Case Study - Trichloroethylene Groundwater Contamination at Vero Beach, Florida

Harbor Branch Foundation
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by

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ABSTRACTS

A trichloroethylene (TCE, CHCl = CCl₂) underground storage tank was found to be leaking in October 1978. The unknown amount of TCE subsequently contaminated the groundwater at Vero Beach, Florida, USA. Samples of shallow groundwater adjacent to the storage tank showed a TCE concentration of 39,000 ppb. Later, the TCE was found to migrate to a Vero Beach water production well. Samples taken from this well showed a concentration of approximately 1500 μg/l TCE, 12,000 μg/l cis and/or trans 1,2-dichloroethylene and 14,000 μg/l of vinyl chloride. The local and state authorities attempted to control the contaminants plume dispersion by pumping and air spraying the groundwater to a nearby surface canal which flows to the Indian River Lagoon at Vero Beach, Florida. This study was initiated to monitor the impacts of dewatering on the pollutants behavior in the aquifer, the assessment of contaminant removal efficiencies, and the impacts of contaminated water discharged to the canal and estuarine environment.

After pumping of the contaminated well began in 1981, the concentration of all contaminants at the Spill Site increased as the most highly contaminated water was pulled back toward this site. Once this water had been removed, contamination levels began to decline. The pollutants are not all being removed from the area at the same rate but are responding to the dewatering in the same general manner. The concentration of contaminants at the Spill Site in December 1983 was 128 μg/l TCE, 1,210 μg/l 1,2-DCE, 10.6 μg/l 1,1-DCE and 196 μg/l vinyl chloride. A total of approximately 778 million gallons of
contaminated water was pumped out during the period of April 1981 to December 1983. The total amount of contaminants removed from the Spill Site during this period was approximately 730 gallons. The contaminated groundwater was sprayed to the air and discharged to a hydraulic jump in a nearby canal. The water was sprayed downward 10 feet through nozzles installed on a water pipe suspended above the bank of the canal. The water was broken down into fine droplets which increased the air-water contact surface area. This treatment scheme resulted in 70 - 80% removal efficiencies for these compounds.

This treated water diluted with canal water goes to the Indian River Lagoon. Canal water was constantly monitored to assess the impact of the contaminated water to the canal and estuarine environment. The pollutants' concentration found in the canal decreased from the discharge points toward the Confluence Site between the canal and the river. Canal flow rate and concentration of discharged water affects the pollutants distribution. Higher concentrations in the discharged water resulted in higher pollutant residues. Rapid canal flow reduced the contaminated concentration and stagnant flow increased the concentration. Canal water reached the Confluence Site and the water continued to flow toward the river. 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 resultant concentrations were due to canal water run-off and lagoonal water movement which transport the pollutants in the river. Since the Confluence Site is
about 20 km away from both Ft. 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.

INTRODUCTION

In October, 1978, a fitting on a 500 gallon underground storage tank of trichloroethylene (TCE), Vero Beach, Florida, was found to be leaking. The tank had been in place approximately three years, but the volume of the spill was undetermined since the duration and leak rate were unknown. Samples of shallow groundwater adjacent to the storage tank revealed a TCE concentration of 39,000 ppb.\(^1\) Trichloroethylene is widely used as a solvent, primarily for metal degreasing.\(^2\) It is soluble in water to 1100 mg/l at 25°C and has a specific gravity of 1.466. This characteristic enabled the TCE at the spill site to migrate at least 900 feet laterally and 60 feet vertically to a Vero Beach City production well. This City well (No. 15) is located about 880 feet southeast of the storage tank (Figure 1). Samples taken from the well showed concentrations of approximately 1,500 µg/l Trichloroethylene, (TCE) 12,000 µg/l Cis and/or Trans 1,2-dichloroethylene (1,2-DCE) and 14,000 µg/l of vinyl chloride.\(^3\) Once this contamination was discovered, the well was closed immediately.

The local and state authorities attempted to control the contaminant plume dispersion by pumping and air spraying the
groundwater to a nearby surface canal. A six-inch gravel packed well was installed in proximity to the spill site. The well was approximately sixty feet deep, the bottom ten feet being screen. Water was pumped from the well at a rate of approximately 0.2 million gallons per day. This study was initiated to monitor the impact of dewatering on the contaminants behavior in the aquifer, the contaminants removal efficiency, and the impact of contaminants discharged to a surface canal.

