tetrachloroethene	0.2
182-69	nd	
194-57	Trichloroethene	0.7
	Tetrachloroethene	0.4
232-58	1,1,1-Trichloroethane	0.2
	Trichloroethene	0.5
	Tetrachloroethene	0.1
236-106	Trichloroethene	0.1
	Tetrachloroethene	0.9
237-88	Trichloroethene	0.1
	Tetrachloroethene	0.8
239-64	1,1,1-Trichloroethane	0.1
	Trichloroethene	94.5
	Tetrachloroethene	133.6
	1,2-Dichloroethene	34.5
	1,1-Dichloroethane	4.7
	1,1-Dichloroethene	0.2
	1,2-Dichloroethane	0.2
	Carbontetrachloride	0.1
	1,2-Dichloropropane	0.2
	1,1,2-Trichloroethane	0.1
	Chlorobenzene	0.2
240-95	1,1,1-Trichloroethane	0.2
241-98	1,1,1-Trichloroethane	1.4
242-77	nd	
244-90	1,1,1-Trichloroethane	0.5
	Trichloroethene	30.2
	Tetrachloroethene	244.7
	1,2-Dichloroethene	113.5
	1,2-Dichloroethane	0.6
	Carbontetrachloride	0.2
	1,2-Dichloropropane	0.3

Table 9.--Organic analyses by purge/trap and gas chromatography/mass spectrometry for samples from the 1983 field season--Continued

[nd = none detected]

Well No.	Compound	Concentration (μg/L)
244-90--Continued	1,1,2-Trichloroethane	0.1
	Chlorobenzene	0.3
	Ethylbenzene	0.2
247-70	nd	
254-216	Trichloroethene	0.3
	Tetrachloroethene	0.7
254-168	Trichloroethene	0.3
	Tetrachloroethene	0.7
	1,2-Dichloroethene	0.3
254-140	Trichloroethene	4.5
254-107	1,1,1-Trichloroethane	2.8
	Trichloroethene	47.9
	Tetrachloroethene	16.2
	1,1-Dichloroethane	1.0
	1,2-Dichloroethene	25.8
254-72	Trichloroethene	65.0
	Tetrachloroethene	416.8
	1,1-Dichloroethane	3.3
	1,2-Dichloroethene	196.6
254-54	Trichloroethene	1.4
	Tetrachloroethene	3.6
	1,2-Dichloroethene	3.1
254-26	nd	
262-85	1,1,1-Trichloroethane	1.7
	Trichloroethene	26.8
	Tetrachloroethene	13.6
	1,2-Dichloroethene	4.6
262-69	Trichloroethene	1.9
	Tetrachloroethene	0.3
	1,2-Dichloroethene	1.5
267-88	1,1,1-Trichloroethane	2.5
	Trichloroethene	0.6
	Tetrachloroethene	6.2
	Carbontetrachloride	0.1
	1,1,2-Trichloroethane	0.1
	Chlorobenzene	0.1

Table 9.--Organic analyses by purge/trap and gas chroma-
tography/mass spectrometry for samples from the 1983
field season--Continued
[nd = none detected]

Well No.	Compound	Concentration (μg/L)
271-141	nd	
271-85	nd	
271-41	nd	
282-123	nd	
282-94	1,1,1-Trichloroethane	1.3
	Trichloroethene	3.2
	Tetrachloroethene	1.1
	1,2-Dichloroethene	0.3
282-70	nd	
288-97	1,1,1-Trichloroethane	1.1
	Trichloroethene	10.0
	Tetrachloroethene	19.2
294-89	Trichloroethene	0.5
299-20	nd	
300-30	Trichloroethene	2.1
	Tetrachloroethene	0.8
	1,2-Dichloroethene	0.9
	Chlorobenzene	0.1
347-67	1,1,1-Trichloroethane	0.5
	Trichloroethene	4.4
	Tetrachloroethene	5.1
	1,1-Dichloroethane	0.1
	1,2-Dichloroethene	1.6
Tap Water Otis Air National Guard Base		
	1,1,1-Trichloroethane	0.3
	Chloroform	5.0
	Bromodichloromethane	9.9
	Dibromochloromethane	7.3
	Bromoform	1.0
Ashumet Pond Boat Landing		
	1,2-Dichloroethene	0.3
	Trichloroethene	0.1

CHAPTER D

Low concentrations of organic chemicals are a critical consideration in studies of ground-water contamination. Even at very low concentrations, these chemicals can render a water supply unsuitable for use as drinking water. This paper describes a technique that was tested at the Otis field site for detecting extremely low concentrations of organic compounds in ground water. These organic constituents may be ideal tracers of the plume which can be simulated with solute transport models.

CLOSED-LOOP STRIPPING, COMBINED WITH CAPILLARY GAS CHROMATOGRAPHY/MASS SPECTROMETRY ANALYSIS TO DEFINE A SEMI-VOLATILE ORGANIC CONTAMINANT PLUME

By

Larry B. Barber, II, E. Michael Thurman, and Michael P. Schroeder

Abstract

Thirty-two wells were sampled using closed-loop stripping combined with capillary gas chromatography/mass spectrometry analysis, to establish whether or not semi-volatile organic compounds are present in a plume of sewage contaminated ground water at Otis Air Base, Cape Cod, Massachusetts. Approximately 40 different organic compounds were tentatively identified in the ground water at the site. Of these substances, trichloroethene and tetrachloroethene were present in all wells sampled within the plume delineated by inorganic constituents. Dichlorobenzene, alkylated phenols, and alkylated benzenes were also present in many of the wells. Contaminant distributions were quite complex, and probably reflect variations in source composition. The closed-loop stripping technique allowed determination of organic compounds at the low nanogram per liter (ng/l) concentration level. The semi-volatile plume defined by the closed-loop stripping technique is considerably larger in areal extent than the plume determined by a purge and trap method; the latter has a detection limit in the low microgram per liter (µg/l) range. Based on this study, it was concluded that closed-loop stripping combined with capillary gas-chromatography/mass spectrometry is an effective method for determination of semi-volatile organic contaminants at the part per trillion (ng/l) level in ground water.

INTRODUCTION

Fifty percent of all residents in the United States rely on ground water as their primary source of drinking water (McCarty and others, 1981). Until recently, this vast natural resource had been considered pristine, and received little or no treatment prior to human consumption. Once contaminated, subsurface waters may remain so for hundreds to thousands of years. The problem of ground-water contamination by trace-level synthetic organic chemicals has been reviewed by a number of workers including McCarty and others (1981), Council on Environmental Quality (1981), and Pettyjohn and Hounslow (1983).

An extensive plume of contaminated ground water resulting from 40 years of disposal of secondary treated wastewater onto sand-infiltration beds was investigated. Of the various land-treatment methods in use today, rapid infiltration is one of the most efficient in terms of the required acreage to disposal volume ratios.

Currently, there are more than 360 rapid infiltration sites in the United States, and many more are planned for the near future (Scheaffer, 1979). Although the effectiveness of these sites for removing refractory-organic compounds from wastewater is not yet known, several recent papers have addressed the problem (Hutchins and Ward, 1983; Clark and Baxter, 1982; Tomson and others, 1981; Bouwer and others, 1981; Schwarzenbach and others, 1983). These studies indicate that many semi-volatile organic compounds (operationally defined as compounds that are extractable from water and are amenable to gas chromatography analysis) are not completely removed during infiltration. Once contamination occurs, natural reclamation of the aquifer is slow because of the reduction or absence of degradative processes such as photolysis, oxidation, volatilization, sorption, bio-degradation and dilution. Relatively small amounts of contaminants have the potential of polluting vast quantities of ground water at the microgram per liter (μg/L) level. Thus, it is important to understand and evaluate the effectiveness of rapid-infiltration processes on the reclamation of wastewater containing refractory organic compounds, and to examine the nature and extent of ground-water contamination resulting from such disposal practices.

This report discusses a method of analyzing for trace-level, semi-volatile organic substances in ground water using a closed-loop stripping (CLS) apparatus for concentrating the organic substances, followed by capillary gas chromatography/mass spectrometry (GC/MS) analysis. The purpose of the investigation is four fold: (1) To determine whether or not semi-volatile organic substances are present in the ground water at the field site; (2) to evaluate the CLS method for sample concentration; (3) to evaluate CLS GC/MS analysis as a tool for contaminant mapping; and (4) to determine the distribution of semi-volatile organic compounds within the plume previously delineated by

inorganic and gross-organic measurements. The data presented in this report are the result of the 1983 field season at the Cape Cod Ground-Water Contamination Research site.

The study area is located at Otis Air Base [1] (OAB), Cape Cod, Massachusetts. The base has a wastewater treatment plant from which secondary treated effluent recharges a sand and gravel aquifer through rapid infiltration sand beds (Vaccaro and others, 1979). An earlier water-quality study by LeBlanc (1982) documented the presence of a contamination plume that extends over 11,000 ft downgradient from the disposal beds, and has a width of over 3000 ft. The plume was delineated on the basis of specific conductance and concentrations of chloride, boron, detergents (as MBAS), sodium, and other inorganic constituents. Figure 31 is a map of the site showing the extent of the plume.

Although the location of the contamination source can be restricted to a relatively small area, little is known about the volume and chemical composition of the effluent prior to the late 1970's. The unknown chemical nature of the source complicates interpretation of the chemical data and understanding of compound distribution within the plume. Observed distribution patterns and concentrations of particular compounds may result from: (1) variations in source composition; (2) accidental spills; or (3) high-volume discharge during peak periods of base use.

