Case Study Abstract

Petroleum Product Recovery and Contaminated Groundwater Remediation, Amoco Petroleum Pipeline Constantine, Michigan

Site Name: Amoco Petroleum Pipeline	**Contaminants:** Benzene, Toluene, Ethylbenzene, Xylenes (BTEX), Methyl tert butyl ether (MTBE) - An estimated 300,000 to 2 million gallons of gasoline, fuel oil, and kerosene released to subsurface - Free product present in an approximate 6-acre area at an average apparent thickness of 2 feet	**Period of Operation:** Status: Ongoing Report covers - 10/88 to 6/94
Location: Constantine, Michigan		**Cleanup Type:** Full-scale cleanup (interim results)
Vendor: Residuals Management Technology, Inc.	**Technology:** Groundwater Extraction followed by Granular Activated Carbon (GAC); In situ Air Sparging of saturated zone Groundwater Extraction With GAC - 4 extraction wells installed in two phases (1988 and 1992); depths up to 28 feet below ground surface (bgs) with extraction rates of 50 and 100 gpm - Extracted water treated using two GAC vessels in series; recovered free product sent to storage in aboveground tanks In-situ Air Sparging - 30 two-inch diameter air sparging wells with 3-foot screens - Installed to depths of 25-30 feet - Two 300 scfm blowers	**Cleanup Authority:** Other: Voluntary cleanup
SIC Code: 4612 (crude petroleum piping)		**Point of Contact:** Paul Ressmeyer Remedial Project Manager Amoco Corporation
Waste Source: Other: Petroleum pipeline leak		
Purpose/Significance of Application: Full-scale pump and treat of petroleum contaminated-groundwater using granular activated carbon to recover free product and treat groundwater. In situ air sparging was subsequently added to treat the saturated zone.	**Type/Quantity of Media Treated:** Groundwater - 775 million gallons of groundwater between 1988 and 1993 - Sand and gravel - Porosity 30-40% - Hydraulic conductivity 0.0002 - 0.0004 cm/sec	
Regulatory Requirements/Cleanup Goals: - The remediation is being performed as a voluntary action by Amoco; final cleanup criteria will be established in the future with concurrence from the Michigan Department of Natural Resources - Treated water required to meet SPDES permit requirements prior to discharge - benzene (5 µg/L), total BTEX (20 µg/L), MTBE (380 µg/L), pH (6.5-9.0)		

Case Study Abstract

Petroleum Product Recovery and Contaminated Groundwater Remediation, Amoco Petroleum Pipeline Constantine, Michigan (Continued)

Results:

Groundwater Extraction with GAC

- 118,000 gallons of free product recovered (10/87-12/93); rate of free product recovery has decreased to 20 to 25 gallons per month as of late 1993
- Free product has been hydraulically contained and observed apparent thickness of free product has been reduced to <0.01 feet
- Concentrations of BTEX in extracted groundwater have remained relatively constant; MTBE concentrations have decreased
- Treated effluent from GAC have generally met SPDES discharge limits

In-situ Air Sparging

- Pilot testing indicated a radius of influence of 65-150 feet per single well
- No additional results were available at the time of this report

Cost Factors:

- Total Capital Costs: about $297,000 for groundwater recovery and treatment system (including well construction, pumps, system installation, engineering); $375,000 for the air sparging system (including 3 months of initial operations, and testing)
- Annual Operating Costs (approximate): about $475,000 for groundwater recovery and treatment system; not yet defined for air sparging system
- An estimated total cost for completing the cleanup is not available at this time

Description:

The Amoco Corporation owns and operates a liquid petroleum product pipeline that transverses the Constantine site. As a result of a pipeline leak, discovered in June 1987, an estimated 350,000 to 2 million gallons of gasoline, fuel oil, and kerosene were released to the subsurface. Free product was present at an average apparent thickness of 2 feet. Beginning in October 1988, a groundwater pump and treat system, consisting of 4 extraction wells and granular activated carbon (GAC) vessels, was used to recover free product and treat the contaminated groundwater. In situ air sparging of the saturated zone was subsequently added and began operating in February 1994.

Through December 1993, groundwater extraction with GAC had recovered an estimated 118,000 lbs of free product and reduced the observed apparent thickness of the free product layer to <0.01 feet. MTBE concentrations were reduced; however, BTEX concentrations near the source of contamination remained relatively constant. No full-scale performance data were available for the air sparging system at the time of this report.

The groundwater extraction with GAC system operated > 95% of the time through December 1993. Periodic shutdowns of 1 to 3 days were required for carbon changeout and extraction well rehabilitation. Leasing the activated carbon system and carbon provided flexibility to modify the treatment system in response to changing operating conditions. However, GAC proved to be inefficient in removing MTBE when compared to BTEX.

TECHNOLOGY APPLICATION ANALYSIS

SITE

Amoco Petroleum Pipeline
A Voluntary Cleanup
Constantine, Michigan
(Constantine Site)

TECHNOLOGY APPLICATION

This analysis covers an effort to **hydraulically contain and recover free product as well as pump and treat groundwater** using **granular activated carbon (GAC)** at a site contaminated with **petroleum products.** Recovery and treatment began in 1988 and is ongoing. **In-situ air sparging** was initiated in February 1994 to enhance groundwater restoration.

