Bull. Environ. Contam. Toxicol. (1985) 34:578–586

Environmental Contamination and Toxicology

Impact of Trichloroethylene Contaminated Groundwater Discharged to the Main Canal and Indian River Lagoon, Vero Beach, Florida

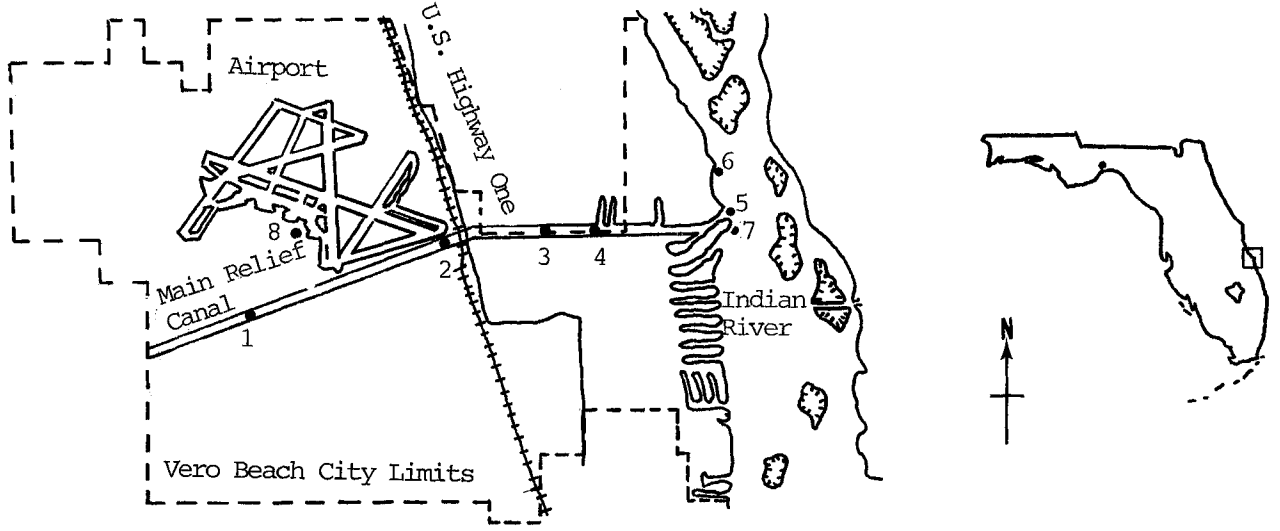
T. Wang, R. Lenahan, and M. Kanik

Harbor Branch Foundation, Inc., R.R. 1, P.O. Box 196, Fort Pierce, FL 33450

Contamination of groundwater by organic pollutants is now widely recognized as a serious threat to the integrity of many municipal and rural water supplies (Burmaster 1982; Wilson and McNabb 1983; Hansen 1983). The source of this contamination includes various waste disposal activities (e.g. industrial impoundments, landfills, accidental spills, underground storage tank leaks, pesticides and fertilizer application). Groundwater highly contaminated with trichloroethylene (TCE) from a leaky storage tank was detected in Vero Beach, Florida in 1978. Aware of this problem, the local and state authorities gave permission to pump out the contaminated water as a means of reducing concentrations in the aquifer. The water was air sprayed to strip the organic compounds and subsequently discharged and mixed by means of a hydraulic pump in the drainage canal. The canal extends from 1.5 km west of Vero Beach and flows toward the Indian River. This canal received the surface drainage water at average monthly rates between 21.2 to 252 cu. ft/sec during the period of May 1981 to May 1982 (USGS 1982).

