# COST AND PERFORMANCE REPORT

Pump and Treat and *In Situ* Bioremediation of Contaminated Groundwater at the French Limited Superfund Site Crosby, Texas

September 1998

Prepared by:

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Technology Innovation Office

# SITE INFORMATION

**Identifying Information:**

French Limited Superfund Site
Crosby, TX

**CERCLIS #:** TXD980514814

**ROD Date:** March 24, 1988

**Treatment Application:**

**Type of Action:** Remedial

**Period of operation:** January 1992 through December 1995 (Performance data collected through December 1995)

**Quantity of material treated during application:** 281 million gallons of groundwater, and 25 million gallons of surface water.

**Background [11, 22]**

**Historical Activity that Generated Contamination at the Site:** Industrial waste disposal

**Corresponding SIC Code:** 4953E (Waste management-refuse systems; sand and gravel pit disposal)

**Waste Management Practice That Contributed to Contamination:** Unlined disposal pit (lagoon)

**Location:** Crosby, TX

**Facility Operations:**

- The French Limited site is a 22.5-acre tract of land located adjacent to Highway US-90 in eastern Harris County, Texas. The site is in the floodplain of the San Jacinto River and was used for sand mining in the 1960s and 1970s. During the period of 1966 through 1971, the site was permitted by the State of Texas to accept industrial waste material for disposal in a 7-acre lagoon created from an open sand pit. About 80 million gallons of waste material was disposed of in the main waste lagoon, creating 300,000 cubic yards of contaminated sludges and soils. The facility's permit was revoked and the site was closed in 1973.
- In 1981, a flood caused the dike surrounding the waste lagoon to breach and in 1982, EPA repaired the dike, and pumped most of the discharged sludges back into the lagoon.
- A remedial investigation was performed from 1983 to 1986 through a cooperative agreement. The French Limited Task Group (FLTG), a private company formed by potentially responsible parties (PRP), conducted a 1986 Field Investigation and prepared a Supplemental Remedial Investigation Report; using the results to select the site remedy.
- In April 1987, the responsible parties conducted a slurry-phase bioremediation pilot demonstration. Based on the results of the demonstration, EPA selected slurry-phase bioremediation as the preferred remedial technology for lagoon sludges and contaminated soils in the EPA Record of Decision (ROD), dated March 24, 1988.
- The 1988 ROD also specified extraction and treatment of contaminated groundwater with *in situ* bioremediation to enhance contaminant reductions. This report focuses on the groundwater remedial activities.
- In 1989, as a source control measure, the 7-acre lagoon was isolated and contained within a wall of double-interlock, steel sheet pile that surrounded the lagoon, and keyed into the second clay unit. The sheetpile wall is also called the floodwall.
- Beginning in January 1992, the contaminated sludges and soils within the lagoon were treated in place using slurry-phase bioremediation. Treatment of the soils and sludges was completed in December 1993. A Cost and Performance

# SITE INFORMATION (CONT.)

## Background (Cont.)

report (Reference #7) describes the slurry-phase bioremediation of lagoon sludges and soils.

- The site was placed on the National Priorities List (NPL) in 1981.

**Regulatory Context [26]:**

- A ROD was signed on May 1987 and amended on March 24, 1988.
- Site activities are conducted under provisions of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980, as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986 §121, and the National Contingency Plan (NCP), 40 CFR 300. Post-closure monitoring of the upper and lower aquifers for a period of 30 years is required under the Resource Conservation and Recovery Act (RCRA) of 1976.

**Remedy Selection [20]:**
The contaminated groundwater was extracted and treated in an aboveground treatment system. *In situ* bioremediation was implemented for the groundwater plume to expedite the cleanup process. The ROD for this site allows for 10 years of natural attenuation to meet final remedial goals. Lagoon sludges were treated via slurry-phase bioremediation. Surface water (from the lagoon) was treated in an aboveground treatment system. Treated water was discharged to the San Jacinto River.

## Site Logistics/Contacts

**Site Lead:** PRP

**Oversight:** EPA

**Remedial Project Manager:**
*Ernest Franke
EPA - Region 6
1445 Ross Avenue
Dallas, TX 75202-2733
214-665-6739

**State Contact:**
Emmanuel Ndame
Texas Natural Resources Conservation Commission (TNRCC)
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**PRP:**
*Richard L. Sloan
ARCO Chemical Company
FLTG Project Coordinator
15010 FM 2100, Ste. 200
Crosby, TX 77532
713-328-3541

**Prime Contractor:**
CH2M Hill
Jon McLeod
512-346-2001

**Treatment System Vendor:**
Applied Hydrology Associates, Inc.
Mike Day, President
Denver, CO

*Indicates primary site contact

# MATRIX DESCRIPTION

## Matrix Identification

**Type of Matrix Processed Through the Treatment System:** Groundwater

## Contaminant Characterization [13]

**Primary Contaminant Groups:** Volatile organic compounds (VOCs)

- Major chemicals in the lagoon sludges included chlorinated and nonchlorinated VOCs and semivolatile organic compounds (SVOCs), polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs). Dense non-aqueous phase liquid (DNAPL), containing a significant component of VOCs, also migrated into the underlying subsoils. Leaching lagoon sludges and contaminated subsoils resulted in a dissolved groundwater plume of VOCs extending approximately 600 feet downgradient (south) of the site.