SITE CHARACTERISTICS

Site History/Release Characteristics

- A liquid petroleum product pipeline owned and operated by Amoco Corporation transverses the Constantine site from northeast to southwest. A leaking gasket associated with a central valve station for the pipeline was discovered in June 1987. Approximately 350,000 to 2 million gallons of gasoline, fuel oil and/or kerosene were released to the subsurface as a result of the leak.

- The leak was immediately repaired. Subsurface investigations to define the nature and extent of free product and groundwater contamination were initiated in July 1987. Manual recovery of free product from monitoring wells was initiated in November 1987.

- An interim free product and ground-water recovery and treatment system commenced operation in October 1988. The interim system was still in operation as of May 1994. In-situ air sparging of the saturated zone began in February 1994.

Contaminants of Concern

Contaminants of Concern used to track the progress of groundwater remediation are:

Benzene
Toluene
Ethylbenzene
Xylenes
} (known as BTEX)
Methyl tert butyl ether (MTBE)

Free petroleum product, the source of the contaminants identified above, was also present.

Contaminant Properties

Properties of contaminants focused upon during remediation are:

Properties*	Units	B	T	E	X	MTBE
Chemical Formula	-	C_6H_6	$C_6H_5CH_3$	$C_6H_5C_2H_5$	$C_6H_4(CH_3)_2$	$C_5H_{12}O$
Specific Gravity	-	0.88	0.87	0.87	0.86-0.88	0.74
Vapor Pressure	mm Hg	95.2	28.1	7	10	245
Water Solubility	mg/l	1,750	536	152	198	48,000
Octanol -Water Partition Coefficient: K_{ow}	-	132	537	1,100	1,830	1.05
Organic Carbon Partition Coefficient: K_{oc}	-	83	300	1,410	240	-

* *Properties at 20 °C.*

Nature & Extent of Contamination

- Characterization of the nature and extent of contamination at the Constantine site focused on free petroleum product and petroleum hydrocarbons dissolved in groundwater. The initial characterization (completed in October 1987) indicated free product was present over an approximate 6 acre area in the vicinity of the valve station, at an average apparent thickness of 2 feet.

- Petroleum hydrocarbons dissolved in groundwater were detected in the vicinity of the free product and to the west and southwest (downgradient) in October 1987. In the spring of 1991, quarterly monitoring data indicated that some dissolved BTEX and MTBE had migrated downgradient beyond the influence of the interim recovery well network, and were entering a drainage ditch.

Contaminant Locations and Geologic Profiles

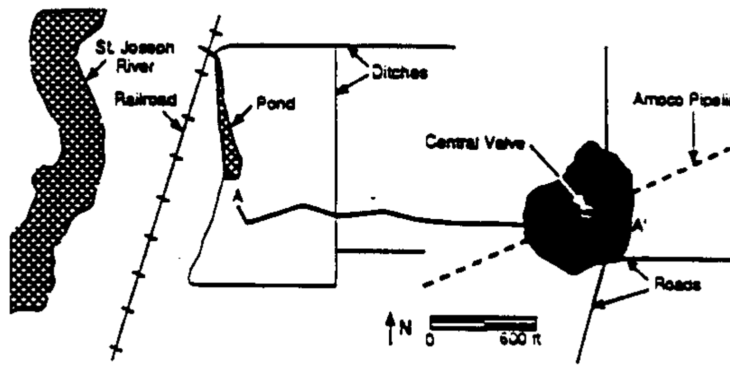
Remedial investigation field activities at the site have included:

- Borings and subsurface sampling
- Monitoring well installation and groundwater sampling
- Groundwater level measurements
- Apparent product thickness measurements
- Hydropunch™ groundwater sampling
- Well permeability and pump testing
- Surface water sampling and water level measurements

Data from some of these efforts have been included here to provide a conceptual understanding of site conditions.

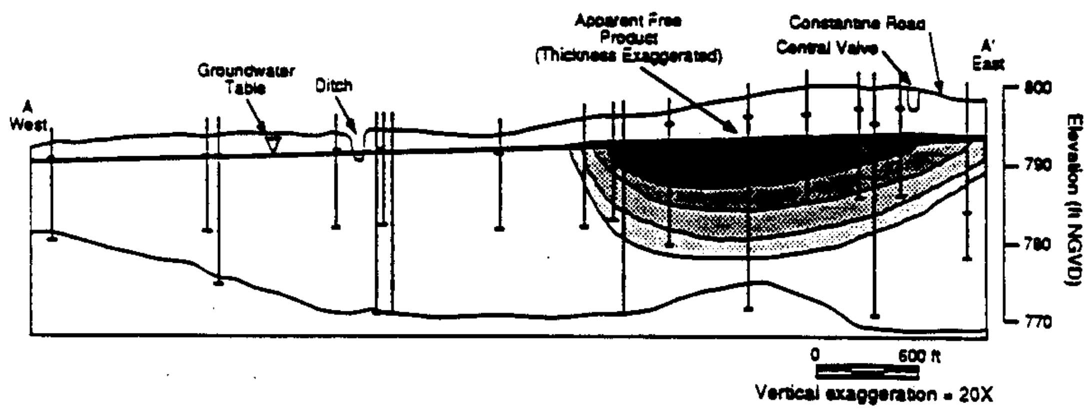
Initial Extent of Free Petroleum Product (Plan View)

Data from October 1987



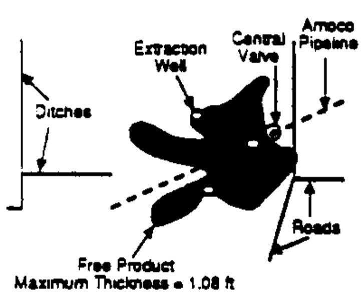
Extent of Free Product and Dissolved BTEX in Groundwater (Cross-Section)

Groundwater monitoring data from 1990 along cross-section A-A' shown in plan view.