The Indian River is a lagoonal estuary situated along the central east coast of Florida. Figure 1 indicates the approximate locations of sample sites in the drainage canal as it flows to the river. The average discharge rate of contaminated water into the canal was approximately 0.2 million gallons per day. The concentration of pollutants in the discharged water ranged between 3165 to 30.3 µg/ℓ, and 1883 to 413 µg/ℓ, for trichloroethylene and 1,2-dichloroethylene; and the range for 1,1-dichloroethylene and vinyl chloride was 36.7 to 9.16 µg/ℓ and 136 to 34 µg/ℓ, respectively. This project was initiated to determine the spatial distribution of pollutants in the canal and river as well as rainfall and canal flow rate effects on water, sediment, and biological organisms.

Prior to flushing the well, a baseline survey of trichloroethylene and other related compounds in the canal and river was performed. Water and sediment samples were collected at the following stations shown in Figure 1. (1) The Main Canal at the 34th Avenue Bridge, (2) The Spillway Discharge Site, (3) The Midway Site between the discharge point and the confluence, (4) The



1. - 34th Ave. Bridge
2. - Spillway Discharge Site
3. - Midway between Discharge Site and Salinity Barrier
4. - Salinity Barrier
5. - Confluence of Relief Canal and Indian River
6. - 300 Meters North of Confluence
7. - 70 Meters South of Confluence
8. - Contaminated Aquifier

FIGURE 1 Sample Stations in the Indian River and the Relief Canal at Vero Beach, Florida

Salinity Barrier, (5) The Confluence of the Main Canal and the Indian River, (6) Approximately 300 meters north of confluence in the river and (7) Approximately 70 meters south of confluence in the river.

Oyster samples (Crassostrea virginica) were collected at the sites (5), (6) and (7). Water samples were collected and analyzed weekly during the initial study period between May 1981 to December 1981. Samples were then collected monthly in 1982. Oyster and sediment samples were collected and analyzed on a monthly basis during the study period.

METHODS AND MATERIALS

Water samples at each station were collected in 40 mℓ vials equipped with teflon lined septa and screw caps. Vials were filled so that no air bubbles were present. Sediment was sampled in a 150 mℓ jar with an aluminum foil lined screw cap. Both water vials and sediment jars were pre-cleaned and dried overnight. A 15 foot aluminum rod with a clamp at one end was used to collect both water and sediment samples. Three sediment samples collected from each station were composited and subsampled for analysis. After collection, samples were immediately iced and delivered to the laboratory for processing. Oyster samples (Crassostrea virginica) collected from the river and confluence site were shucked and homogenized in the laboratory. The sample was then frozen until it was ready for analysis.

Sample size ranged from a few microliters for highly contaminated water in the well up to 20 mℓ for a very diluted sample from the river. Five grams of oyster and ten grams of sediment were employed for the contaminant measurements. A purge and closed loop method (Wang and Lenahan 1984) was used to analyze the environmental samples. Volatile organic compounds were purged from the bubbler unit to the sample loop, which were subsequently injected to the gas chromatograph. Ten mℓ of organic free water was introduced to the bubble unit to purge both sediment and oyster samples. Glass wool and sodium sulfate were added to the sample to prevent the foam from rising in the purging unit. Gas chromatographic analysis was performed with a 63 Ni electron captured detector and 1% SP-1000 on 60/80 carbopack B column. Each water, sediment and oyster sample was analyzed and duplicated. Average results were used in the report. The minimum detectable concentrations for TCE, 1,1-DCE, 1,2-DCE and vinyl chloride were 0.1, 0.2, 4.0 and 1.0 µg/ℓ; 0.5, 2, 30 and 2 ng/g; 1.0, 5, 100 and 4.0 ng/g for water, sediment and oyster samples, respectively.

RESULTS AND DISCUSSION

The baseline survey on the concentration of trichloroethylene (TCE), 1,2-dichloroethylene (1,2-DCE), 1,1-dichloroethylene (1,1-DCE) and vinyl chloride (VC) in the Main Canal and the Indian River was performed before the contaminated water was discharged.