- Contaminants of concern in the groundwater were benzene, toluene, chloroform, 1,2-dichloroethane (1,2-DCA), and vinyl chloride. Benzene was the most prevalent organic compound. 1,2-DCA was the primary chlorinated solvent compound found in the DNAPL in the source areas. Initial maximum detected levels of selected contaminants were benzene (19,000 µg/L), vinyl chloride (8,200 µg/L), and 1,2-DCA (920,000 µg/L).

- Figures 1 and 2 show the extent of benzene and 1,2-DCA contamination, respectively, in the uppermost aquifer (S1) as of December 1991.

- The VOC plume at the site initially consisted of 91 million gallons of contaminated groundwater. In the S1 aquifer, the plume was 500 feet long (north-south) and 1,500 feet wide (east-west), or 750,000 square feet. In the INT unit, the plume was 950 feet long (north-south) and 1,800 feet wide (east-west), or 1.7 million square feet. The plume volume was determined for this report based on the areal extent of the plumes, a depth of 20 feet in the S1 aquifer, a depth of 15 feet in the INT aquifer, and a standard porosity of 30% [1].

- Slight mounding of the water table near the waste pit indicated slow seepage. Lateral contaminant migration within the shallow aquifer was estimated at approximately 80 feet per year.

- In January 1992, shortly after the startup of the pump and treat (P&T) system, DNAPL was detected at well S1-16 inside the floodwall and at well INT-11 just outside the floodwall. A preliminary study conducted by Applied Hydrology Associates, Inc. (AHA) in the spring of 1992 confirmed the presence of DNAPL in the INT-11 area outside the floodwall. A comprehensive DNAPL field study was conducted by AHA between March and July 1993. The subsequent field data report concluded that the INT-11 area was the only area where DNAPL was confirmed to exist outside the sheetpile floodwall. DNAPL extended up to 63 feet south of the floodwall and was a continuing source of contamination to the groundwater. Construction of a second sheetpile wall around the DNAPL source area was completed in August 1994.

## MATRIX DESCRIPTION (CONT.)

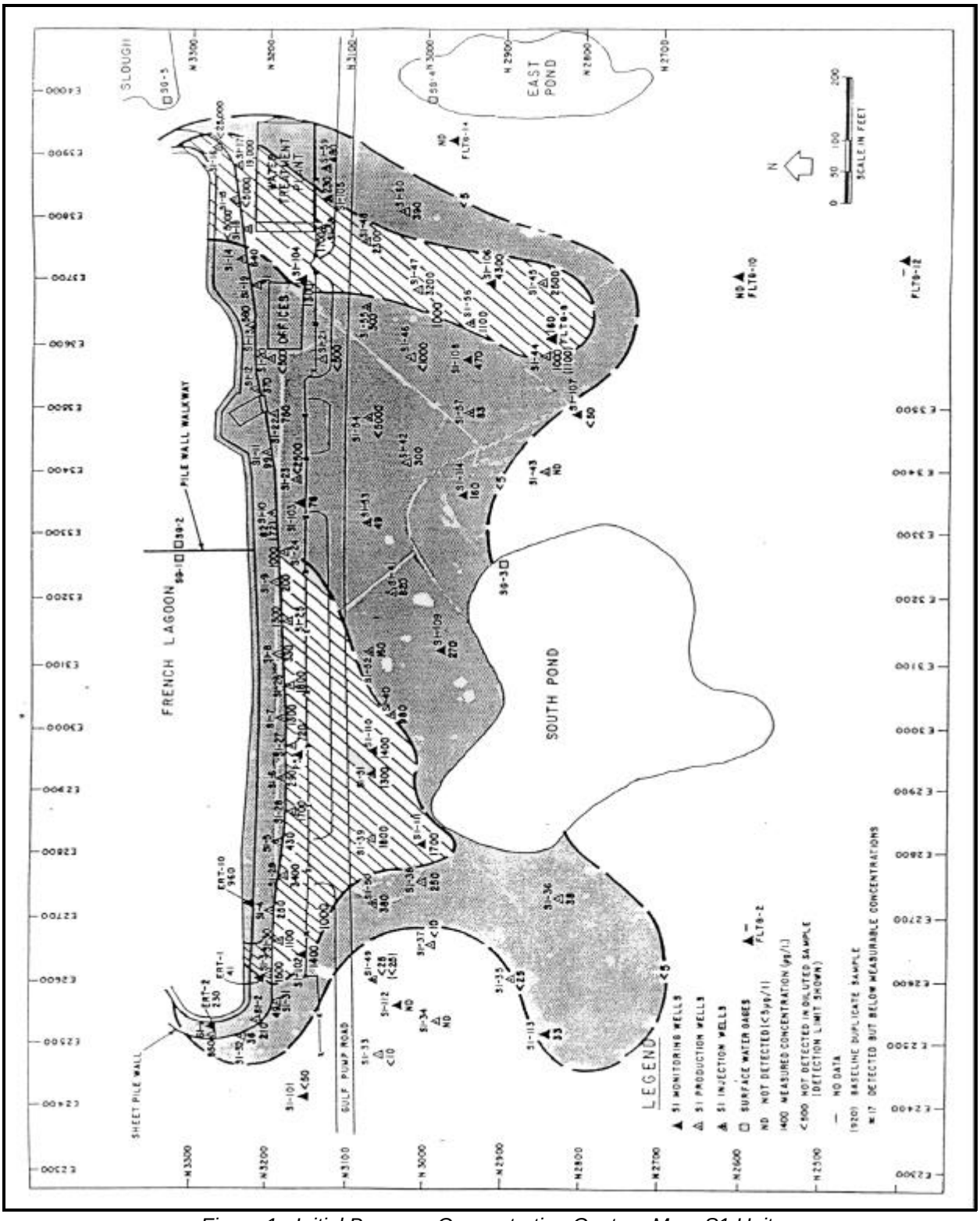


*Figure 1. Initial Benzene Concentration Contour Map, S1 Unit (October - December 1991 baseline sampling) [24]*