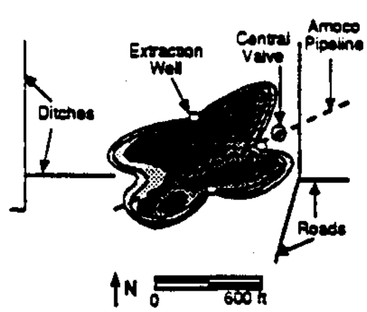
Extent of Free Product (Plan View)

Groundwater monitoring data from1990.



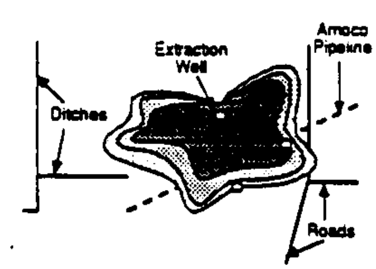
Extent of Dissolved BTEX in Groundwater (Plan View)

Groundwater monitoring data from1990.



Extent of Dissolved MBTE in Groundwater (Plan View)

Groundwater monitoring data from1990.



Legend

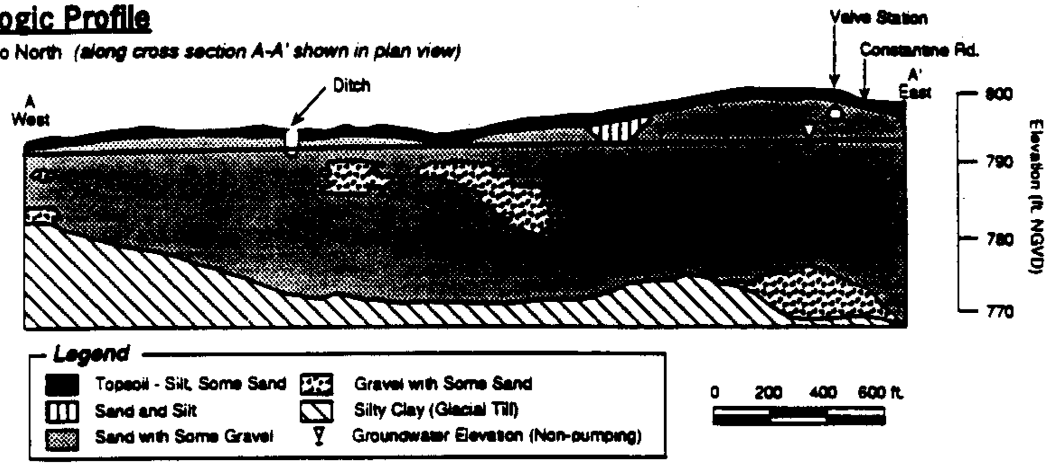
all concentrations in ppb

- 10-100 ppb
- 100-1,000 ppb
- 1,000-10,000 ppb
- >10,000 ppb
- Free Product

Contaminant Locations and Geologic Profiles (Continued)

Geologic Profile

View To North *(along cross section A-A' shown in plan view)*



Site Conditions

- Topography of the Constantine site is relatively flat, ranging from ~ 800 ft. N.G.V.D. near the pipeline's central valve station to ~ 788 ft. N.G.V.D. at the St. Joseph River, located ~ 3,000 ft. west of the central valve station.
- Groundwater flow from the site is generally to the west and southwest, discharging to drainage ditches, a pond, and ultimately the St. Joseph River. The water table in the shallow sand and gravel unit is 2 to 10 ft. below ground surface.
- Site stratigraphy is relatively straight forward. Approximately 10 to 29 ft. of interbedded sand and gravel overlies a silty clay glacial till unit. Cobble-size sediments and sandy silt deposits were also occasionally encountered.