METHOD AND MATERIALS

Water samples were collected in 40 mL vials equipped with Teflon lined septa and screw caps. The vials were pre-cleaned and dried overnight in an oven at 200°C. The vials were then filled so that no air bubbles were present. After collection, the samples were immediately iced and delivered to the laboratory for analysis. Sample size ranged from a few microliters for highly contaminated water in the well up to 20 mL for very dilute samples from the canal. A purge and closed loop method(4) was used to analyze the environmental samples. Volatile organic compounds were purged from the bubbler unit to the sample loop, which was subsequently injected to the gas chromatograph. The gas chromatograph analysis was performed with a Ni 63 electron capture detector and 1% SP-1000 on 60/80 carbopack B column. Each sample was performed in duplicate. Average results were used in the report. The minimum detectable concentrations for
trichloroethylene (TCE), 1,1-dichloroethylene (1,1-DCE), 1,2-dichloroethylene (1,2-DCE) and vinyl chloride were 0.1, 0.2, 4.0 and 1.0 µg/l, respectively.

Contaminant Spill Site

Contaminants in the vicinity of the original spill site are reduced as the contaminants are removed by the pumping of the decontamination aquifer. The average monthly concentration for the groundwater present in both Well 15 and the storage tank site are shown in Figures 2, 3, 4 and 5. The chemicals are not all being removed from the area at the same rate but are responding to the treatment in the same general manner. After pumping of the contaminated well began in 1981, the concentration of all contaminants at this site increased as the most highly contaminated water was pulled back towards the spill site. Once this water had been removed, contamination levels began to decline. Figure 2 shows the average monthly trichloroethylene concentration in both Well 15 and the storage tank site during the study period. At the storage tank site, trichloroethylene rapidly increased from 3,006 µg/l in April to 8,981 µg/l in June, 1981. Since that time, TCE concentrations have declined at an approximate rate of 850 µg/l per month to a concentration of 1,356 µg/l in March, 1982. Further dewatering continued to remove the TCE at a slower monthly rate of approximately 60 µg/l. The TCE level in December, 1983 was reduced to 128 µg/l.

Cis and/or Trans 1,2-dichloroethylene and 1,1-dichloroethylene have responded to the decontamination pumping in a manner similar to
TCE but at a much slower rate. These compounds reached their peak concentrations in March, 1982, ten months after pumping began, whereas peak TCE levels were recorded only two months after the commencement of pumping. Cis and/or Trans 1,2-dichloroethylene, initially present at 983 μg/L in April, 1981, increased with pumping to a peak of over 4,028 ppb (Figure 3). These compounds have subsequently declined in concentration to a level of approximately 1,102 μg/L in December, 1983. Following a similar pattern, 1,1-dichloroethylene increased from an initial concentration of 20.2 μg/L to a maximum of 144 μg/L in March, 1982 (Figure 4). This compound was then gradually reduced to 10.6 μg/L in December, 1983. Vinyl chloride in the spill area has declined from a peak concentration of 526 μg/L in August, 1981 (Figure 5). It has not, however, responded as positively to the pumping as the other contaminants. The level of vinyl chloride in December, 1983 was 196 μg/L.

Production Well 15

Since pumping of the contaminated well began, the water quality of Well 15 has been constantly monitored. Approximately 2,500 gallons of water were pumped to flush out the well before a sample was collected and analyzed.

Trichloroethylene was initially present in Well 15 at a concentration of 29 μg/L in April, 1981. Since then, the level of TCE rapidly declined. By January, 1982, it declined to a trace level (< 0.1 ppb), where it remains with no indication of increasing (Figure 2). Cis and/or Trans 1,2-dichloroethylene, initially present at 1747...
μg/l has continually declined in concentration since decontamination pumping began in April, 1981 (Figure 3). The concentration of 1,2-DCE in December, 1983, was reduced to 39 μg/l. 1,1-dichloroethylene levels have also shown a reduction from 41 μg/l in April, 1981 to approximately less than 0.2 μg/l in December, 1983. (Figure 4). Vinyl chloride in Well 15 had a highly erratic but slightly upward trend after March of 1982. The vinyl chloride level was initially at 55 μg/l in April, 1981 and declined gradually to 9.9 μg/l in September, 1981. Since that time the concentration has increased to 92.1μg/l in December, 1983. The higher level of vinyl chloride suggested the possibility of microbial degradation of the other compounds present. Previous analyses showed that TCE in the original storage tank was not contaminated with 1,2-DCE, 1,1-DCE or vinyl chloride. The high concentrations of these compounds observed in both well samples could be the results of biodegradation of trichloroethylene. (5, 6, 7)

Rainfall Effect

Heavy rainfall during the summer recharged the aquifer and diluted the contaminant concentration in the groundwater. Figure 6 demonstrates that as the total monthly rainfall increased the total contaminants concentration in both Well 15 and the storage tank site decreased. Since the decreasing of the contaminant level in the aquifer could also be attributed to the biodegradation and the dewatering process to remove the contaminants, the actual rainfall effect on the contaminants concentration cannot be clearly defined. A total of approximately 778 million gallons of contaminated water was
pumped from the storage tank site during the period of April, 1981 to December, 1983. Table 1 shows the amount of trichloroethylene, 1,1-dichloroethylene, cis and/or trans 1,2-dichloroethylene and vinyl chloride removed from the storage tank site. The total amount of contaminants removed from the spill site during the 1981 to 1983 period was found to be approximately 730 gallons.