## MATRIX DESCRIPTION (CONT.)

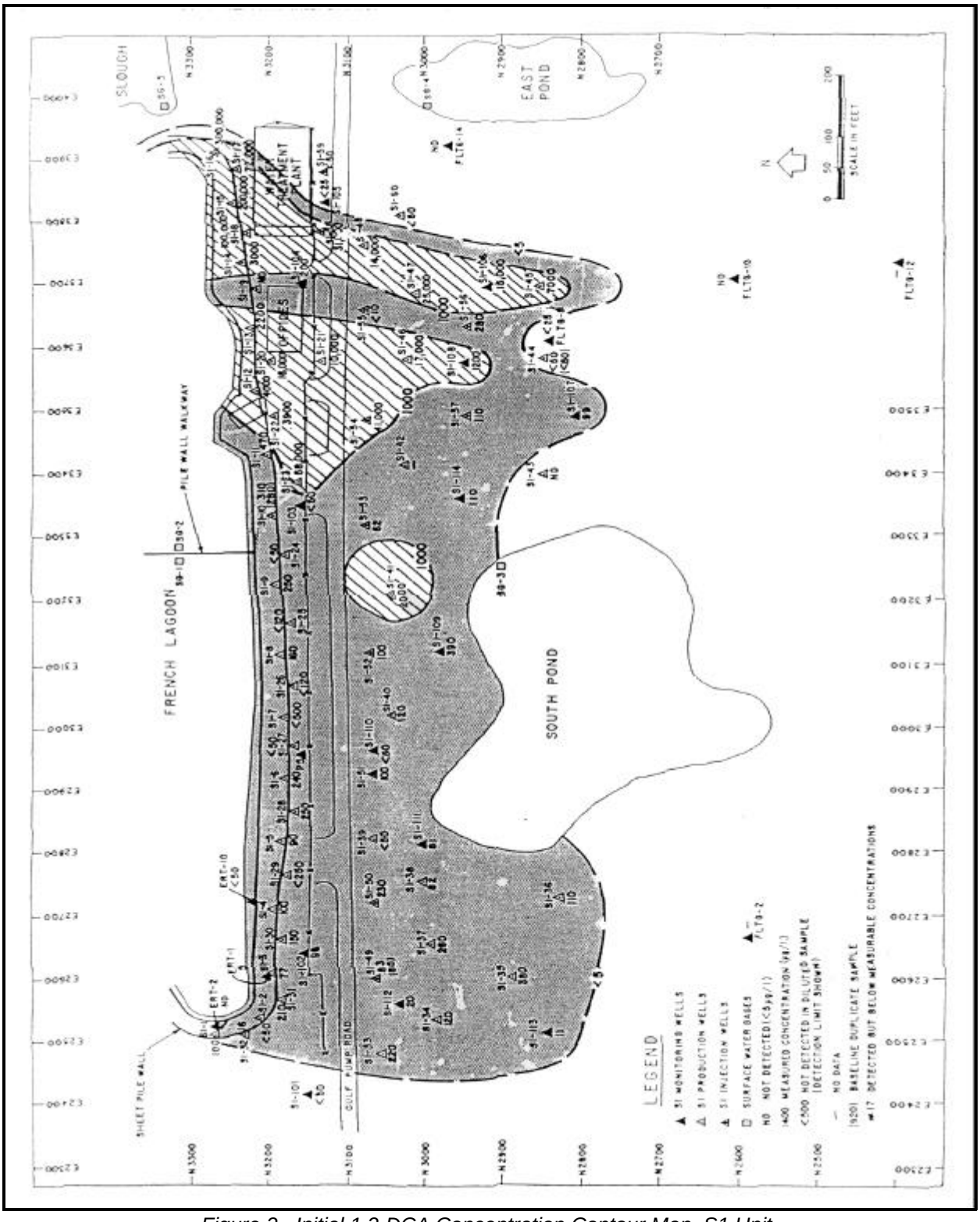


*Figure 2. Initial 1,2-DCA Concentration Contour Map, S1 Unit (October - December 1991 baseline sampling) [24]*

# MATRIX DESCRIPTION (CONT.)

**Matrix Characteristics Affecting Treatment Costs or Performance**

**Hydrogeology [13]:**

Five distinct hydrogeological units have been identified beneath this site. Groundwater is encountered approximately 10 to 12 feet below ground surface. Shallow alluvial deposits of Holocene age, consisting of sands, silts, and clays extend to a depth of 55 feet. These sediments were deposited in the San Jacinto River flood plain and have been subdivided into the following hydrogeologic units. Table 1 presents technical aquifer information.