Geology of the study area is characterized by Pleistocene glacio-fluvial deposits that overlie less permeable crystalline igneous and metamorphic rocks (Oldale, 1976). The hydrology of the area is fairly well understood. The top 90 to 140 feet of the aquifer consists of stratified glacial sand-and-gravel outwash deposits. Ground water moves through the permeable outwash towards the south at about 1 foot per day (ft/d). Details of the hydrology are given by LeBlanc (1984, 1982).

EXPERIMENTAL PROCEDURES

Sample Collection

At the beginning of the 1983 field season, 66 observation wells were in place at the OAB site. Of these, 55 were sampled for inorganic and gross organic constituents as well as for volatile organic analysis (Thurman and others, 1984). Thirty-two of the wells were sampled for analyses by CLS with GC/MS (fig. 31).

[1]
A description of the site, including its geologic and hydrologic setting, is given in Chapter A of this volume.
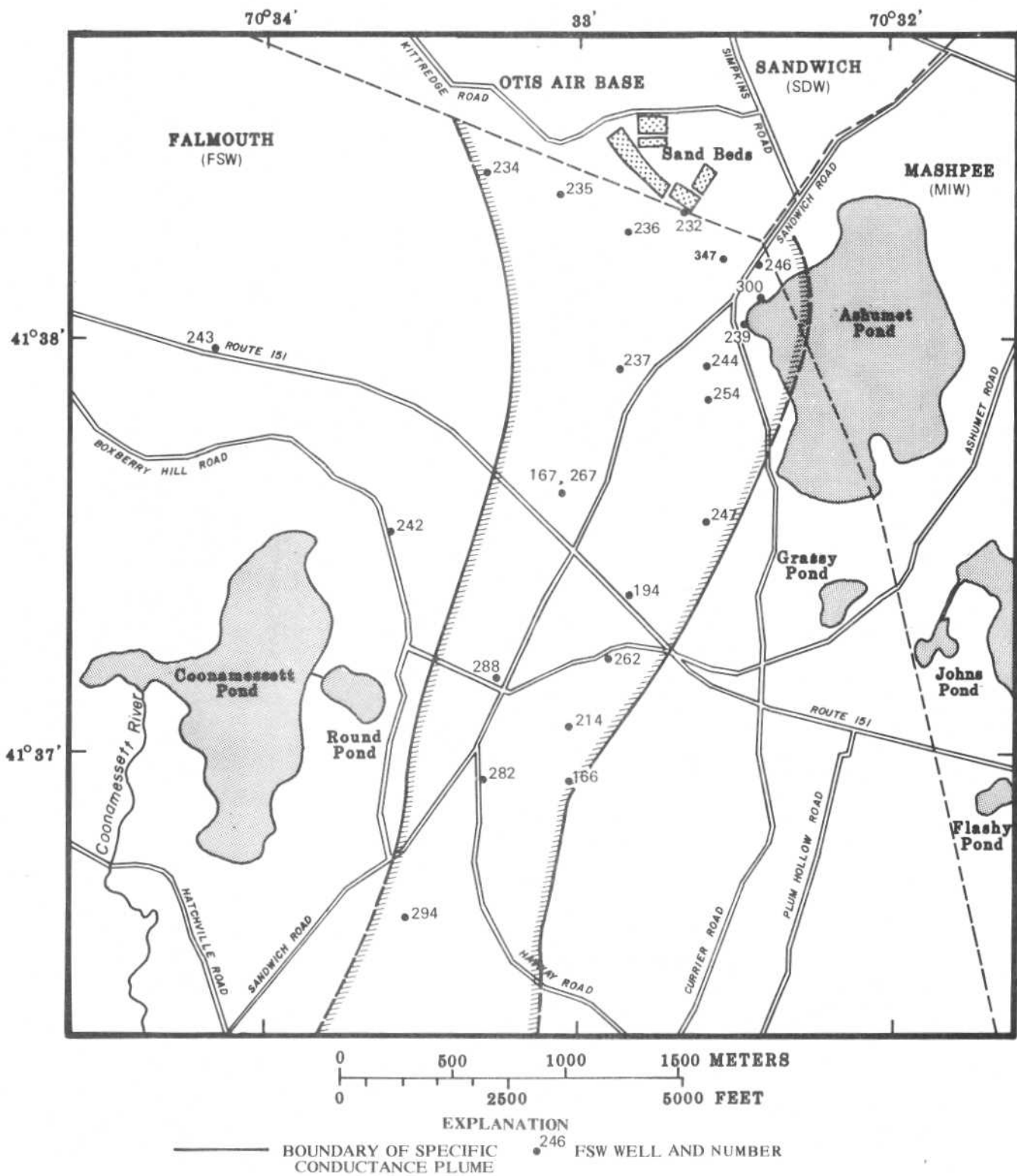
Figure 31.-- Specific conductance plume and location of wells.

Because of the ability of CLS to detect organic compounds at the nanogram per liter (ng/l) level, questions have been raised about the ability to obtain representative samples that have not been contaminated by the sample collection process. This problem has been considered by a number of workers including Clark and Baxter (1982), Keely and Wolf, (1983), Nacht (1983), Pettyjohn and others (1981), and Scalf and others (1981). The following cleaning procedure was used to minimize contamination from sample containers and processing equipment. Samples were collected in 4-liter amber bottles with Teflon-lined screw caps. The bottles were first washed with hot soapy water and rinsed. Next, they were rinsed with a 20 percent hydrochloric acid/distilled water solution, followed by low-organic distilled water. Finally the bottles were baked for 12 hours at 300 degrees C. This cleaning procedure removed all purgeable organic compounds from the sampling containers and processing equipment.

Ground-water samples were collected by (1) a small diameter stainless-steel submersible pump fitted with Teflon tubing; and (2) a peristaltic pump equipped with Teflon tubing. When the peristaltic pump was used, the well was first evacuated with a gasoline-powered suction pump. In both types of sampling, a minimum of three well-casing volumes were discharged before sampling was initiated. After evacuation, the site was cleared of vehicles and other potential sources of contamination, and was left undisturbed for 4 hours. Before sample collection, the pumping system was flushed for 30 minutes with native well water. Sample bottles were rinsed three times, then filled to the top with a minimum of turbulence and headspace; immediately prior to capping, the samples were spiked with a surrogate standard solution containing 1-chlorohexane ($C_6H_{13}Cl$), 1-chlorododecane ($C_{12}H_{25}Cl$), and 1-chloro-octadecane ($C_{18}H_{37}Cl$). After collection, the samples were stored at 4 degrees C. In all cases, the semi-volatile compounds were stripped from the sample within 12 hours of the time of collection; GC/MS analysis was performed within 1 to 2 weeks. Preliminary data indicate that no significant loss of organic components occurred between the time of stripping (and trapping on charcoal) and the time of analysis. However, the subject of loss both during sample collection and during trap storage and transport is currently being investigated in more detail.

Closed-Loop Stripping

The application of closed-loop stripping (CLS), as developed by Grob (1973), has been established as a valuable tool for the analysis of trace-level semi-volatile organic compounds in water (Coleman and others, 1981; Schwarzenbach and others, 1978; McCarty and Reinhard, 1980). Closed-loop stripping involves purging headspace air through a water sample, trapping the organic fraction onto a solid adsorbent (activated charcoal), and then repurging the water-saturated vapor back through the sample in an air-tight glass-Teflon system (fig. 32). Organic compounds with a significant vapor pressure over water are partitioned from