Table 1. The Amount of Contaminants Removed from the Spill Site
(April 1981 - December 1983)

<table>
<thead>
<tr>
<th>Compound</th>
<th>Weight in kg (lb)</th>
<th>Volume in liter (gallons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trichloroethylene</td>
<td>1617 (3565)</td>
<td>1104 (292)</td>
</tr>
<tr>
<td>1,1-Dichloroethylene</td>
<td>36.5 (80.5)</td>
<td>30 (7.94)</td>
</tr>
<tr>
<td>Cis and/or Trans</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1,2-Dichloroethylene</td>
<td>1703 (3756)</td>
<td>1335 (353)</td>
</tr>
<tr>
<td>Vinyl Chloride</td>
<td>257 (569)</td>
<td>289 (77)</td>
</tr>
</tbody>
</table>

Contaminants Removal

The contaminated groundwater was sprayed to the air and discharged to a hydraulic jump in a nearby drainage relief canal (Figure 7). The contaminated water was sprayed down to the surface of the canal through ten nozzles installed on a water pipe suspended above the canal. Each nozzle had a 19/32 inch orifice diameter and a capacity of 13.5 gpm at 3 psi pressure. The nozzles broke down the water into fine droplets which increased the air-water contact surface.
area. Samples were collected at three meters below the spray heads. Table 2 shows the concentration of contamination in the aerated effluent, the contaminated groundwater and the removal efficiency of each compound. The results showed that 70-80% efficiency was normally observed for all compounds. The efficiency apparently varied with initial groundwater concentration, air and water temperature, Henry's law constants, wind speed and direction at the discharge site. (8, 9)

Table 2. Contaminants Concentration and Removal Efficiency

<table>
<thead>
<tr>
<th>Compound</th>
<th>Storage Tank Site</th>
<th>Aerated Effluent</th>
<th>Removal Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trichloroethylene</td>
<td>8980-2217</td>
<td>2468-674</td>
<td>70-83</td>
</tr>
<tr>
<td>1,1-Dichloroethylene</td>
<td>128-60</td>
<td>36-14</td>
<td>71-83</td>
</tr>
<tr>
<td>1,2-Dichloroethylene</td>
<td>3651-2286</td>
<td>1452-588</td>
<td>61-83</td>
</tr>
<tr>
<td>Vinyl Chloride</td>
<td>528-273</td>
<td>120-45</td>
<td>72-88</td>
</tr>
</tbody>
</table>

Impact of Contaminants Discharged to a Relief Canal

The aerated effluent was discharged to the main relief canal which extends 2.5 km west of Vero Beach and flows toward the Indian River (Figure 1). This canal received surface drainage water at average monthly rates of 21.2 to 252 cu. ft/sec during the period of May, 1981 to May, 1982. (10) Water samples at different sites were
collected from the canal on a weekly basis to assess the impact of the contaminated water to the canal.

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 pollutant distribution. Higher concentrations in the discharged water resulted in higher pollutant residues in the canal water. Rapid canal flow reduced the contaminant 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 1.594 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 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 increased rapidly. A flow of 556 cu ft/sec could dilute the contaminant concentration to 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.

The summary of weekly monitoring data is presented in Tables 3, 4 and 5 for TCE, 1,1-DCE and 1,2-DCE, respectively. The results show that the pollutant concentrations in the discharged water and the canal flow rate affect the concentrations in the canal. With TCE concentrations in the discharged water between 3165 and 2969 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 the canal flow was greater than 30 cu. ft/sec, the resulting concentration in the canal water was less than 0.1 μg/ℓ, as presented in Table 3. 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. This information is included in Table 4. 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 (Table 5). The highest 1,2-DCE and 1,1-DCE concentrations found in the canal were 43.6 and 14.0 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.

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 ng/g at the Discharge Site which normally exhibited the highest concentration in the canal. Samples from the Midway and Confluence Sites were between <0.5 to 2.38 ng/g and <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 <0.1, 2.8 and <0.1 and non-detectable (<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 found to be less than 1.0 µg/l, 2.0 µg/l and 4.0 µg/l, respectively.