| | | |
|---|---|---|
| Unit 1 | S1 | Clean medium to coarse sand with minor amounts of fine gravel. The unit is comprised of primarily fluvial channel deposits. The French lagoon was created by mining sand from this unit. |
| Unit 2 | C1 | Laterally discontinuous clay with minor thin silt and fine sand layers. Where present, it functions as an aquitard between the S1 and INT units. |
| Unit 3 | INT | Interbedded fine sand and clayey silts. This unit represents overbank flood deposits and exhibits a fining-upward sequence with transitional contact with overlying clays. |
| Unit 4 | C2 (Beaumont Formation) | Predominantly clay deposit with minor thin silt and fine sand layers. This unit functions as a major aquitard between the upper alluvial units and the underlying Chicot aquifer. |
| Unit 5 | S2 (Chicot Aquifer) | A sequence of fluvial-deltaic sands, silts, and clays. This unit (along with the Evangeline aquifer beneath it), composes the primary water supply aquifer in this area. This unit is not contaminated. |

*Table 1. Technical Aquifer Information* [13]

| Unit Name | Depth Below Surface (ft) | Conductivity (ft/day) | Average Velocity (ft/day) | Flow Direction |
|---|---|---|---|---|
| S1 | 10-35 | 2.835 | NA | S/SE |
| C1 | 0-4 | --- | --- | --- |
| INT | 40-55 | 0.283 | NA | S/SE |
| C2 | 70 | --- | --- | --- |
| S2 | NA | NA | NA | NA |

NA- Data not included in documentation.
Source: [13]

# TREATMENT SYSTEM DESCRIPTION

**Primary Treatment Technology**

Pump and treat (P&T) with activated sludge for extracted groundwater. *In situ* bioremediation for contaminated groundwater.

**Supplemental Treatment Technology**

Carbon adsorption, metals precipitation, and neutralization

**System Description and Operation**

*Table 2. Extraction and Injection Well Data*

| Well Name (Number of Wells) | Unit Name | Depth (ft) | Yield (gal/min) |
|---|---|---|---|
| Pumping wells (53) | S1 | 35 | 1.8 |
| Pumping wells (56) | INT | 55 | 0.6 |
| Injection wells (17) | S1 | 35 | 2.3 |
| Injection wells (42) | INT | 55 | 0.7 |

Source: [1, 14]

**System Description [19]**

- Groundwater at the French Limited site was actively remediated from January 1992 through December 1995 via a combination of conventional pumping and above-ground treatment, enhanced aquifer flushing through pressure injection of clean water, and accelerated *in situ* bioremediation through the addition of dissolved oxygen, diammonium phosphate, and nitrate to injection water. The aboveground treatment unit operations included equalization, biological treatment, metals precipitation, clarification, filtration, neutralization and carbon adsorption (polishing).

- Source control was achieved by installing cutoff (sheet-pile) walls around the lagoon in 1989 and around the DNAPL source area in 1994. The sheet-pile wall around the lagoon is referred to as the floodwall and consists of 996 sheet-pile pairs. The total length of the floodwall is 2,090 feet. The top of the floodwall is 3 feet higher than the 100-year flood level. The bottom of the 65- to 75-foot-long sheet-piles is keyed into the clay stratum underlying the INT unit [27].

- A phased groundwater remediation strategy was developed for this site. The strategy involved installing unit operations in incremental steps to verify design assumptions for P&T enhanced by *in situ* bioremediation. The first phase of the groundwater strategy was aimed at hydraulic containment of all groundwater that exceeded cleanup criteria. The *in situ* bioremediation equipment was next installed to enhance contaminant reduction. The metals precipitation unit was added later when the activated sludge system failed to sufficiently remove metals. Effluent from the treatment system was discharged to the San Jacinto River under a state discharge permit, following treatment to the State of Texas standards.

- The *in situ* bioremediation sequence of flushing, nitrifying conditions, and finally aerobic conditions was designed to stimulate different types of microorganisms. This design created cometabolic biodegradation processes to biodegrade a wide variety of chlorinated and nonchlorinated constituents throughout the plume. First, clean water only (no added nitrate or oxygen) was injected for 30 days. Second, the nitrate and diammonium phosphate was mixed with clean water and injected for 90 days. Finally, the oxygen was mixed with clean water and injected for 44 months.

# TREATMENT SYSTEM DESCRIPTION (CONT.)

**System Description and Operation (Cont.)**

- Table 2 shows well-specific extraction rates. The goal of well placement was hydraulic containment. Most wells were located downgradient (outside) of the floodwall, to intercept the larger portion of the plume and contain the plume. The wells located inside the floodwall were used to contain DNAPLs within the floodwall area.

- The injection and extraction system consisted of 109 recovery wells and 59 injection wells; 53 recovery wells and 17 injection wells for the S1 unit and 56 recovery wells and 42 injection wells for the INT unit.

**System Operation**

- Quantity of groundwater pumped from aquifer by year:

| Year | Total Volume Pumped (gal) | Unit Name |
|---|---|---|
| 1992 | 42.8 million | S1 |
| | 13.2 million | INT |
| 1993 | 68 million | S1 |
| | 13.6 million | INT |
| 1994 | 54 million | S1 |
| | 26 million | INT |
| 1995 | 24.5 million | S1 |
| | 23.4 million | INT |

- The P&T system at this site was operational nearly 90% of the time. Major causes of groundwater extraction system downtime included problems with pneumatic pumps, flow meters clogging, air valves locking, surface leaks in injection wells, and low yields in several INT extraction wells [1].

- 1.5 million pounds of carbon was used in the water treatment plant from 1992 through 1995.