Key Aquifer Characteristics

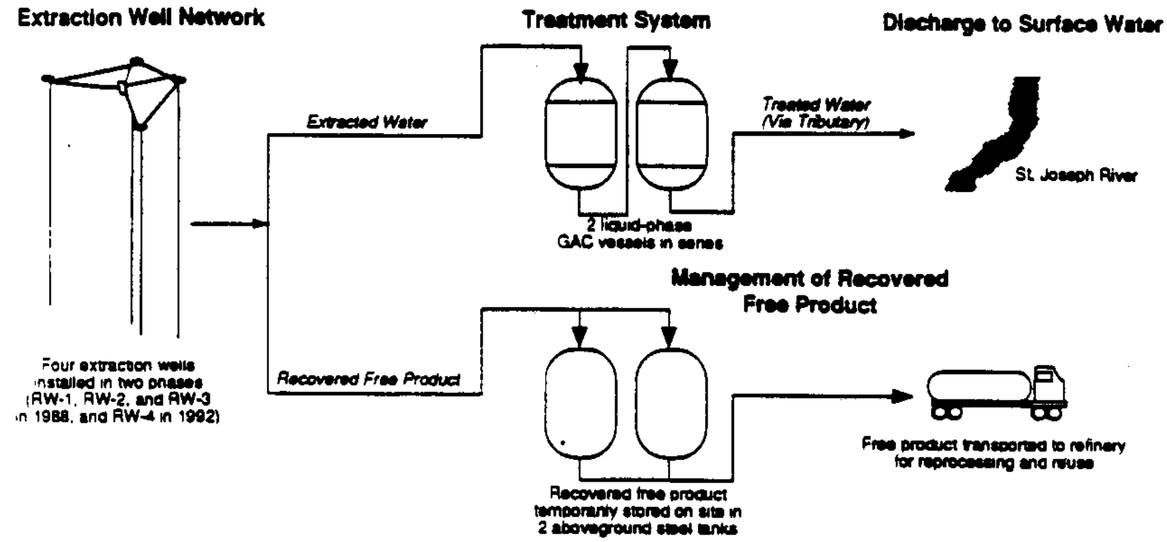
Aquifer parameters for the shallow sand and gravel unit at the Constantine site have been estimated as:

Property	Units	Range	Property	Units	Range
Soil Porosity	%	30 - 40	Dissolved O_2 (in plume)	mg/l	0.8
Particle Density	g/cm^3	2.65 - 2.70	Dissolved O_2 (background)	mg/l	7.8
			Total Phosphorous	mg/l	0.029 - 2.15
Bulk Density	g/cm^3	1.8 - 2.2	Nitrate-N	mg/l	3.6 - 13
Particle Diameter	mm	0.9 - 4.5	Nitrite-N	mg/l	0.001 - 0.005
Organic Content	%	0.8	Kjeldahl-N	mg/l	0.28 - 1.1
Permeability	cm^2	2E-9 to 4E-9	Ammonia-N	mg/l	<0.02 - 0.08
Hydraulic Conductivity	cm/s	2E-4 to 4E-4	Calcium	mg/l	30 - 46
Static Hydraulic Gradient	ft/ft	0.0018	Total Alkalinity	mg/l	139 - 154
			Hardness (as $CaCO_3$)	mg/l	150 - 450
Groundwater Flow Velocity (Avg.)	ft/yr	500	pH	-	6.96 - 7.08
			Iron	mg/l	<0.02 - 0.82
Rainfall Infiltration	cm/day	0.07	Manganese	mg/l	<0.01
Microbial Plate Counts	CFU/g	2.2E4 to 4.1E5	Magnesium	mg/l	5.68 - 10.4

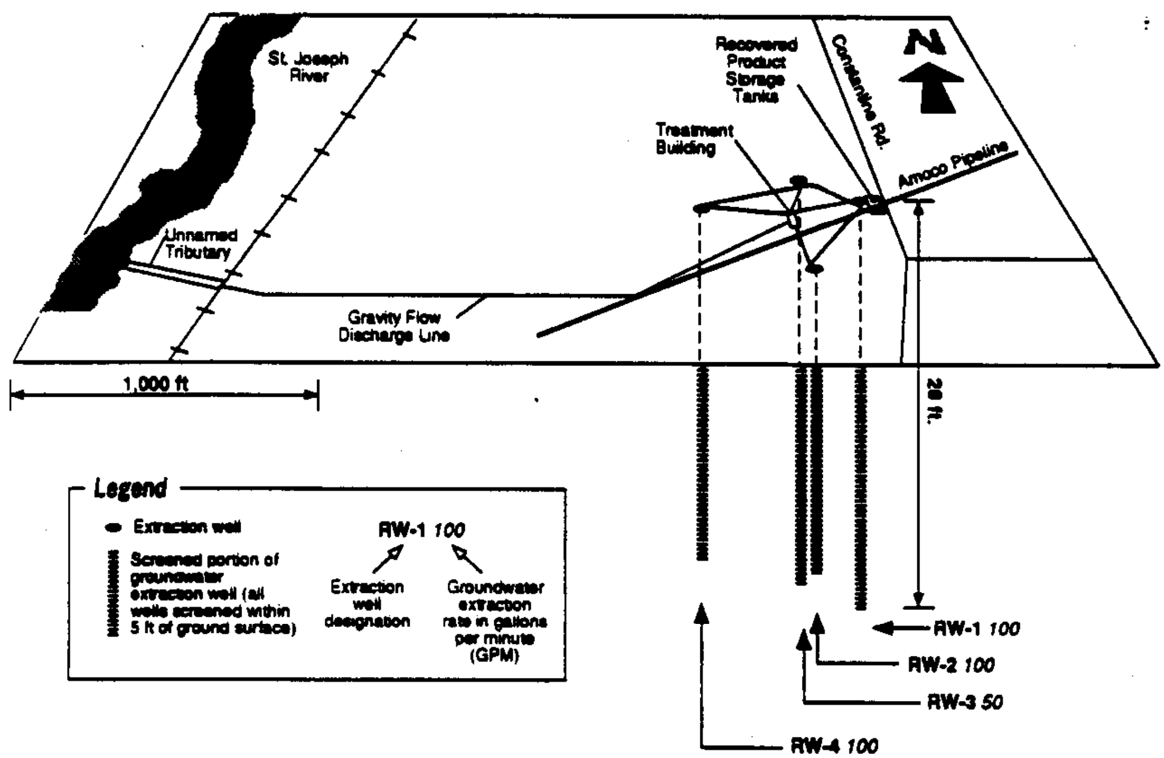
- Unconfined groundwater conditions exist at the Constantine site.
- The presence of a substantial number hydrocarbon-degrading micro-organisms within the dissolved hydrocarbon plume, the difference in dissolved O_2 concentrations in groundwater outside versus within the dissolved hydrocarbon plume, and the sharp decrease in BTEX concentrations at the downgradient edge of the dissolved hydrocarbon plume indicate that natural (intrinsic) bioremediation of the BTEX dissolved in groundwater is occurring.