ACKNOWLEDGEMENTS

The authors wish to thank Debbie Farb for typing the manuscript and Mariam Kanik for analyzing some water samples. Special thanks also to Ocean Engineering Division, Harbor Branch Foundation for providing community service to assist groundwater contamination problems at Vero Beach, Florida. This work was funded by Piper Aircraft Corporation, Vero Beach Division, Florida.
### Table 3. Trichloroethylene in the Discharge Water and Canal Flow Rate Effects on the Canal Water

<table>
<thead>
<tr>
<th>TCE Concentration (µg/l) in the Discharged Water</th>
<th>Canal Flow Rate (cu. ft/sec)</th>
<th>Highest TCE Concentration (µg/l) Detected in the Canal Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>3165-2969</td>
<td>18-19</td>
<td>56.7-44.8</td>
</tr>
<tr>
<td>2182-2780</td>
<td>456-254</td>
<td>2.40-4.62</td>
</tr>
<tr>
<td>1907-1510</td>
<td>15-30</td>
<td>24.7-64.9</td>
</tr>
<tr>
<td>1540-1160</td>
<td>556-144</td>
<td>1.33-4.92</td>
</tr>
<tr>
<td>725-651</td>
<td>31-35</td>
<td>14.7-5.97</td>
</tr>
<tr>
<td>167-135</td>
<td>27-82</td>
<td>2.49-1.51</td>
</tr>
<tr>
<td>51-11</td>
<td>78-258</td>
<td>&lt; 0.72-0.1</td>
</tr>
<tr>
<td>&lt; 10</td>
<td>&gt; 30</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>2092</td>
<td>7.4</td>
<td>80.9</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>1,1-DCE Concentration (µg/l) in the Discharged Water</th>
<th>Canal Flow Rate (cu. ft/sec)</th>
<th>Highest 1,1-DCE Concentration (µg/l) Detected in the Canal Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>36.7-28.6</td>
<td>35-38</td>
<td>0.48-0.35</td>
</tr>
<tr>
<td>20.0-19.4</td>
<td>556-144</td>
<td>&lt; 0.2</td>
</tr>
<tr>
<td>18.6-20</td>
<td>13-16</td>
<td>0.89-0.61</td>
</tr>
<tr>
<td>&lt; 15.5</td>
<td>&gt; 30</td>
<td>&lt; 0.2</td>
</tr>
<tr>
<td>16.7</td>
<td>7.4</td>
<td>1.40</td>
</tr>
</tbody>
</table>
Table 5 1,2-Dichloroethylene in the Discharge Water and Canal Flow Rate Effects on the Canal Water

<table>
<thead>
<tr>
<th>1,2-DCE Concentration (µg/L) in the Discharged Water</th>
<th>Canal Flow Rate (cu. ft/sec)</th>
<th>Highest 1,2-DCE Concentration (µg/L) Detected in the Canal Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>1452-1086</td>
<td>35-31</td>
<td>25-80-27.0</td>
</tr>
<tr>
<td>738-887</td>
<td>556-144</td>
<td>&lt; 4.0</td>
</tr>
<tr>
<td>690-580</td>
<td>25-31</td>
<td>4.4-11.9</td>
</tr>
<tr>
<td>699-542</td>
<td>13-15</td>
<td>23.8-15.1</td>
</tr>
<tr>
<td>565-515</td>
<td>19-30</td>
<td>7.41-8.06</td>
</tr>
<tr>
<td>&lt; 501</td>
<td>&gt; 25</td>
<td>&lt; 4.0</td>
</tr>
<tr>
<td>740</td>
<td>7.4</td>
<td>43.6</td>
</tr>
</tbody>
</table>

REFERENCES


(2) EPA "Identification of Organic Compounds in Effluents from Industrial Sources", EPA-560/3-75-002, April 1975.


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. Storage Tank Site
9. Production Well #15

Figure 1. Sample Stations in the Indian River and the Relief Canal at Vero Beach, Florida
Figure 2. Trichloroethylene Concentration at the Storage Tank Site and Well 15.
Figure 3. Cis and/or Trans 1,2-Dichloroethylene Concentration at the Storage Tank Site and Well 15
Figure 4. 1,1-Dichloroethylene Concentrations at the Storage Tank Site and Well 15
Figure 5. Vinyl Chloride Concentrations at Storage Tank Site and Well 15
Figure 7. Schematic of Contaminated Water Discharged to the Main Relief Canal of Vero Beach, Florida
Figure 7. Schematic of Contaminated Water Discharged to the Main Relief Canal of Vero Beach, Florida