- The nitrate additive for *in situ* bioremediation was controlled so that the concentration of nitrate in the groundwater did not exceed the drinking water standard of 10 mg/L. The oxygen concentration in the injected water was maintained between 35 and 40 mg/L.

- Active pumping of groundwater at this site was stopped in December 1995. Natural attenuation has been allowed to reduce the remaining concentrations of contaminants where possible. In March 1998, the FLTG began adding liquid oxygen in areas where contaminants persisted along with a focused groundwater pumping program. This allowed the site operators to control and monitor the spread of increased dissolved oxygen (DO) levels and to enhance bioremediation.

# TREATMENT SYSTEM DESCRIPTION (CONT.)

## Operating Parameters Affecting Treatment Cost or Performance [16]

Table 3 presents major operating parameters affecting performance.

*Table 3: Performance Parameters*

| Parameter | Value | |
|---|---|---|
| Average Extraction Rate | 189 gpm | |
| Performance Standards (effluent) | TNRCC discharge permit limits for the San Jacinto River | |
| | pH | 6-9 |
| | TSS | 55 mg/L |
| | Benzene | 150 µg/L |
| | Halogenated VOCs | 500 µg/L |
| | Napthalene | 300 µg/L |
| | Arsenic | 150 µg/L |
| | Barium | 1,000 µg/L |
| | Cadmium | 50 µg/L |
| | Chromium | 500 µg/L |
| | Copper | 15 µg/L |
| | Lead | 66 µg/L |
| | Manganese | 300 µg/L |
| | Mercury | 1 µg/L |
| | Nickel | 148 µg/L |
| | Selenium | 20 µg/L |
| | Silver | 5 µg/L |
| | Zinc | 162 µg/L |
| Remedial Goal for Target Compounds (aquifer) | Vinyl Chloride | 2 µg/L |
| | Benzene | 5 µg/L |
| | Toluene | 1,000 µg/L |
| | 1,2-DCA | 100 µg/L |
| | Chloroform | 100 µg/L |

Source: [16]

## Timeline

Table 4 presents a timeline for this remedial project.

*Table 4: Project Timeline*

| Start Date | End Date | Activity |
|---|---|---|
| --- | 1973 | Site closed to receiving wastes |
| 1981 | | Site listed on NPL |
| 1982 | 1987 | EPA and PRP remedial investigations, feasibility studies, and pilot studies conducted |
| 03/87 | --- | ROD signed |
| 03/88 | --- | Amended ROD signed |
| 04/90 | 12/90 | Remedial system designed |
| 1991 | | Construction completed |
| 1989 | --- | First sheetpile floodwall installed around lagoon |
| 01/92 | --- | Site remediation operations begun (operational and functional letter) |
| 01/92 | --- | DNAPL detected in S1 and INT extraction wells |
| 03/93 | 07/93 | Comprehensive DNAPL field study conducted |
| 08/94 | --- | Second sheetpile wall installed to contain DNAPL residue found outside original sheetpile floodwall |
| 12/95 | --- | Active site remediation completed. 10-year timeframe to achieve ground water cleanup criteria through natural attenuation begun. |

# TREATMENT SYSTEM PERFORMANCE

## Cleanup Goals/Standards [20]

The 1988 ROD states: "Groundwater recovery and treatment will continue until modeling shows that a reduction in the concentration of volatile organics to a level which attains the $10^{-6}$ human health criteria (listed in Table 3) at the site boundary can be achieved through natural attenuation in 10 years or less."

## Additional Information on Goals

The aquifer remediation compliance point is the point of first public exposure downgradient from the site (i.e., the first point where someone could install a potable water well in the shallow alluvial aquifer). The PRPs own the site and much of the surrounding property to limit the point of first public exposure. The compliance point is located along Gulf Pump Road toward the Riverdale subdivision.

## Treatment Performance Goals [20]

- The primary goal of the remedial system was plume containment, accompanied by *in situ* bioremediation and source control via sheetpile walls.
- The secondary goal of the P&T system was to reduce effluent contaminant levels to meet TNRCC discharge permit requirements for discharge to the San Jacinto River. Table 3 lists effluent permit requirements.

## Performance Data Assessment [10,13-18, 28]

- A natural attenuation modeling study conducted in late 1995 demonstrated that natural attenuation would reduce groundwater contaminant concentrations below the remedial goals at the site boundaries within 10 years after system shut-off. The October 1, 1995 data were used as starting conditions for the natural attenuation study. Visual MODFLOW and BioTrans were used for modeling purposes. As a result, EPA allowed the groundwater recovery and treatment operations to be shut down in December 1995.
- In May 1994, one well in a downgradient residential subdivision showed levels of vinyl chloride at 7 µg/L. Other wells sampled in the area showed no contaminants above detection limits. No contaminants have been detected in downgradient monitoring wells since May 1994, indicating successful plume contaminant at that time.
- Figure 3 illustrates how contaminant concentrations in the groundwater have changed in the S1 unit. Wells S1-108, S1-109, and S1-111 in the S1 unit (all located outside the floodwall) were used to illustrate the trend. These wells are evenly spaced along the downgradient side of the lagoon. A geometric mean of the data from all three wells was calculated and presented in the figure. The figure shows declining concentrations for benzene, 1,2-DCA, and vinyl chloride from 516 to 0.6 µg/L, 256 to 0.8 µg/L, and 129 to 1.2 µg/L, respectively.
- Figure 4 illustrates how contaminant concentrations in the groundwater have changed in the INT unit. Wells INT-102, INT-104, INT-108, INT-109, and INT-110 in the INT unit (all located outside the floodwall) were used to illustrate the trend. A geometric mean of the data was calculated and presented in Figure 4. The figure shows declining concentrations for benzene, 1,2-DCA, and vinyl chloride from 640 to 2 µg/L, 917 to 1 µg/L and 420 to 1 µg/L, respectively.