REMEDIATION SYSTEM

Overall Process Schematic

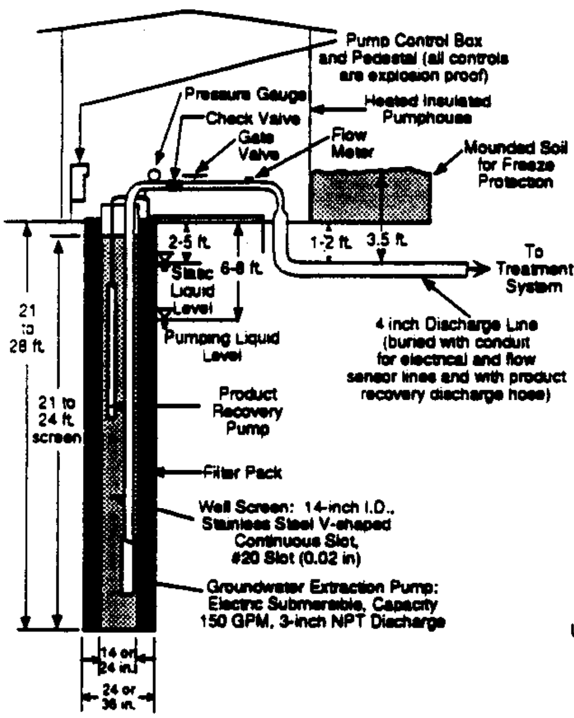


Extraction Well Network



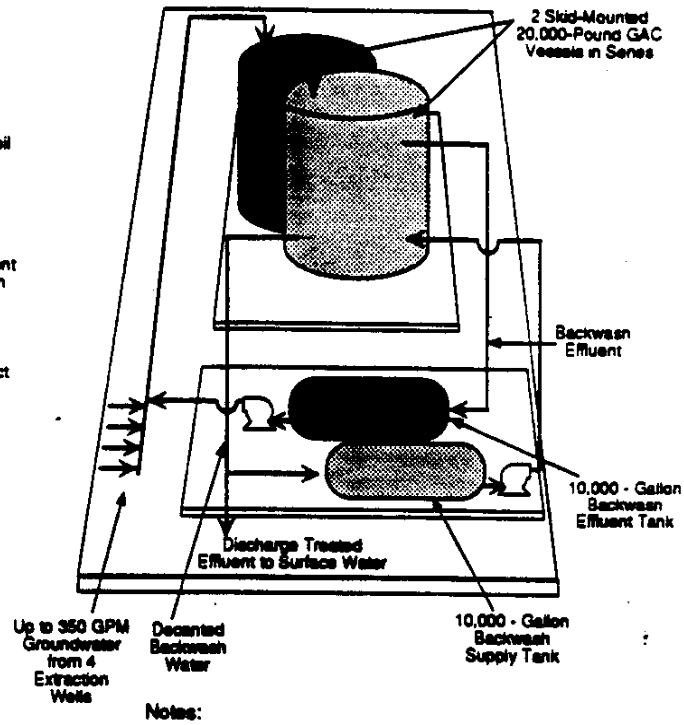
Extraction Well Detail

Typical Extraction Well



Notes: Extraction well RW-4 not equipped with product recovery pump.
All extraction wells developed by surging and pumping.

Treatment System Schematic



Notes:

1) Piping configured to allow use of either carbon vessel as primary absorber and backwashing of both carbon vessels.

2) Free product piped from extraction wells to 2-5,000 gallon storage tanks located remote from treatment system building.

Key Design Criteria

- Hydraulic containment of free product and dissolved-phase contamination.
- Recovery of water and free product using two-pump system to avoid emulsifying water/oil.
- Handle range of flow rates to allow for operational flexibility.
- Maximize efficiency of activated carbon to remove BTEX from extracted groundwater.
- Automated treatment system monitoring and shutdown.