VAPOR IS RECYCLED
THROUGH Ni SAMPLE
LINE

VAPOR PASSES
THROUGH GLASS
TUBING, 65°

HEADSPACE VAPOR PASSES
THROUGH GLASS PURGE
TUBING

ORGANICS PARTITION
INTO VAPOR PHASE

STAINLESS
STEEL
BELLOW
PUMP

4-LITER SAMPLE
WITH 0.5 LITER
HEADSPACE,
40°C

ORGANICS TRAPPED
ONTO 1.5 Mg CHARCOAL
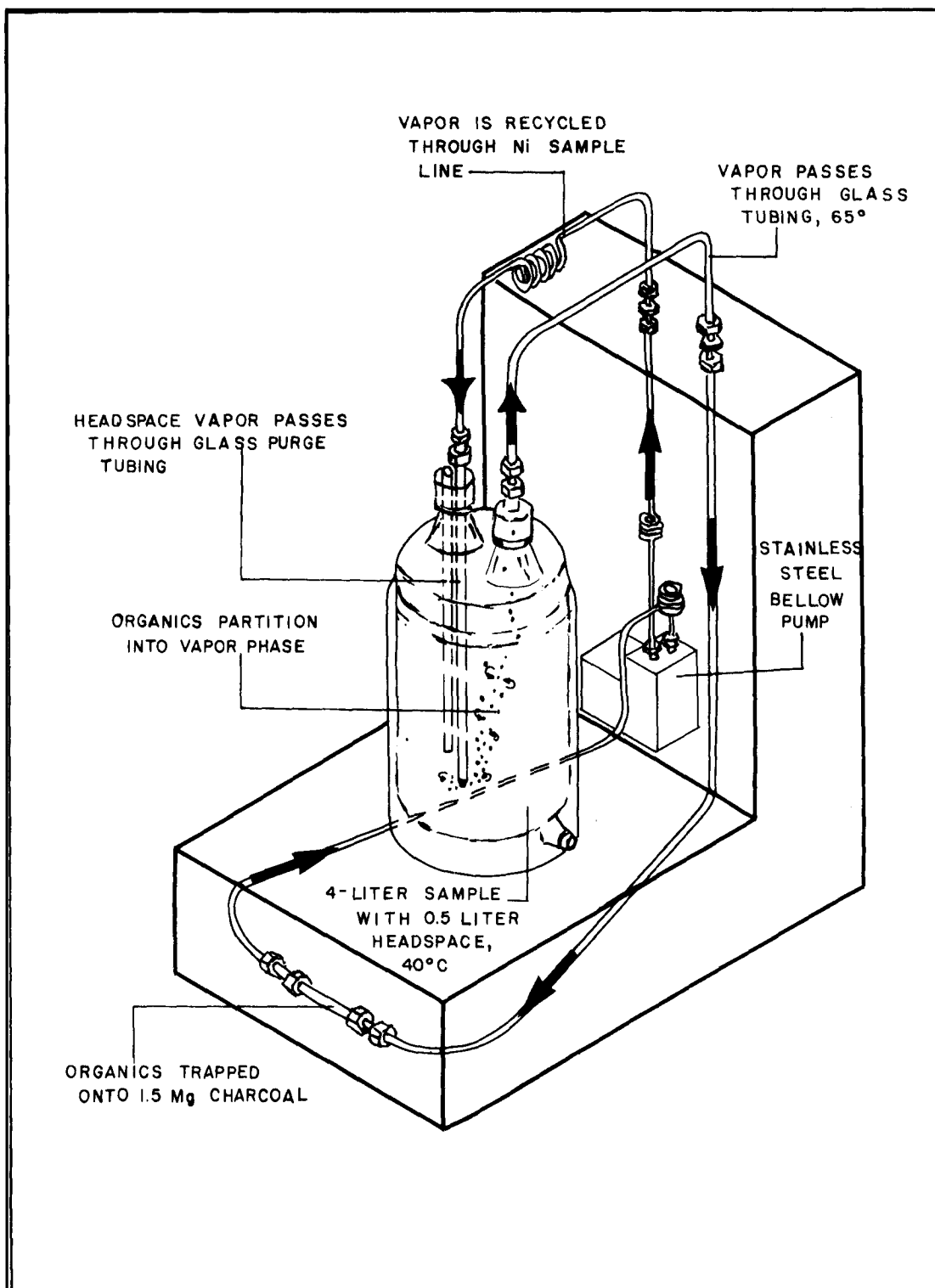
Figure 32.--Schematic diagram showing operation of closed-loop stripping
apparatus. Arrows indicate direction of vapor movement.

- 94 -

the aqueous phase into the vapor phase during the purging process. The saturated water vapor containing the stripped organics is pumped through glass tubing to an activated carbon trap. The glass tubing and the trap are maintained at 20 to 30 degrees C above the temperature of the water sample to prevent water condensation in the trap which reduces trapping efficiency. As the water vapor passes through the charcoal filter, the organic components are partitioned onto the solid phase and retained, and the vapor is recycled through the sample, repeating the purge process. After the sample has been stripped of its semi-volatile components, the trap is removed, and the organics are extracted with a small volume of solvent. For this study 15 μl of distilled-in-glass methylene chloride was used to elute the 1.5 mg charcoal traps. The methylene chloride extract containing the desorbed organics is ready for direct injection into the GC/MS system. Assuming an average recovery of 90 percent (which is reasonable based on published data), a 4-liter sample volume, and a final extract volume of 10 μl, the concentration factor will be 360,000. Because of the high concentration factor, CLS allows the detection of organic compounds at extremely low levels.

Although this method is capable of concentrating organic compounds with a wide range of volatilities (boiling points range from less than 70 to greater than 300 degrees C), substances that are strongly ionic or that have low vapor pressures (humic acids, detergents, urea and carbohydrates) are not concentrated by the procedure (Grob and Grob, 1974). Advantages of CLS include (1) high reproducibility; (2) minimal influence by water sample conditions; (3) wide range of sensitivity; (4) suitability of extracts for GC/MS analysis; and (5) good recovery of moderately polar substances (Grob and Zurcher, 1976). Closed-loop stripping is most effective for low to medium molecular weight organic compounds, from C_2 up to about C_{18} in the n-alkane series. Highly volatile substances coelute with the methylene chloride and cannot be separated from the solvent peak and thus are not determined by this method.

The CLS apparatus used in this study is a commercially available unit manufactured by Tekmar[2]. This semi-automated device allows ready standardization of purge time, sample temperature, trap temperature, and line temperature. All samples were run under the conditions listed in table 10. These conditions are optimal for the recovery of the surrogate standards used in this study, and for a wide range of semi-volatile environmental contaminants (Coleman and others, 1983). Based on data from preliminary sample analysis, it was concluded that because of the trace level of organic substances in the ground water at the Otis site, a 4-liter sample volume was necessary to attain a sufficient concentration factor for consistent detection of low-level compounds.

[2]
Use of brand names is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.

All solvents and chemicals used for the preparation of standards were reagent grade or better. A surrogate-standard solution consisting of approximately 49 ng/µL each of 1-chlorohexane, 1-chlorododecane, and 1-chlorooctadecane was prepared in methanol. A 10-µl aliquot of the 1-chloroalkane standards was spiked into the water samples with a microliter syringe by injecting below the meniscus at the time of collection, so that the standards underwent all phases of sample processing. The reference amount of surrogate standard added to the samples resulted in a final concentration of 122 ng/L for each of the 1-chloroalkanes.

Table 10. Closed-loop stripping operational conditions used in this study.

Sample size	4-liter
Sample temperature	40 degrees C
Line temperature	65 degrees C
Trap size	1.5 mg
Trap temperature	50 degrees C
Purge time	2 hours

Standards and Blanks

Procedural blanks were incorporated into the analytical scheme because of the potential for sample contamination. Before analysis of actual samples, carbon-filter blanks and CLS system blanks of low-organic distilled water containing the surrogate standards were analyzed. In addition, distilled water blanks were run after any suspected highly contaminated samples to evaluate the possibility of cross-contamination.

Gas Chromatography/Mass Spectrometry Analysis

After the semi-volatile organic component of each sample was concentrated by CLS, specific compound identification was performed using a Hewlett Packard 5985 GC/MS system . The gas chromatograph was equipped with a 0.21 mm internal diameter, 25 meter capillary column (Hewlett Packard SE-54 (Ultra II) cross-linked 5 percent phenyl-methyl silicone). One microliter of CLS extract was injected with the spitless injector purge vent closed. The injector vent was opened after 30 seconds. The helium carrier-gas had a linear velocity through the GC column of 28 cm/second. The injector temperature was maintained at 250 degrees C. Samples were injected with the column temperature lowered to 30 degrees C by cooling the GC oven with liquid nitrogen. After a 10 minute hold at 30 degrees C the oven temperature was programmed to increase to 300 degrees C at a rate of 6 degrees C/minute. Temperature was held at 300 degrees C for 5 minutes. Mass spectra were acquired from 40 to 450 amu at a

rate of 2 scans per second. The electron energy was 70 eV, and the source temperature was 200 degrees C. Source pressure was approximately 0.000003 torr when the GC temperature was 25 degrees C. Data acquisition was terminated after 60 minutes.

Identification of organic compounds was based solely on computerized matching of sample mass spectra with those in the NBS (National Bureau Of Standards) and Wiley libraries, using a Hewlett-Packard 1000 data system. The computerized matches were evaluated by the mass spectrometer operator to assure the quality of identification. This method of identification is only tentative, and further work is in progress to confirm the identity of compounds by analyzing authentic standards under identical analytical conditions, and comparing mass spectra and retention indices of the analyte with those of the authentic standards.

Quantification

Concentrations of the organic compounds tentatively identified in the CLS extracts have not yet been quantified. However, semi-quantitative values have been calculated using an internal standard method by which concentrations are determined relative to the reference standard compound 1-chlorododecane, spiked into the sample at 122 ng/L. The formula used is shown in equation 1; calculations were made using baseline corrected total ion current peak areas.

$$\text{Amount Z} = \frac{\text{corrected area compound Z}}{\text{corrected area surrogate standard}} \times 122 \quad (1)$$

Due to the preliminary nature of this study, insufficient data are available to determine the absolute recovery of the surrogates and the analytes of interest. Likewise, precision data for the semi-quantitative values given in this report have not yet been determined. Work is underway to evaluate both recovery and precision.

RESULTS

Approximately 40 semi-volatile organic compounds were tentatively identified in the plume of contaminated ground water at the OAB site (table 11). These compounds generally fall into the following classes: (1) aliphatic hydrocarbons; (2) chlorinated aliphatic hydrocarbons; (3) chlorinated aromatics; (4) alkyl-substituted aromatics; (5) alkyl-substituted phenols; (6) aldehydes; (7) phthalates; and (8) miscellaneous. Three of these compounds were present in most of the wells screened within the plume identified by inorganic contaminants: (1) trichloroethene

Table 11. Partial list of organic compounds tentatively identified by mass spectra library fits from gas chromatography/mass spectrometry analysis of closed-loop stripping extract.

Alkyl Substituted Aromatics
benzene
methyl benzene
C2 benzene isomers
C3 benzene isomers
C4 benzene isomers
C5 benzene isomers
1-methyl-3-(4-methylphenyl) benzene
propyl benzene

Aliphatic Hydrocarbons
2-methyl-1-propene
trimethylpentane isomers
trimethylpentene isomers
1,1-dimethylcyclohexane
1,1,3-trimethylcyclohexane
1-methyl-4-(methylethyl)-cyclohexane
4-ethyl-3-heptene
3,5-dimethyloctane
1-octene

Chlorinated Hydrocarbons
trichloroethene
trichloroethane
tetrachloroethene
tetrachloroethane

Chlorinated Benzenes
dichlorobenzene isomers
chlorobenzene
1-chloro-2-methyl benzene

Phthalates
bis-(2-ethylhexyl)-phthalate
dibutyl phthalate
butyl-2-methylpropyl phthalate

Alkyl Substituted Phenols
4-(2,2,3,3-tetramethylbutyl)-phenol
nonyl phenol isomers

Table 11. Partial list of organic compounds tentatively identified by mass spectra library fits from gas chromatography/mass spectrometry analysis of closed-loop stripping extract-- continued.