Water, sediment and oyster samples were collected and analyzed. The concentrations for these samples were less than the minimum detectable concentration. In April 1981, the contaminated water was air sprayed to strip the volatile organics and subsequently discharged to the Main Canal which flows to the River. Samples were collected from the river and canal on a weekly basis for the water and monthly for sediment and oyster samples to assess the impact of contaminated water on the canal and the river.

The pollutants concentration found in the canal normally decreased from the discharge point toward the confluence site between the canal and the river. Canal flow rate and concentration of discharged contaminated water affected the pollutants distribution. Table 1 illustrates the flow rate influence on the TCE, 1,1-DCE and 1,2-DCE concentration in the canal. Higher concentrations in the discharged water resulted in higher pollutant residues in the canal water. Rapid canal flow reduced the contaminated concentrations and stagnant flow increased the concentrations in the water. With a canal flow of 24 cu. ft/sec and a TCE concentration in the contaminated water of 1594 µg/ℓ, the TCE concentration in the discharge site was found to be 32.5 µg/ℓ and gradually decreased to 21.5 µg/ℓ at the salinity barrier. When the water reached the confluence where the canal water was further diluted with the river water, the concentration was only 2.61 µg/ℓ. With a stagnant canal flow rate at 7.4 cu. ft/sec, the TCE concentration in the canal was increased to 74.7 µg/ℓ and 34.8 µg/ℓ at the discharged site and salinity barrier, respectively, and the concentration at the Midway Site was 80.5 µg/ℓ. During stagnant flows, the highest concentration found in the canal normally occurred at the Midway Station. The wider canal surface and deeper water at this site reduced the water flow allowing the pollutants to accumulate. During the rainy season, the canal flow rapidly increased. A flow at 556 cu. ft/sec could dilute the water concentration less than 1.59 µg/ℓ, even with TCE concentrations in the contaminated water as high as 1540 µg/ℓ. This high flow "washed off" the canal water to the confluence site creating higher TCE concentrations than at the other stations in the canal as shown in Table 1.

The summary of weekly monitoring data is presented in Tables 2, 3 and 4 for TCE, 1,1-DCE and 1,2-DCE, respectively. The results show that the pollutant in the discharged water and canal flow rate affects the concentrations in the canal. With TCE concentrations in the discharged water between 3165 to 2169 µg/ℓ, the canal concentration varied from 56.7 to 44.8 µg/ℓ at a canal flow rate of 18 cu. ft/sec. When the trichloroethylene concentration in the discharged water was less than 10 µg/ℓ and canal flow was greater than 30 cu. ft/sec, the resulting concentration in the canal water was less than 0.1 µg/ℓ. For 1,2-DCE concentrations less than 500 µg/ℓ in the discharged water and canal flows greater than 25 cu. ft/sec, the 1,2-DCE concentration was less than 4.0 µg/ℓ in the canal. The highest 1,2-DCE and 1,1-DCE concentrations found in the canal were 46.6 and 1.40 µg/ℓ which occurred with a canal flow of 7.4 cu. ft/sec and the

concentrations in the discharged water were 740 and 16.7 µg/ℓ, respectively. With flow rates greater than 30 cu. ft/sec and a 1,1-DCE concentration in the discharged water less than 15.5 µg/ℓ, the concentration was found to be less than 0.2 µg/ℓ in the canal.

When the canal flow rate was less than 50 cu. ft/sec, the TCE concentration at the surface of canal water was normally lower than that in the bottom water, except at the confluence site. Table 5 shows a typical concentration between surface and bottom water at various canal flow rates. The contaminated groundwater was discharged to a hydraulic jump in the canal where it mixed the upstream canal water with the discharged contaminated water. There was little differentiation between top and bottom water at the discharge site. The depth of this site was only 3 to 4 feet around the sampling area. As the water flows downstream toward the Midway Station, the canal has a wider surface and deeper depth and thus reduces the water speed. Higher concentrations in bottom as opposed to surface waters can be attributed to the higher density of TCE to that of water. However, when the canal flow increased up to 270 cu. ft/sec, the rapid canal flow washed off the canal water and the TCE concentration of the surface water was slightly higher than that of the bottom water. As the water reached the confluence site, the fresh canal water floated on the surface layer entraining salt water from below and providing higher TCE concentrations on the surface than those at the bottom as shown in Table 5.