## TREATMENT SYSTEM PERFORMANCE (CONT.)

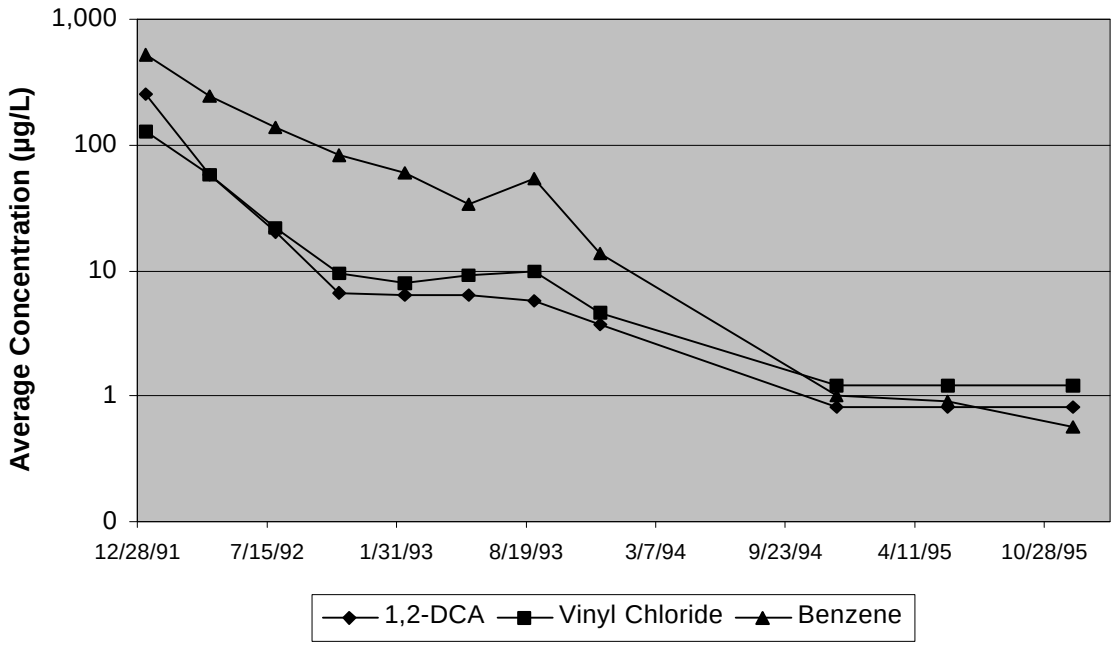


*Figure 3. Average Groundwater Concentrations in S1 Unit (1992 - 1995) [5,28]*

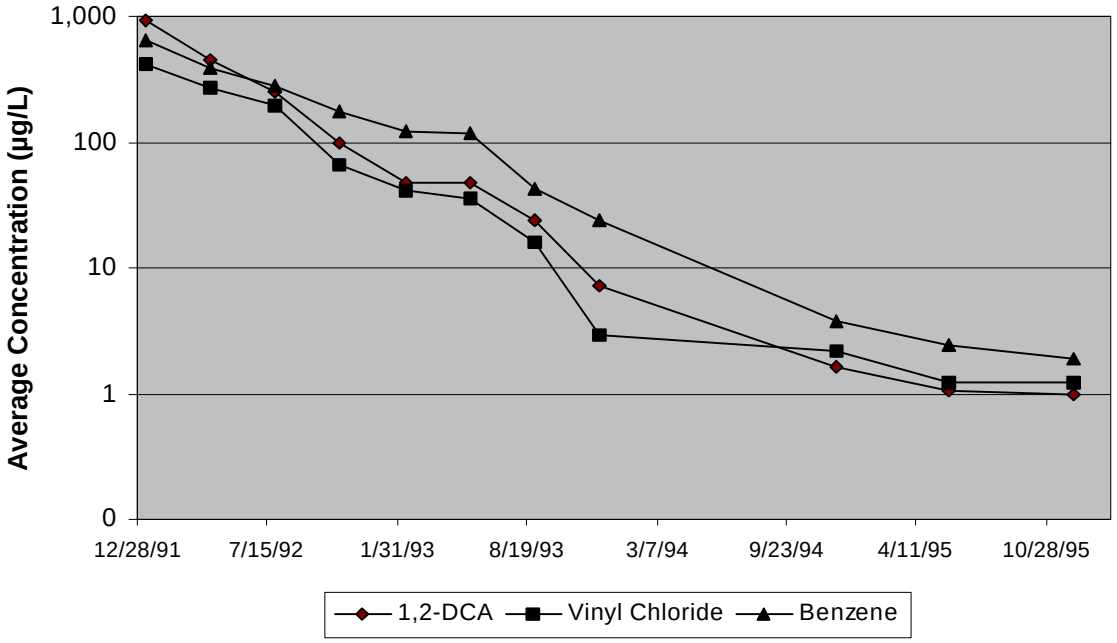


*Figure 4. Average Groundwater Concentrations in INT Unit (1992 - 1995) [5,28]*

# TREATMENT SYSTEM PERFORMANCE (CONT.)

## Performance Data Assessment (Cont.)

- Figure 5 presents the mass flux and cumulative removal of contaminants through the treatment system from 1992 to 1995. Mass flux through the treatment system varied between 170 lbs/day and 735 lbs/day. From 1992 to December 1995, the P&T system removed 517,000 pounds of contaminant mass (measured as TOC) from the groundwater.
- The contaminant removal rate has not followed the expected asymptotic decline as seen in typical P&T applications. Likewise, the cumulative mass removal data have not reached a plateau as seen in typical P&T applications.
- No data were available to quantify the amount of contaminants destroyed through bioremediation.