Key Monitored Operating Parameters

- Water flows
- Pump discharge pressures
- Carbon bed pressures
- Automated processes

(to assess system operation)

- Groundwater levels

(to assess capture zone)

- Contaminant concentrations in treatment system influent & effluent

(to assess treatment system effectiveness)

- Apparent free product thickness and contaminant concentrations in groundwater

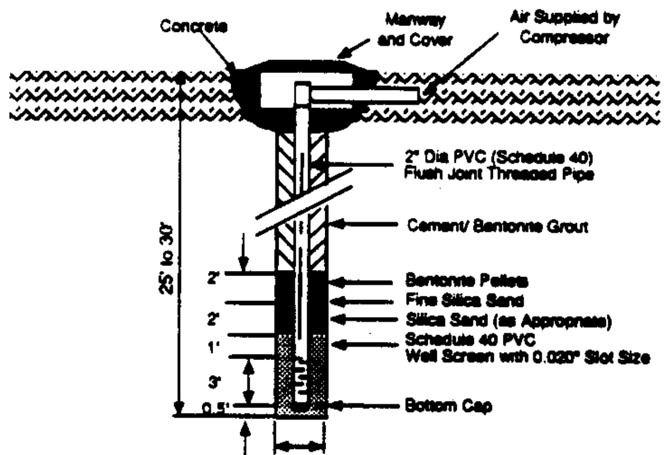
(to assess remediation progress)

In-situ Sparging System

• The in-situ sparging system consists of 30 two-inch diameter air sparging wells within a 3-foot long screened section installed into a depth of approximately 25 to 30 feet, two 300 scfm blowers housed within the groundwater treatment shed, and buried manifold connecting the blowers and sparging wells.

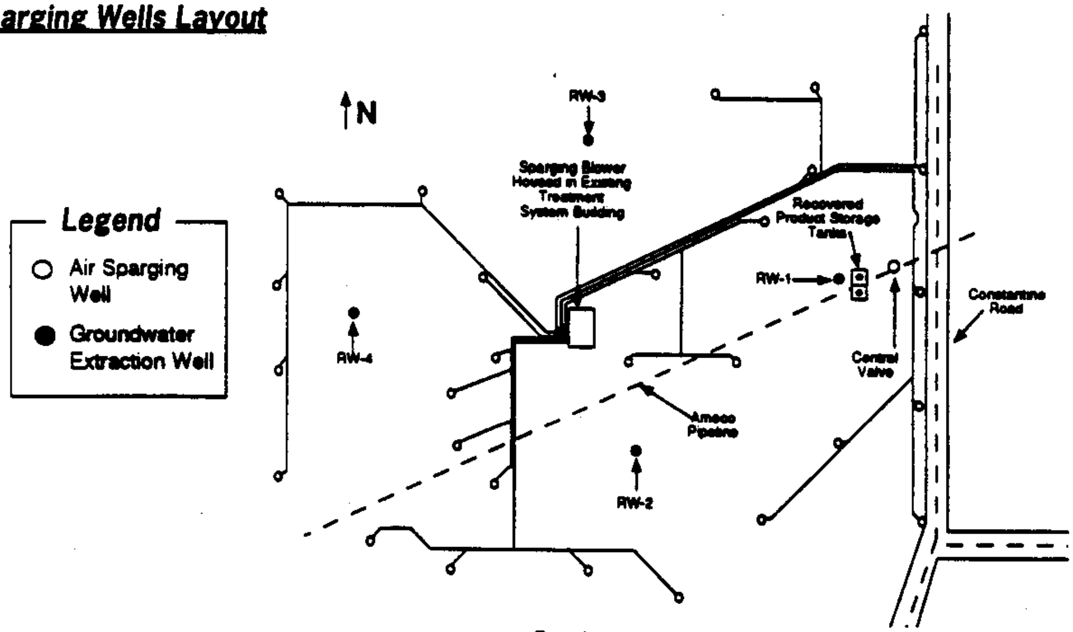
• Sparging will be performed at an air flow rate of between ~10 and 30 scfm and a pressure of 12 pounds per square inch at each well.

Typical Sparging Well



Drawing not to scale

Sparging Wells Layout



Drawing not to scale

PERFORMANCE

Performance Objectives

- Prevent migration of free petroleum product and petroleum constituents dissolved in groundwater.
- Recover free petroleum product.
- Reduce concentrations of petroleum hydrocarbons dissolved in groundwater.

Remedial Action Plan

Remediation at the Constantine site is being implemented in a phased manner:

1987/ 1988 Installation and operation of interim free product and groundwater recovery and treatment system based on results of preliminary investigation.

↓

1988 - 1992 Subsequent extraction and treatment system modifications/enhancements based on comprehensive investigation results.

↓

Initiated 1994 In-situ saturated zone air sparging to enhance natural volatilization and bioremediation.

Overall Performance Summary

Conclusions drawn after 5 (plus) years of operating the interim free product and groundwater recovery and treatment system are summarized below:

- Successful hydraulic containment and substantial recovery of observed free-phase petroleum product was achieved.
- Substantial hydraulic containment of petroleum constituents dissolved in groundwater was achieved near the release source.
- A portion of the dissolved phase contamination migrated beyond the capture zone of 3 extraction wells. A fourth extraction well installed in 1992 was apparently effective in limiting additional migration of dissolved-phase constituents from near the source area.
- The concentration of BTEX in extracted groundwater did not decrease substantially due to continued solubilization of hydrocarbons from free product and residual soil contamination. Substantial decreases of MTBE in extracted groundwater occurred during the same period.
- Concentrations of petroleum constituents in treated effluent have met State Pollution Discharge Elimination System (SPDES) discharge limits with minor exceptions.