Canal water reached the Confluence Site and the water continued to flow toward the river. Samples were collected about 300 meters north and 70 meters south of the Confluence Site in the river. The TCE concentrations for both sampling sites are shown in Table 1. The concentration at the North Confluence Site was higher than that at the South Confluence Site from April to September and the samples collected from October to March had higher concentrations at South Confluence than at North Confluence. The concentration during the study period ranged between 7 to $\leq$ 0.1 and 3.2 to $\leq$ 0.1 for both North and South Confluence Sites, respectively. The resultant concentrations were due to canal water run-off and lagoonal water movement which transport the pollutants in the river. During the summer months, northwestern bound wind drove the run-off water northwest of the Confluence Site. Similarly, the southeastern bound wind observed during the winter months blew the surface water southeast in the river. Since the Confluence Site is about 20 km away from both Fort Pierce and Sebastian Inlets, the exchange of the run-off water with the ocean is restricted. The tidal motion plays a less important role than the wind driven force to transport the pollutants in the river (Smith 1981).

Sediment samples were collected from the Discharge, Midway and Confluence Sites. Quartz sand with shell fragments was most abundant in the Midway and Discharge Sites in the canal and organic mud was the primary component observed in the Confluence Site. Trichloroethylene concentrations ranged between 0.5 to 6.24

Table 1 Pollutant Concentration (µg/ℓ) in the Main Canal and Indian River

Date	Canal Flow Rate (cu. ft/sec)	Concentration in Discharged Water	Discharge Site	Midway Site
		Trichloroethylene		
5-11-81	24	1594	32.5	27.6
6-8-81	254	2780	4.62	3.0
7-6-81	20	2560	56.5	45.5
8-10-81	7.4	2092	74.7	80.9
8-31-81	556	1540	1.33	1.23
9-8-81	271	1548	1.43	1.85
10-26-81	23	1000	26.8	22.1
11-30-81	31	725	13.0	11.8
12-29-81	50	664	6.44	6.34
1-25-82	35	652	4.40	5.88
2-22-82	33	679	6.98	9.42
3-22-82	27	167	1.65	2.49
4-5-82	45	141	1.14	<0.1
5-17-82	20	28.7	0.60	0.35
		1,1-Dichloroethylene		
5-11-81	24	14.8	0.40	0.3
6-8-81	254	17.9	< 0.2	< 0.2
7-6-81	20	15.5	0.61	0.47
8-10-81	7.4	16.7	0.93	1.40
9-8-81	271	17.2	< 0.2	< 0.2
10-26-81	23	9.8	0.2	< 0.2
11-30-81	31	22.3	1.4	0.63
12-29-81	38	28.6	0.35	< 0.2
1-25-82	35	36.7	0.48	< 0.2
2-22-82	33	31.4	1.34	< 0.2
3-22-82	22	26.6	1.91	0.94
4-19-82	35	20.9	< 0.2	< 0.2
5-7-82	20	30.3	0.98	< 0.2
		1,2-Dichloroethylene		
5-11-81	24	547	11.1	11.7
6-8-81	254	736	< 4.0	< 4.0
7-6-81	20	585	9.09	8.94
8-10-81	7.4	740	43.6	48.1
9-8-81	271	821	< 4.0	< 4.0
10-26-81	23	597	17.2	13.1
11-30-81	31	1087	27.0	< 4.0
12-29-81	38	1522	24.1	6.01
1-25-82	35	1452	25.8	< 4.0
2-22-82	33	1374	15.7	4.00
3-22-82	27	1307	14.0	< 4.0
4-19-82	35	929	4.0	< 4.0
5-17-82	20	1083	14.0	< 4.0