Miscellaneous
2,3-dihydro-1-methyl-1H-indene
2,3-dihydro-1,1-dimethyl-1H-indene
2,6-bis-di-t-butyl-p-benzoquinone
7-methyl-3,4-octadiene
cyclooctanone
decahydro-trans-napthalene
2-beta-pinene
2-propenylidene-cyclobutane
butyl ester thiocyanic acid
2,2,4,4-tetramethyl-3-pentanone
3-methyl-1-butanolbenzoate

Aldehydes
nonanal
decanal
octanal
hexanal

(2) tetrachloroethene; and (3) dichlorobenzene. These compounds are common in both industrial and domestic wastewater. Dichlorobenzene is a common component of toilet-bowl cleansers and many other household products; trichloroethene and tetrachloroethene are both widely used as degreasing solvents.

Mapping the plume using the chromatograms from CLS GC/MS analysis proved to be useful in determining the distribution of the different classes of semi-volatile compounds. Each well had a relatively unique chromatographic signature indicating which compounds were present. Four distinct semi-volatile organic subplumes existed within the overall plume (fig. 33): (1) A zone of tri- and tetrachloroethene of considerable extent that corresponds to the detergent and boron plumes; (2) a zone of alkylated phenols near the source area; (3) a zone of alkylated benzenes near the source area; and (4) a zone of dichlorobenzene extending along the core of the plume. The observed distribution of the chlorinated ethene compounds is similar to the boron plume and suggests that these compounds are moving in a somewhat conservative manner. The boron plume coincides approximately with that of the conservative ion, chloride; thus boron appears to behave conservatively in this particular aquifer (Thurman and others, 1984). Dichlorobenzene appears to be retained relative to tri- and tetrachloroethene, and the alkylated benzenes and phenols are restricted to a small portion of the total plume. The similarity of the distribution of the semi-volatile organics with the distribution of detergents (MBAS) and boron is shown in figures 33 and 34. It is apparent that the semi-volatile organics can be used in conjunction with these parameters to identify and characterize the plume.

The discrete plumes of individual classes of organic compounds could be the result of several factors. It is possible that separation of compounds is the result of different rates of movement in the aquifer, in particular for tri- and tetrachloroethene, and dichlorobenzene. The different rates could be due to varying degrees of hydrophobicity as expressed by the octanol/water partition coefficients (Kow) (trichloroethene Kow=2.3; dichlorobenzene Kow=3.4). However, such separations are difficult to achieve even in an analytical chromatography column. The apparent variable retention of the organic compounds needs to be evaluated in detail by column experiments using native aquifer material to determine if different retardation factors exist for the various classes of compounds. Another possible cause for the discrete plumes is variation in the source input in time, space, and concentration. This seems likely, particularly for the alkylated benzene and phenol compounds near the beds. A third possibility is that specific compound movement may be influenced by the presence of detergents and the formation of micelles.

One of the most significant observations from the data is the difference in the tri- and tetrachloroethene plumes defined by two separate analytical methods: (1) CLS GC/MS and (2) purge and trap GC/MS (Thurman and others, 1984). The CLS GC/MS
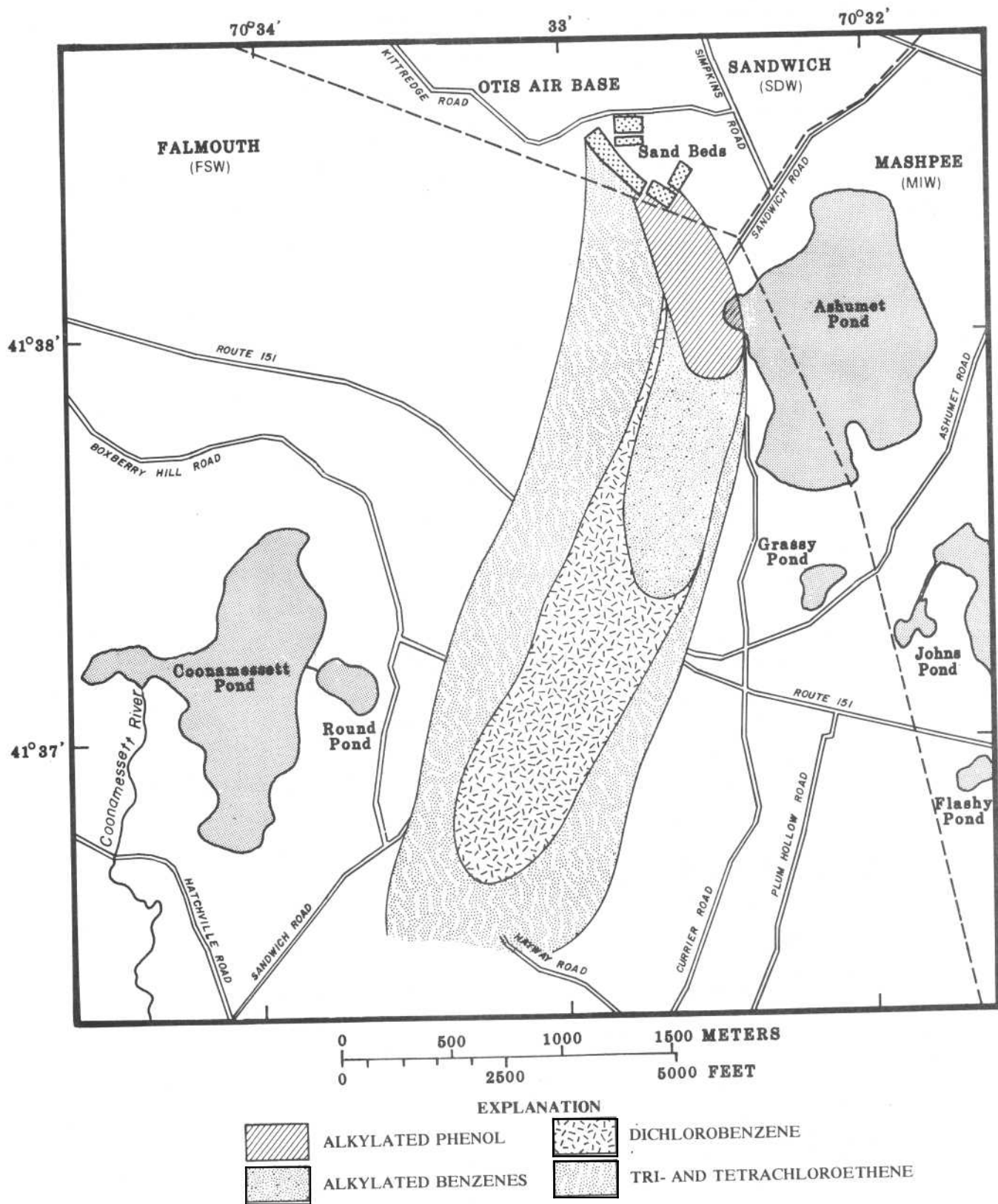
Figure 33.—Distribution of semi-volatile organic substances in ground water, 1983, by closed loop-stripping technique.
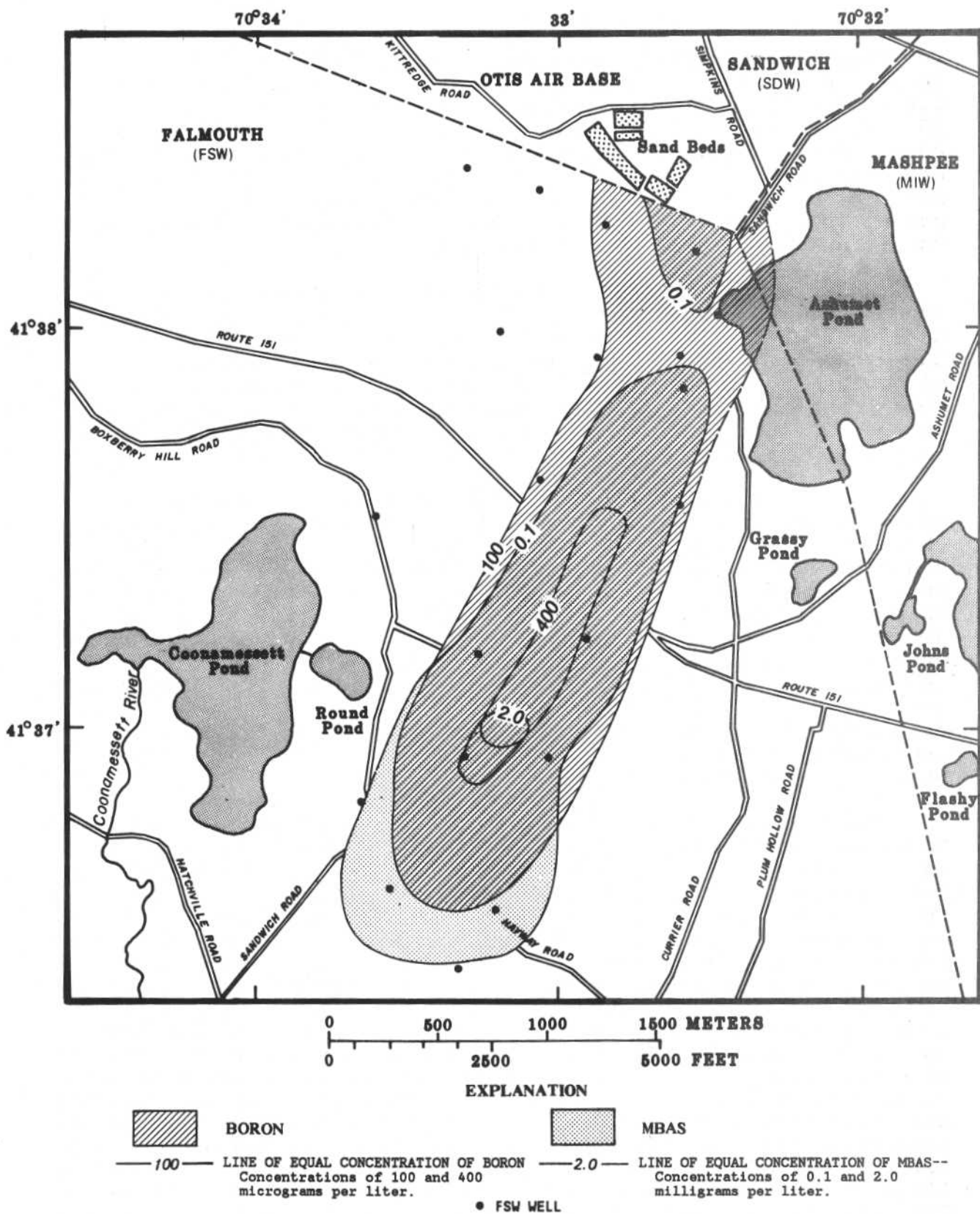
Figure 34.--Distribution of detergents (as MBAS) and boron in ground water, 1983.