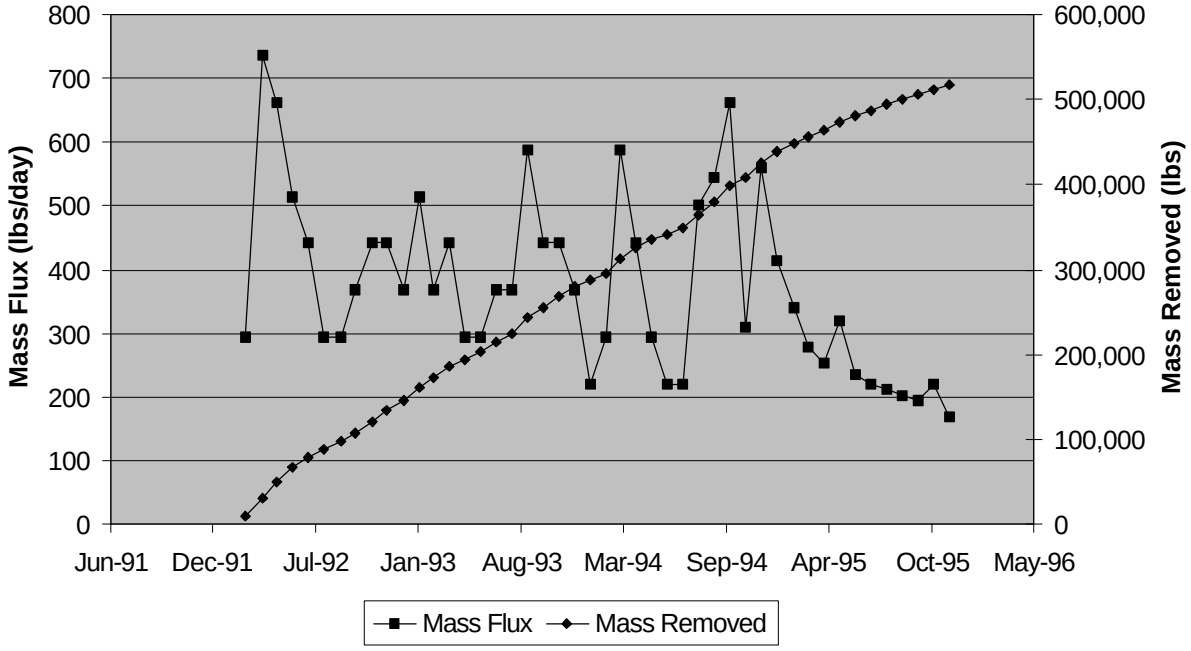


*Figure 5. Mass Flux Rate and Cumulative Contaminant Removal (1992 - 1995) [15,16]*

## Performance Data Completeness

- Monthly data on treatment performance are available in annual groundwater monitoring reports.
- Monthly influent rates to the treatment plant and yearly average total organic carbon (TOC) data were provided by the site contact in a correspondence dated April 20, 1998 [12].
- Data on groundwater concentrations were reported in figures included in the Five Year Review as well as annual groundwater reports [5, 16-18].
- Contaminant mass removal data were provided in annual monitoring reports. Mass removal was calculated with TOC data. Actual TOC composition was not available.

# TREATMENT SYSTEM PERFORMANCE (CONT.)

## Performance Data Quality

The QA/QC program used throughout the remedial action met the EPA and the State of Texas requirements. All monitoring was performed using EPA-approved methods, and the site contact did not note any exceptions to the QA/QC protocols.

# TREATMENT SYSTEM COST

## Procurement Process

FLTG was responsible for the design, construction, and operation of the remedial action at the French Limited site. Oversight was provided by EPA Region 6 and TNRCC. The EPA oversight contractor was CH2M Hill. The design, construction, operation, and maintenance contractors were ENSR, Bechtel, ROG, AHA.

## Cost Analysis

- All costs for investigation, design, construction, and operation of the treatment system at this site were borne by the 76 PRPs that comprise the FLTG. Costs for the two sheet-pile walls are included under capital costs because they are an integral part of containing the groundwater contaminant plume.