Table 1. Pollutant Concentration (µg/ℓ) in the Main Canal and Indian River (continued)

Date	Salinity Barrier	Confluence Site	North Confluence	South Confluence
		Trichloroethylene		
5-11-81	21.5	2.61	< 0.1	< 0.1
6-8-81	2.48	3.03	0.48	1.33
7-6-81	50.9	9.88	1.48	< 0.1
8-10-81	34.8	2.07	1.35	1.00
8-31-81	1.42	1.59	0.74	0.26
9-8-81	1.65	2.40	0.33	2.01
10-26-81	21.3	2.88	2.92	< 0.1
11-30-81	14.4	2.77	< 0.1	< 0.1
12-29-81	8.74	4.47	< 0.1	0.13
1-25-82	5.97	3.16	< 0.1	0.98
2-22-82	4.36	2.34	0.20	0.28
3-22-82	2.34	1.34	< 0.1	< 0.1
4-5-82	< 0.1	< 0.1	< 0.1	< 0.1
5-17-82	0.65	0.27	< 0.1	< 0.1
		1,1-Dichloroethylene		
5-11-81	0.35	< 0.2	< 0.2	< 0.2
6-8-81	< 0.2	< 0.2	< 0.2	< 0.2
7-6-81	0.45	< 0.2	< 0.2	< 0.2
8-10-81	1.11	< 0.2	< 0.2	< 0.2
9-8-81	< 0.2	< 0.2	< 0.2	< 0.2
10-26-81	< 0.2	< 0.2	< 0.2	< 0.2
11-30-81	0.51	< 0.2	< 0.2	< 0.2
12-29-81	< 0.2	< 0.2	< 0.2	< 0.2
1-25-82	< 0.2	< 0.2	< 0.2	< 0.2
2-22-82	< 0.2	< 0.2	< 0.2	< 0.2
3-22-82	0.91	< 0.2	< 0.2	< 0.2
4-19-82	< 0.2	< 0.2	< 0.2	< 0.2
5-7-82	< 0.2	< 0.2	< 0.2	< 0.2
		1,2-Dichloroethylene		
5-11-81	7.41	< 4.0	< 4.0	< 4.0
6-8-81	< 4.0	< 4.0	< 4.0	< 4.0
7-6-81	9.08	< 4.0	< 4.0	< 4.0
8-10-81	20.2	< 4.0	< 4.0	< 4.0
9-8-81	< 4.0	< 4.0	< 4.0	< 4.0
10-26-81	13.2	< 4.0	< 4.0	< 4.0
11-30-81	< 4.0	< 4.0	< 4.0	< 4.0
12-29-81	4.98	< 4.0	< 4.0	< 4.0
1-25-82	< 4.0	< 4.0	< 4.0	< 4.0
2-22-82	8.92	< 4.0	< 4.0	< 4.0
3-22-82	< 4.0	< 4.0	< 4.0	< 4.0
4-19-82	< 4.0	< 4.0	< 4.0	< 4.0
5-17-82	< 4.0	< 4.0	< 4.0	< 4.0

Table 2. Trichloroethylene in the Discharge Water and Canal Flow Rate Effects on the Canal Water

TCE Concentration (µg/ℓ) in the Discharged Water	Canal Flow Rate (cu. ft/sec)	Highest TCE Concentration (µg/ℓ) Detected in the Canal Water
3165-2169	18-19	56.7-44.8
2182-2780	456-254	2.40-4.62
1907-1510	15-30	24.7-64.9
1540-1160	556-144	1.33-4.92
725-651	31-35	14.7-5.97
167-135	27-82	2.49-1.51
51-11	78-258	< 0.72-0.1
< 10	> 30	< 0.1
2092	7.4	80.9

Table 3. 1,2-Dichloroethylene Concentration in the Discharge Water and Canal Flow Rate Effects on the Canal Water