technique is capable of detecting compounds in the 1 to 10 ng/L level, whereas the purge and trap GC/MS method has a detection limit of 1 to 5 µg/L. As can be seen by comparing figures 33 and 35, the areal definition of the plume based on CLS GC/MS is considerably greater in extent than the plume defined on purge and trap data. This has important implications in determining the rate of transport of organic compounds in the aquifer. It also points out the ability for early detection of trace level contamination by using the CLS method.

Well number FSW 242-77 yields uncontaminated ground water from a control site (based on inorganic measurements). The clean baseline of the chromatogram for this well (fig. 36) shows that the water is uncontaminated by semi-volatile substances. The lack of organic compounds at the ng/L level suggest minimal contamination from well construction materials or from sample collection and processing. Well FSW 242-77 contained less semi-volatile compounds than laboratory-distilled waters.

The FSW 254 series is a cluster of wells located in the core of the plume that is representative of the type of contamination observed at other locations within the plume. The vertical distribution of semi-volatile substances relative to boron and MBAS is shown in figure 37. At this well cluster, the greatest extent of organic contamination occurs in the upper part of the plume, possibly the result of changes in the source composition or the location of the infiltration bed used, or the influence of geologic structure in the aquifer. At other locations where vertical profiles were constructed, slightly different distribution patterns were observed for the semi-volatile substances, confirming the existence of several sub-plumes of organic contamination.

Compounds tentatively identified on mass spectra for CLS GC/MS analysis of key wells in the FSW 254 series are summarized in figures 38 to 40 and tables 12 to 14. Although the concentrations reported are semi-quantitative, reproducible results were obtained for samples that were run in duplicate. It is interesting to note the presence of several aldehydes throughout the well series, both in the contaminated and uncontaminated waters, suggesting that they may be naturally occurring compounds. Schwarzenbach and others (1978), in an investigation of volatile organic compounds in surface waters in the same general area of this study reported a similar set of aldehyde compounds at concentrations comparable to those reported here. The reversal of concentration levels for tetrachloroethene and trichloroethene between wells FSW 254-54 and FSW 254-140 indicates that these compounds occur as two subplumes with tetrachloroethene overlying trichloroethene at this location. Alkylated benzene compounds are present in wells FSW 254-54 to FSW 254-140 but their levels decrease rapidly with increasing depth. Single well points are insufficient to accurately define the plume as can be seen by the rapid vertical variations both in
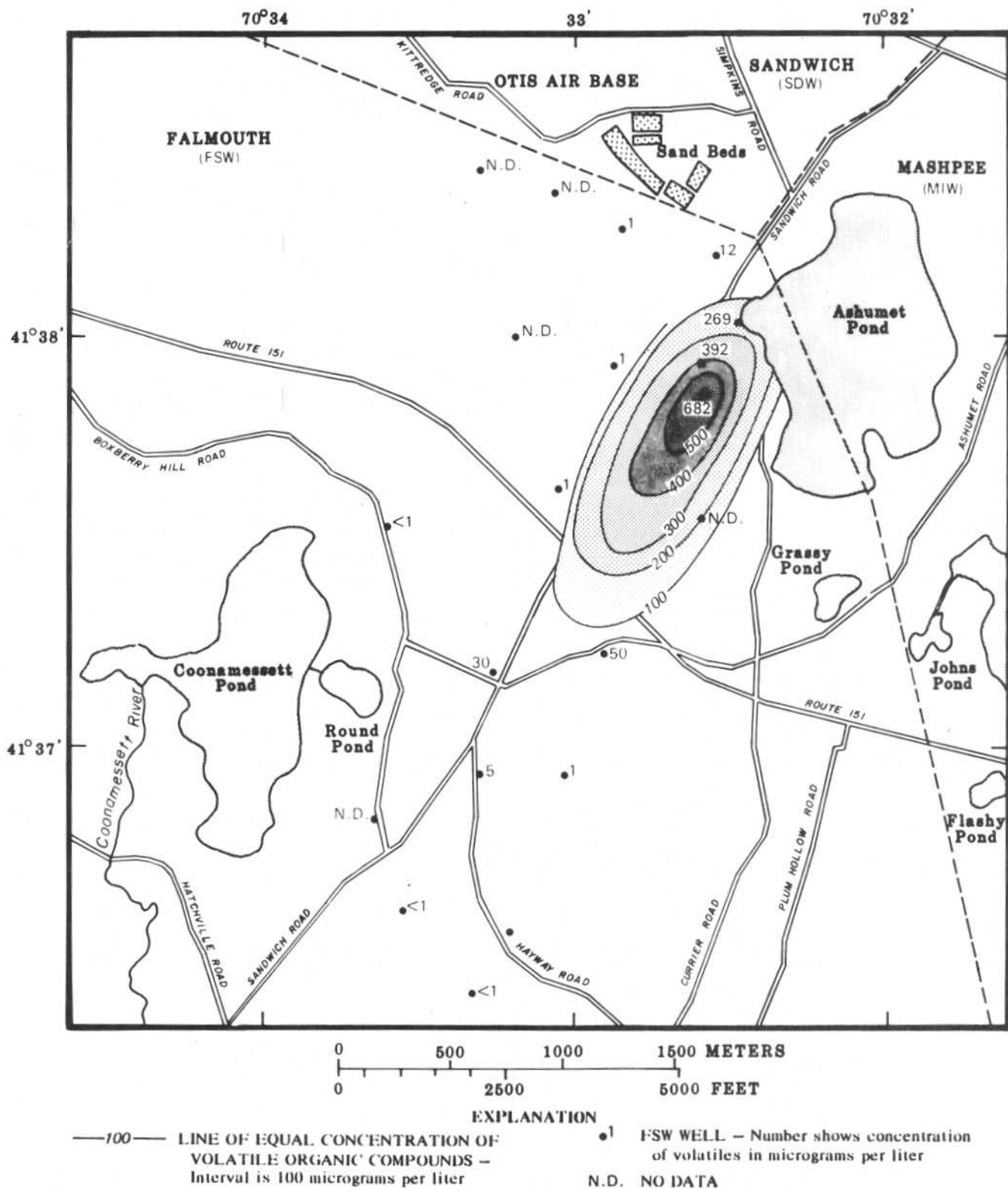
Figure 35.--Distribution of tri- and tetrachloroethene in ground water, 1983, by purge and trap technique.
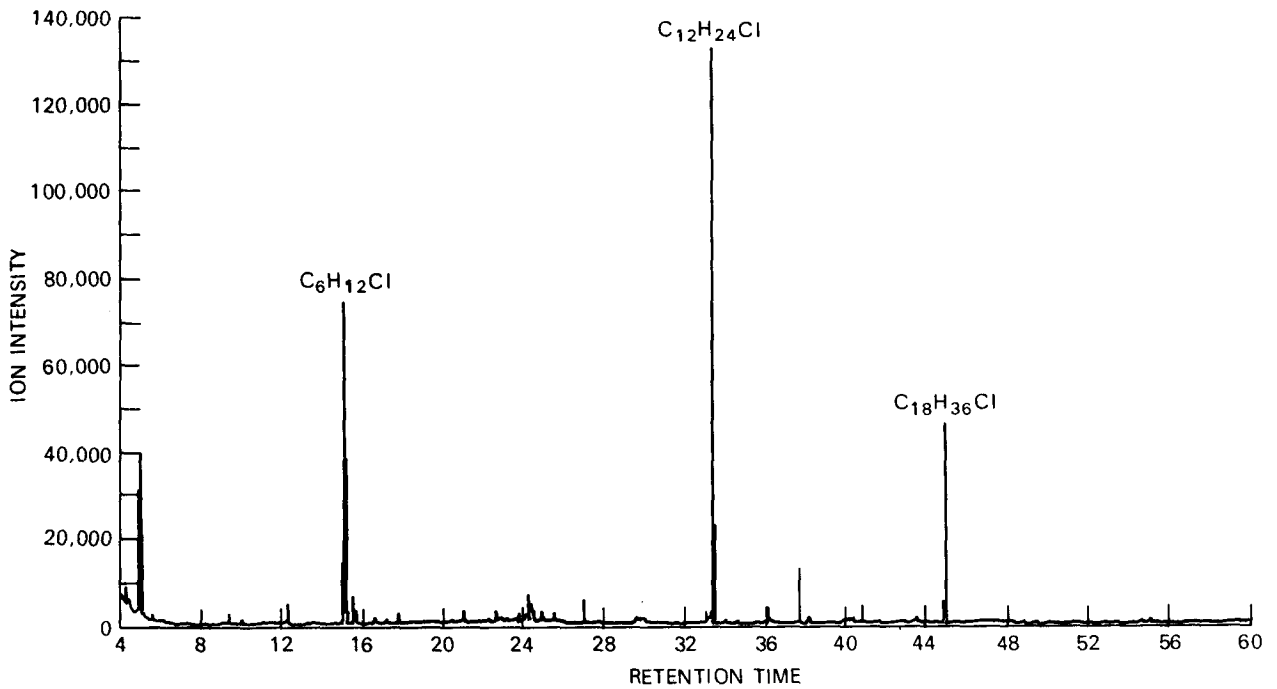
Figure 36.—Total ion chromatogram for gas chromatography/mass spectrometry analysis of closed-loop stripping extract from well FSW 242-77.
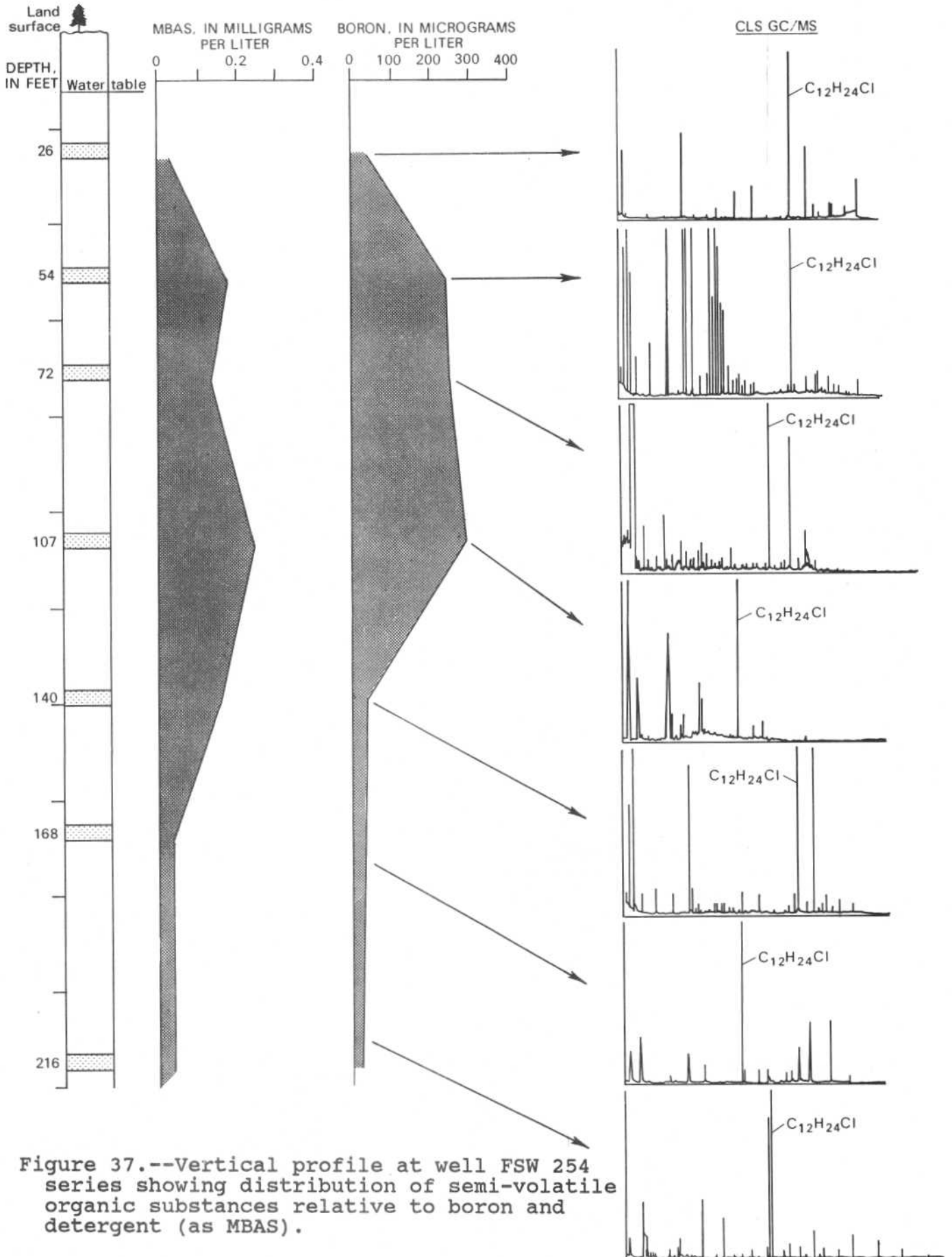
Figure 37.--Vertical profile at well FSW 254 series showing distribution of semi-volatile organic substances relative to boron and detergent (as MBAS).