Operational Performance

Volume and Rate of Water Pumped

- From Oct. 1988 through Dec. 1993 approximately 800 million gallons of groundwater was pumped from 3 to 4 extraction wells; average daily flows were maintained below the SPDES permit limit of 350 GPM.
- During this period, suspended solids loading on the GAC system limited flow rates to a (project) average rate of approximately 315 GPM.

System Downtime

- The treatment system has operated 95% (plus) of the time between Oct. 1988 through Dec. 1993. Periodic shutdowns of 1 to 3 days occur for carbon changeout and extraction well rehabilitation. Additional downtime was experienced for equipment modification and replacement.
- A 10-day shutdown in early July 1991 was caused by the delivery of contaminated GAC by a carbon vendor.

Volume and Rate of Free Product Recovered

- From Oct. 1987 through Dec. 1993, approximately 118,000 gallons of free product had been recovered.
- The rate of free product recovery plateaued in late 1990. Free product recovery rates had decreased to approximately 20 to 25 gallons per month by late 1993.

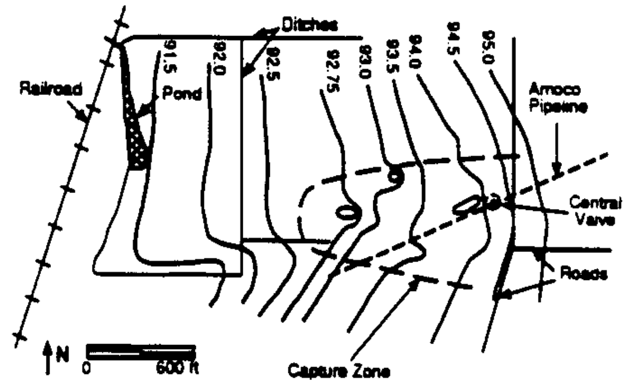
Hydrodynamic Performance

• The capture zone created by the extraction well network provides for substantial hydraulic containment of petroleum constituents dissolved in groundwater.

• The capture zone does not allow for recovery of dissolved petroleum constituents near the surface ditches. This downgradient contamination probably resulted from periodic decreased pumping rates caused by plugging of extraction wells with biomass and oxidized inorganics.

Groundwater Elevations and Zone of Capture

Data from October, 1993.



Remediation System Performance

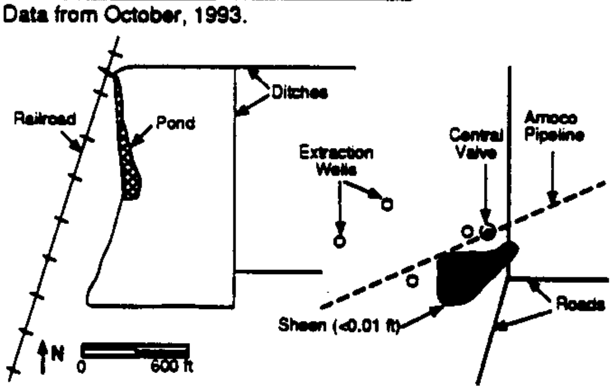
Effect on Free Product

• The recovery system has hydraulically contained free petroleum product and has reduced the observed apparent product thickness to a sheen (<0.01 feet).

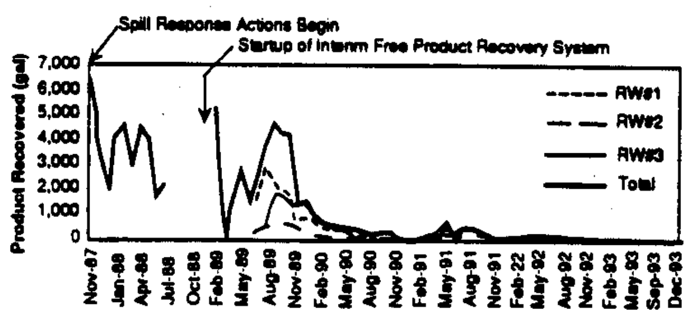
• Product recovery rates plateaued in late 1990. Free product recovery rates had decreased to approximately 20-25 gallons/month by October 1993.

Apparent Free Product Thickness

Data from October, 1993.



Product Recovery Per Month



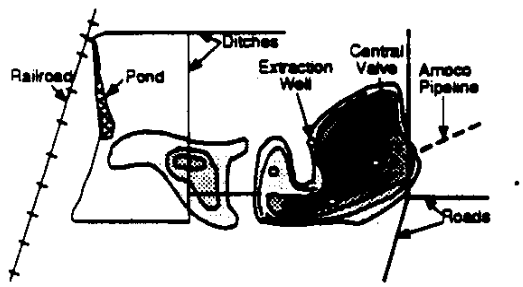
Remediation System Performance (Continued)

Effects on Dissolved Constituents in Groundwater

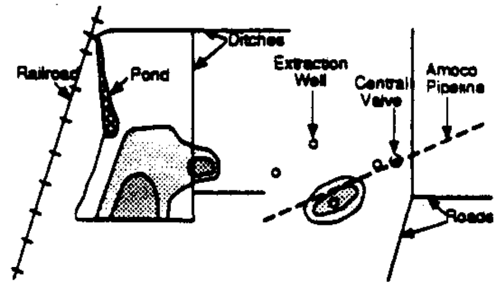
• Concentrations of BTEX in groundwater within the capture zone have remained relatively constant since initiating remediation. Increasing concentrations of BTEX in groundwater was observed downgradient from the capture zone in 1990.