1,2-DCE Concentration (µg/ℓ) in the Discharged Water	Canal Flow Rate (cu. ft/sec)	Highest 1.2-DCE Concentration (µg/ℓ) Detected in the Canal Water
1452-1086	35-31	25.80-27.0
738-887	556-144	< 4.0
690-580	25-31	4.4-11.9
699-542	13-15	23.8-15.1
565-515	19-30	7.41-8.06
< 500	> 25	< 4.0
740	7.4	43.6

Table 4. 1,1-Dichloroethylene in the Discharged Water and Canal Flow Rate Effects on the Canal Water

1,1-DCE Concentration (µg/ℓ) in the Discharged Water	Canal Flow Rate (cu. ft/sec)	Highest 1,1-DCE Concentration (µg/ℓ) Detected in the Canal Water
36.7-28.6	35-38	0.48-0.35
20.0-19.4	556-144	< 0.2
18.6-20	13-16	0.89-0.61
< 15.5	> 30	< 0.2
16.7	7.4	1.40

Table 5. Trichloroethylene Concentration (ug/l) at the Surface and Bottom of Water in the Canal

Sampling Date	Canal Flow Rate (cu. ft/sec)	Discharge Site		Midway Station		Confluence	
		Surface	Bottom	Surface	Bottom	Surface	Bottom
7-06-81	20	49.1	50.9	45.5	64.5	9.88	0.66
8-17-81	456	2.40	2.15	2.69	2.23	2.00	1.66
8-31-81	556	1.33	0.77	1.23	1.21	1.59	1.57
9-08-81	271	1.23	1.43	1.85	1.70	2.40	2.04
10-26-81	23	31.6	32.9	22.1	27.6	8.85	$\leq$ 0.1
12-29-81	50	6.44	6.77	6.34	7.07	4.47	1.73

at the Discharge Site which normally exhibited the highest concentration in the canal. Samples from the Midway and Confluence Sites were between $\leq$ 0.5 to 2.38 ng/g and $\leq$ 0.5 to 1.70 ng/g, respectively. Oyster samples from the Confluence Site and the west shore of the Indian River approximately 70 meters south and 300 meters north of the Main Canal were analyzed. Oysters collected at the Confluence Site had higher concentrations than the other two sites in the river. The concentration from these three sites ranged between 10.8 to $\leq$ 0.1, 2.8 to $\leq$ 0.1 and non-detectable ($\leq$ 0.1) for the Confluence, North Confluence and South Confluence Sites, respectively.

Vinyl chloride was another compound in the discharged water. Since this compound has a high vapor pressure (= 2660 mm at 25°C) and low solubility in the water (= 1.1 mg/ℓ at 25°C), the concentrations of vinyl chloride in the water, sediment and oyster samples were less than 1.0 µg/ℓ, 2.0 µg/ℓ and 4.0 µg/ℓ, respectively.

Acknowledgments. The authors wish to thank D. Farb for typing the manuscript and John TenEyck for technical assistance. This is Harbor Branch Contribution No. 383.

REFERENCES

Burmaster DE (1982) Groundwater contamination. Environment 24: 6-13.

Wilson JT, McNabb JF (1983) Biological transformation of organic pollutants in groundwater. Amer Geophy Union 64: 505-507.

Hansen HF (1983) The occurrence of contamination in groundwater. American Chemical Society. Div Environ Chem 23: 61-62.

United States Department of Interior - Geological Survey (1982) Main Canal Discharge Rate at Vero Beach, Florida, Station Number 02253000.

Wang TC, Lenahan RA (1984) Determination of volatile halocarbons in water by purge-closed loop gas chromatography. Bull Environ Contam Toxicol 32: 429-438.

Smith NP (1981) Local energy exchanges in a shallow coastal lagoon. Atmosphere-Ocean 19: 307-319.

Received May 19, 1984, accepted June 5, 1984