Table 12. Semi-volatile organic compounds tentatively identified by mass spectra library fits from GC/MS analysis of closed-loop stripping extract, well FSW 254-26.

COMPOUND	CONCENTRATION ng/L
1. Octanal	7
2. Nonanal	19
3. Decanal	22
4. 1-(1,1-dimethylethyl-1,3-propanediyl ester propanoic acid	52
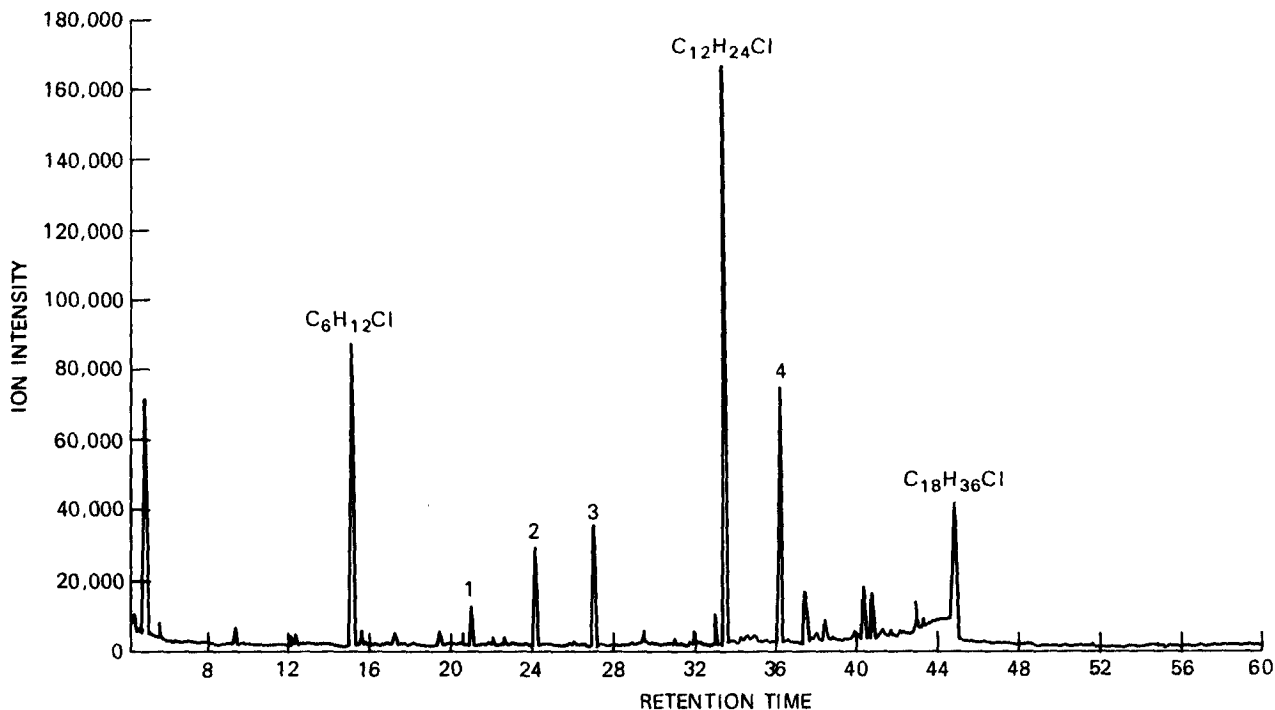
Figure 38.--Total ion chromatogram for gas chromatography/mass spectrometry analysis of closed-loop stripping extract from well FSW 254-26.

Table 13. Semi-volatile organic compounds tentatively identified by mass spectra library fits from GC/MS analysis of closed-loop stripping extract, well FSW 254-54.