### Capital Costs [25]

| | |
|---|---|
| Site Preparation | |
| Sitework Construction | $300,000 |
| Site Facility | $1,250,000 |
| Installation of wells and piping | $3,000,000 |
| Groundwater P&T Facility | $3,500,000 |
| Nutrient Addition Facilities | $100,000 |
| Sheet-pile Floodwall-Lagoon | |
| Construction | $4,000,000 |
| Sheet-pile Wall-DNAPL | |
| Construction | $230,000 |
| DNAPL Response | $507,000 |
| Demobilization | $2,600,000 |
| **Total Capital Cost** | **$15,487,000** |

### Operating Costs [25]

| | |
|---|---|
| Operations and Maintenance | $11,000,000 |
| Admin/Site Management | |
| Project Coordinator | $462,000 |
| Project Manager | $287,500 |
| Project Control | $1,088,000 |
| Security | $364,500 |
| FLTG Tech. Oversight | $5,000,000 |
| **Total Operating Costs (1992-1995)** | **$18,202,000** |

### Other Costs [25]

| | |
|---|---|
| Design | |
| Engineering Design | $700,000 |
| Engineering Design Floodwall | $260,000 |
| Engineering Design Sheetpile Wall | $15,000 |

## Cost Data Quality

Cost data were provided by the site contact. No independent analysis has been performed to provide quality control of cost data.

## OBSERVATIONS AND LESSONS LEARNED

- Actual costs for the P&T and *in situ* bioremediation were $33,689,000 ($15,487,000 in capital costs and $18,202,000 in operating and maintenance costs) corresponding to unit costs of $110 per 1,000 gallons treated and $15 per pound of contaminant removed.
- This site met requirements specified in the ROD that allowed it to shut down the groundwater treatment system within three years of operation. Computer models predict that groundwater concentrations will meet final cleanup criteria by December 2005. Land surrounding the site has been purchased by PRPs to provide a buffer zone until the groundwater concentrations have been reduced to below cleanup criteria.
- The treatment system performance data indicate that approximately 517,000 pounds of contaminants were removed from the groundwater over three years.
- Treatment costs at this site are relatively high. This may be due, in part, to the combined efforts of a P&T system, an *in situ* bioremediation system, and source control measures. Sheet pile walls were constructed around the lagoon and the DNAPL source area at a cost of $4,230,000.
- The ROD for this site included a provision to allow for 10 years of natural attenuation to meet final remedial goals. Groundwater flow and contaminant transport models were relied upon to predict compliance within 10 years after pumping ceased.
- This treatment application was part of a multifaceted cleanup program. The remedial program at this site included source control, *in situ* bioremediation, and P&T. The site contact reported that the combination of cleanup efforts resulted in successful remediation of the site within a reasonable time frame [3].

## REFERENCES


1. Correspondence between Richard Sloan, FLTG Representative, and Lynn Gilbert, Dyncorp, Inc., September 1, 1994.
2. French Buy-Out Proposal, March 12, 1996.
3. Correspondence between Richard Sloan, FLTG Representative, and David Boram, ERG, June 25, 1997.
4. Site Remediation Report, FLTG, Inc. January 16, 1995.
5. Five Year Review, CH2M Hill, January 26, 1995.
6. EPA Fact Sheet, French Ltd., November 5, 1997.
7. Cost and Performance Report, Slurry-Phase Bioremediation at the French Limited Superfund Site, U.S. EPA, March 1995.
8. FLTG Memo, “Aquifer Remediation Review, December 10-11, 1992," January 18, 1993.
9. FLTG Memo, “Pulse Pumping Plan,” October 8, 1993.
10. Natural Attenuation Modeling Report, Applied Hydrology Associates, December 1995.
11. Hydraulic Characterization of a Superfund Site: Remedial Investigation Through Remedial Action, O’Hayre A.P., April 1993, Proceedings of the Georgia Water Resources Conference, April 20-21, 1993.
12. Correspondence between Richard Sloan, FLTG Representative, and Charlie Carter, ERG, April 20, 1998.
13. Evaluation of Stratigraphic Controls on DNAPL Migration, Applied Hydrology Associates, September 1995.
14. Monthly Progress Report, FLTG, Inc., December 1994.

## REFERENCES (CONT.)


15. Monthly Progress Report, FLTG, Inc., July 1994.

16. Annual Groundwater Monitoring Report, December 1994, FLTG, Inc., March 1995.

17. Annual Groundwater Monitoring Report, December 1993, FLTG, Inc., March 1994.

18. Annual Groundwater Monitoring Report December 1992, FLTG, Inc. March 1993.

19. "*In situ* Bioremediation of Groundwater and Subsoils at the French Limited Site, Texas," Biotreatment News.

20. "Remediation Facilities Design Report," ENSR Consulting and Engineering, June 1991.

21. *In situ* Bioremediation at the French Limited Site, Woodward R., IGT Symposium December 11-13, 1989.

22. "French Limited: A Successful Approach to Bioremediation," Biotreatment News, December 1992.

23. "Reverse Osmosis Reverses Conventional Wisdom with Superfund Cleanup Success," Mark Collins and Ken Miller, Wastewater Management, September 1994.

24. Correspondence between Richard Sloan, FLTG Representative, and Charlie Carter, ERG, April 1, 1998.

25. Correspondence between Will Schorp, FLTG Representative and Charlie Carter, ERG, April 8, 1998.

26. U.S. Environmental Protection Agency, Record of Decision, March 24, 1988.

27. Evaluation of Subsurface Engineered Barriers at Waste Sites, U.S. EPA/OERR, September 30, 1998.

28. 1995 Annual Aquifer Sampling Report, FLTG, Inc., March 1996


**Analysis Preparation**

This case study was prepared for the U.S. Environmental Protection Agency's Office of Solid Waste and Emergency Response, Technology Innovation Office. Assistance was provided by Eastern Research Group, Inc. and Tetra Tech EM Inc. under EPA Contract No. 68-W4-0004.