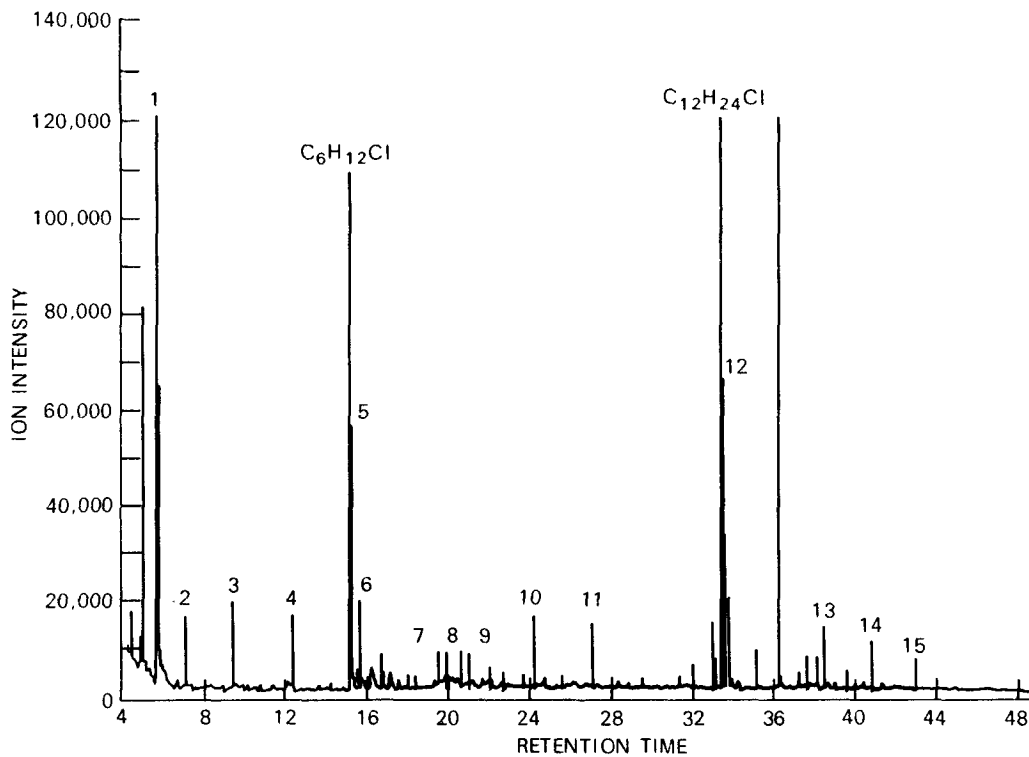| COMPOUND	CONCENTRATION ng/L
1. Trichloroethene	185
2. 2,2,4-trimethyl-1-pentene	48
3. 2,3,4-trimethyl-2-pentene	33
4. Methylbenzene	64
5. Tetrachloroethene	1640
6. Dimethylbenzene (+ isomers)	470
7. Methylethylbenzene (+ isomers)	270
8. Propylbenzene	18
9. Trimethylbenzene (+ isomers)	450
10. Dichlorobenzene isomers	50
11. Tetramethylbenzene isomers	63
12. Nonanal	11
13. 2,3-dihydro-5-methyl-1H-indene	13
14. Decanal	10
15. 2,6-bis-di-t-butyl-p-benzoquinone	113
16. Hexadecane	11
17. Heptadecane	10
18. Octadecane	12
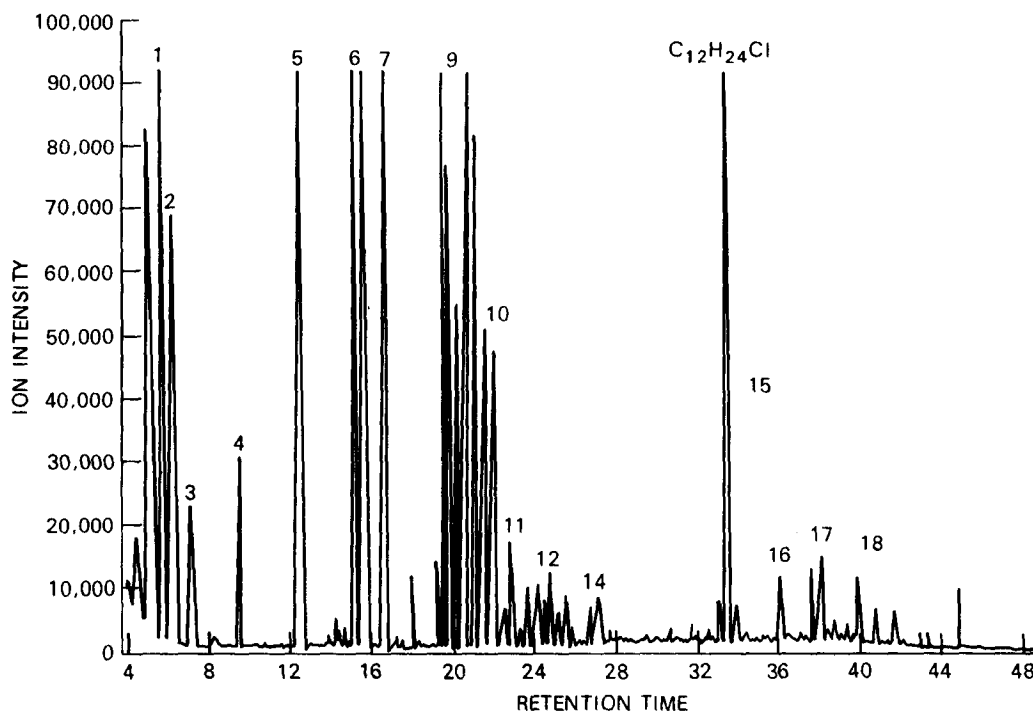
Figure 39.--Total ion chromatogram for gas chromatography/mass spectrometry analysis of closed-loop stripping extract from well FSW 254-54.

Table 14.   Semi-volatile organic compounds   tentatively
    identified by mass spectra library fits from GC/MS
    analysis of closed-loop stripping extract for well FSW
    254-140.

COMPOUND   CONCENTRATION ng/L

 1. Trichloroethene   1219
 2. 2,3-dimethyl-2-butanol   14
 3. Methylbenzene   24
 4. Tetrachloroethene   22
 5. Ethylbenzene   10
 6. Dimethylbenzene isomers   33
 7. Trimethylbenzene isomers   20
 8. 2,2,4,4-tetramethyl-3-pentanone   10
 9. Octanal   7
10. Nonanal   15
11. Decanal   15
12. 2,6-bis-di-t-butyl-p-benzoquinone   70
13. 3-methyl-1-butanolbenzoate   13
14. Farnesol   11
15. Dibutyl phthalate   11

Figure 40.--Total ion chromatogram for gas chromatography/mass
    spectrometry analysis of closed-loop stripping extract from
    well FSW 254-140.

compounds present and their concentrations. In fact, single point values can easily lead to misinterpretations.

Samples analyzed by the purge and trap GC/MS method give considerably higher concentrations than those analyzed by CLS GC/MS for tri- and tetrachloroethene where concentrations of these compounds exceed 10 to 20 $\mu g/L$ (Thurman and others, 1984). However, results for samples with low concentrations (less than 10 $\mu g/L$) give comparable values for the two methods if differences in sorbate amount and sample size are considered. The differences for the high-level samples are probably due to overloading of the 1.5 mg charcoal trap; thus, a portion of the contaminants may be recirculated without being trapped.

CONCLUSIONS

Closed-loop stripping (CLS) for the concentration of semi-volatile trace-level organic compounds from water, combined with gas chromatography/mass spectrometry (GC/MS) analysis, can be used successfully to establish the distribution of contaminants in ground water. To make a study more cost-effective, gas chromatography can be combined with other detectors, such as flame ionization or electron capture, to identify areas that are contaminated. Selected samples can then be analyzed by GC/MS for specific-compound identification. By picking appropriate indicator compounds that are amenable to CLS GC/MS analysis for a particular source of pollution, the occurrence of low-level contamination and the distribution of contaminants can be readily determined.

In the case of the OAB contaminant plume, three compounds serve as good tracers of sewage effluent: (1) trichloroethene; (2) tetrachloroethene ; and (3) dichlorobenzene. These compounds were present in almost all contaminated ground-water samples analyzed. Chlorinated ethene compounds are widespread environmental contaminants; trichloroethene is the most frequently cited organic contaminant in ground water (Council on Environmental Quality, 1981). The distribution of the above three compounds corresponded closely with the distribution of inorganic and gross organic constituents within the plume. In addition, over 40 organic compounds were tentatively identified. They include chlorinated benzenes, alkylated benzenes, saturated and unsaturated aliphatic hydrocarbons, chlorinated aliphatic hydrocarbons, phthalates, alkylated phenols, and aldehydes.

Several discrete plumes of different classes of semi-volatile compounds were identified within the plume that was defined from inorganic measurements. The existence of these subplumes can be the result of several factors including different retardation factors for the various compounds; variations in the source input in time, space, and concentration;

and influence of geologic structure on the direction and rate of flow.

The plume of tri- and tetrachloroethene contamination was determined by two analytical methods: closed-loop stripping (CLS) combined with GC/MS analysis, and purge and trap combined with GC/MS analysis. The CLS concentration technique allows the determination of organic compounds at the 1 to 10 ng/L level, whereas the purge and trap method has a higher detection limit of 1 to 5 μg/L. The plume defined from the CLS data had an areal extent that was considerably larger than the plume defined by purge and trap data. Thus, with the lower detection limit of the CLS method, the apparent dimensions of the plume increased significantly. This has important implications when field data are used to estimate the rate of transport for individual organic compounds in the aquifer.

In general, total recovery of the semi-volatile compounds concentrated by the CLS method amounts to only a small fraction (less than 0.1 percent) of the total dissolved carbon. Thus, it should be noted that the method is restricted in its application and cannot be used to determine the total organic contamination load. However, the compounds isolated by CLS are an important group of pollutants that are refractory and quite mobile in the ground – water environment. These compounds can be used to establish whether or not water has been contaminated by other trace-level organics.

Closed-loop stripping methodology may also be used to characterize trace-level naturally occurring organic compounds in ground water. This is an area of research that deserves more attention both to develop an understanding of the specific compounds that comprise natural dissolved organic carbon and to determine baseline data to be used in evaluating the impact of ground-water contamination.

REFERENCES CITED

Bouwer, E.J., McCarty, P.L. and Lance, J.C., 1981, Trace organic behavior in soil columns during rapid infiltration of secondary wastewater; Water Res., v. 15, p. 151-159.

Clark, L. and Baxter, K.M., 1982, Organic micropollutants in effluent recharge to ground water; Water Sci. Technol., v. 14, p. 15-30.

Coleman, W.E., Melton, R.G., Slater, R.W., Kopfler, F.C., Voto, S.J. , Allen, W.K. and Aurand, T.A., 1981, Determination of organic contaminants by the Grob closed-loop stripping technique; J. AWWA, v. 73, p. 119-125.

Coleman, W.E., Munch, J.W., Slater, R.S., Melton, R.G. and Kopfler, F.C., 1983, Optimization of purging efficiency and quantification of organic contaminants from water using a 1-L closed-loop stripping apparatus and computerized capillary column GC/MS; Environ. Sci. Technol., v.17, p. 571-576.

Council on Environmental Quality, 1981, Contamination of ground water by toxic organic chemicals; Washington D.C., 84 p.

Grob, K., 1973, Organic substances in potable water and its precursor, Part 1: Methods for their determination by gas-liquid chromatography; J. Chromatography, v. 84, p. 255-273.

Grob, K. and Grob, G., 1974, Organic substances in potable water and its precursor, Part 2: Applications in the area of Zurich; J. Chromatography, v. 90, p. 303-313.

Grob, K. and Zurcher, F., 1976, Stripping of trace organic substances from water, equipment and procedures; J. Chromatography, v. 117, p. 285-294.

Ho, J.S.Y., 1983, Effect of sampling variables on recovery of volatile organics in water; J. AWWA, p.583-585.

Hutchins, S.R. and Ward, C.H., 1983, A predictive laboratory study of trace organic contamination of ground water: Preliminary results; J. Hydrology, v.33, p.223-233.

Keely, J.F. and Wolf, F., 1983, Field applications of chemical time-series sampling; Ground Water Monitoring Review, Fall, p.26-33.

LeBlanc, D.R., 1984, Digital modeling of solute transport in a plume of sewage-contaminated ground water, Cape Cod, Massachusetts; U.S. Geol.Survey Open-File Report (this volume).

LeBlanc, D.R., 1982, Sewage plume in a sand and gravel aquifer, Cape Cod, Massachusetts; U.S. Geol. Survey, Open-File Report 82-274, 35 p. Superseded by USGS Water-Supply Paper 2218, 28p.

McCarty, P.L. and Reinhard, M., 1980, Trace organic removal by advanced wastewater treatment; J. WPCF, v. 52, p.1907-1922.

McCarty, P.L., Reinhard, M. and Rittmann, B.E., 1981, Trace organics in ground water: Environ. Sci. Technol., v. 15, p.40-51.

Nacht, S.J., 1983, Monitoring sample protocol considerations; Ground Water Monitoring Review, Summer, p. 23-29.

Oldale, R.N., 1976, Notes on the generalized geologic map of Cape Cod; U.S. Geol. Survey, Open-File-Report 76-765, 23p.

Pettyjohn, W.A. and Hounslow, A.W., 1983, Organic compounds and ground water pollution; Ground Water Monitoring Review, Fall, p. 41-47.

Roberts, P.V., Reinhard, M. and Valocchi, A.J., 1982, Movement of organic contaminants in ground water: Implications for water supply; J. AWWA, v. 74, p. 408-412.

Scalf, M.R., McNabb, J.F., Dunlap, W.J., Cosby, R.L. and Fryberger, J.S., 1981, Manual of ground water sampling procedures; U.S. Environ. Protection Agency, EPA-600/2-81-160, 93p.

Schwarzenbach, R.P., Bromunds, R.H., Gschwend, P.M., and Zsfiriou, O.C., 1978, Volatile organic compounds in coastal seawater; Organic Geochemistry, v. 1, p. 93-107.

Schwarzenbach, R.P., Giger, W., Hoehn, E. and Schneider, J.K., 1983, Behavior of organic compounds during infiltration of river water to ground water: Field studies; Environ. Sci. Technol., v. 17, p.472-479.

Schwarzenbach, R.P. and Westall, J., 1981, Transport of nonpolar organic compounds from surface waters to ground water: Laboratory sorption studies; Environ. Sci. Technol., v. 15, p. 1360-1367.

Sheaffer, J.R., 1979, Land applications of waste: Important alternatives; Proceedings 4th National Ground Water Quality Symposium, p. 62-68.

Thurman, E.M., Barber, L.B., Ceazan, M.L., Smith, R.L., Brooks, M., Schroeder, M.P., LeBlanc, D.R. and Nichols, W., 1984, Sewage contaminants in ground water, U.S. Geol. Survey Open-File Report (this volume).

Tomson, M.B., Dauchy,J., Hutchins, S., Curran, C., Cook, C.J. and Ward, C.H., 1981, Ground water contamination by trace level organics from a rapid infiltration site; Water Res., v. 15, p. 1109-1116.

Vaccaro, R.F., Kallio, P.E., Ketchum, B.H., Kerfoot, W.B., Mann, A., Deese, P.L., Palmer, C., Dennet, M.R., Bowker, P.C., Corwin, N. and Manganini, S.J., 1979, Wastewater renovation and retrieval on Cape Cod; U.S. Environ. Protection Agency Rept. EPA-600/2-79-176, 174p.

CHAPTER E

Microbial processes may play a key role in determining the fate of some contaminants in ground-water systems. In this paper, chemical and biological evidence are presented which show that bacteria significantly affect the distributions of organic carbon and inorganic nitrogen in the plume. Future microbiological research will focus on the zones in the plume where evidence of microbial activity was found.

EVIDENCE OF MICROBIAL PROCESSES IN

SEWAGE-CONTAMINATED GROUND WATER

by Marnie L. Ceazan, David M. Updegraff, and E. Michael Thurman

Abstract

This study investigates the importance of microbial degradation of organic compounds and the transformation of inorganic compounds in the sewage plume at Otis Air Base, Massachusetts.

The number of plate-count bacteria in the water was determined by plating the ground-water samples on nutrient agar and dilute soil-extract (DSEA). The number of colony-forming units (CFU) on both nutrient agar and dilute soil-extract agar showed the same spatial distributions, but dilute soil-extract agar yielded higher numbers of colony-forming units than nutrient agar. An increase in bacterial count occurred in the contaminated zone. Evidence exists that microbially mediated denitrification, dissimilatory nitrate reduction, and nitrification could be occurring in the plume.

INTRODUCTION

Ground water contaminated by sewage effluent can be a significant problem (Burden, 1982; Jensen, 1981). Biological alteration by microorganisms may be an important factor in determining the effects of wastewater on ground-water quality (Rittman and others, 1980; Davis and others, 1981). The region of the Earth's crust considered as true soil has been studied extensively and is recognized as a zone of high biological activity; therefore, it was long thought that soils protected ground water from entry by pollutants. Early studies indicated that microbial numbers decreased sharply with depth (Waksman, 1916). Leenheer and others (1974) showed that the concentration of organic matter in pristine aquifers is typically about 1 mg/L; therefore, organic nutrients were considered to be too limited to support appreciable levels of microbial growth in ground water. Methods for sampling ground water aseptically are difficult and expensive; thus, relatively little published information is available on the microbiology of ground-water systems.

Interest in subsurface biological activity has been increasing because of widespread ground-water pollution by potentially hazardous organic compounds (Burmaster, 1982). Recently, several studies have suggested that microbes can be present at great depths in the subsurface. McNabb and Dunlap (1975) suggest that most subsurface environments are suitable as microbial habitats. As an example, nitrate-reducing bacteria were found at depths up to 12 feet in a study by Whitelaw and Rees (1980).

This paper describes the results of a study to determine if microorganisms potentially play a major role in determining the fate of contaminants in a sewage plume in ground water.[1] The objectives of the study were: (1) To conduct a broad reconnaissance of microbial numbers and chemical composition of the ground water in the aquifer that contains the plume; and (2) to obtain evidence that microorganisms affect distributions of selected contaminants such as ammonium (NH_4^+), nitrate (NO_3^-), and organic compounds. Subsurface biology was assessed by enumerating bacteria in water samples using standard plating techniques. Plate-count populations were then compared to nitrate, ammonium, orthophosphate (PO_4^{3-}), and dissolved organic carbon (DOC) distributions in the plume. In addition, samples were analyzed for coliform bacteria.

EXPERIMENTAL PROCEDURES

Water samples were collected during the summer of 1983 from observation wells (fig. 41) screened at different depths in the aquifer. Specific conductance, dissolved oxygen, pH, and temperature were measured at the time of collection, and samples were refrigerated at 4 ^{O}C. Bacteriological analyses and analyses for ammonium and nitrate were done within 2 days of collection. Other analyses were done later. The results of these water analyses are listed in table 15.

------

[1]A description of the site, including its geologic and hydrologic setting, is given in Chapter A of this volume.