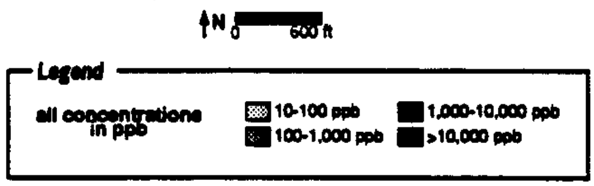
• Concentrations of MTBE in groundwater decreased more rapidly than BTEX in the capture zone area. MBTE also migrated downgradient of the capture zone more rapidly than BTEX .

BTEX in Groundwater
Data from October, 1993.



MTBE Groundwater
Data from October, 1993.





Treatment Equipment Performance

• The treatment system was modified late in 1991 because of operational limitations caused by suspended solids clogging of bag filters and carbon vessels. Two parallel sets of 10,000 - pound carbon vessels were replaced with one pair of 20,000 - pound carbon vessels (in series). A manual water and air backwash system was also installed to extend carbon life and allow ground-water extraction rates to be maintained. The bag filters were eliminated in late 1992.

• Except for occasional excursions of discharge limits caused by operator error and delivery of contaminated carbon during the initial stages of remediation, the GAC treatment system has achieved a 99% (plus) removal rate for BTEX. Removal efficiencies for MTBE have been highly variable, depending on the frequency of carbon replacement. MTBE influent and effluent concentrations have remained well below the discharge limit since being instituted in 1993.

Sparging Wells Performance

• Pilot testing indicated a radius of influence of 65 to 150 feet for single sparging wells based on measured rise in groundwater levels and initial dissolved oxygen increases in groundwater up to 25 feet from the sparging wells. Close monitoring of the sparging system is planned to determine actual remedial performance and ensure continued hydraulic containment of petroleum hydrocarbons dissolved in groundwater using the existing groundwater extraction system.

COST

• The interim free product and groundwater recovery and treatment system was designed and constructed in 1987-1988. The treatment system was modified and an additional extraction well was put into service in 1992. Leasing of the activated carbon vessels and activated carbon (with purchase option) provided the flexibility to adjust to changing operating conditions, resulting in increased operating efficiency and cost effectiveness. Approximate capital and operating costs are provided below.

• During 1988 - 1993, the average volume of water treated by the interim groundwater pump and treat system was approximately 155 million gallons per year. The total cost of operation and maintenance is ~ **$0.003 per 1,000 gallons treated.**

Capital Costs

Construction of Wells (4 extraction)	$ 32,000
Groundwater and Product Recovery Pumps	30,000
Trenches/Piping and Well Houses	10,000
Treatment System Installation	40,000
Treatment System Controls	10,000
Building, HVAC, Utility Service	53,000
Access Road	2,000
Recovered Product Storage Tanks, Diked	20,000
Engineering (excluding site characterization & other studies)	100,000
Total Capital Cost	**~$ 297,000**

Annual Operating Costs

The total annual operation and maintenance cost (excluding laboratory analysis of groundwater samples) is ~**$475,000**. This cost includes:

- **Carbon System Rental**
- **Carbon Changeout, Transport & Regeneration**
- **Electrical Power**
- **Equipment, Repair and Replacement**
- **Laboratory Analysis for Influent/Effluent**
- **Transport of Recovered Product**
- **O&M Labor**
- **Engineering Support**

An **in-situ sparging system** was installed in late 1993/early 1994 to further reduce the concentration of saturated zone petroleum hydrocarbons. The total capital cost for the sparging system was $375,000, including 3 months of initial operations and testing. Operating costs sparging system have not yet been defined.

Notes: All costs presented are approximate. Costs for Amoco project management are not included.

REGULATORY/INSTITUTIONAL ISSUES

• The Constantine site remediation is being performed as a voluntary action by Amoco. Final cleanup criteria for the site will be established in the future with the concurrence from the Michigan Department of Natural Resources (MDNR).

• The interim product and groundwater recovery and treatment system was designed in 1987 but was not installed until 1988 due to administrative delays in obtaining the SPDES permit.

• Treated water is discharged under the authority of a SPDES permit issued by the MDNR. The initial SPDES permit was issued in 1987 and modified in 1989. The current SPDES permit was issued in in 1993. Discharge limits are summarized below:

	1987/1989 Permit		1993 Permit
Compounds	Monthly Average	Daily Maximum	Monthly Maximum
Benzene	51	-	5
Toluene	100	-	-
Ethylbenzene	62	-	-
Xylenes	40	-	-
Total BTX	-	20	-
Total BTEX	-	-	20
MTBE	-	-	380
pH	-	-	6.5 - 9.0

Note: All units in ug/l (except pH).

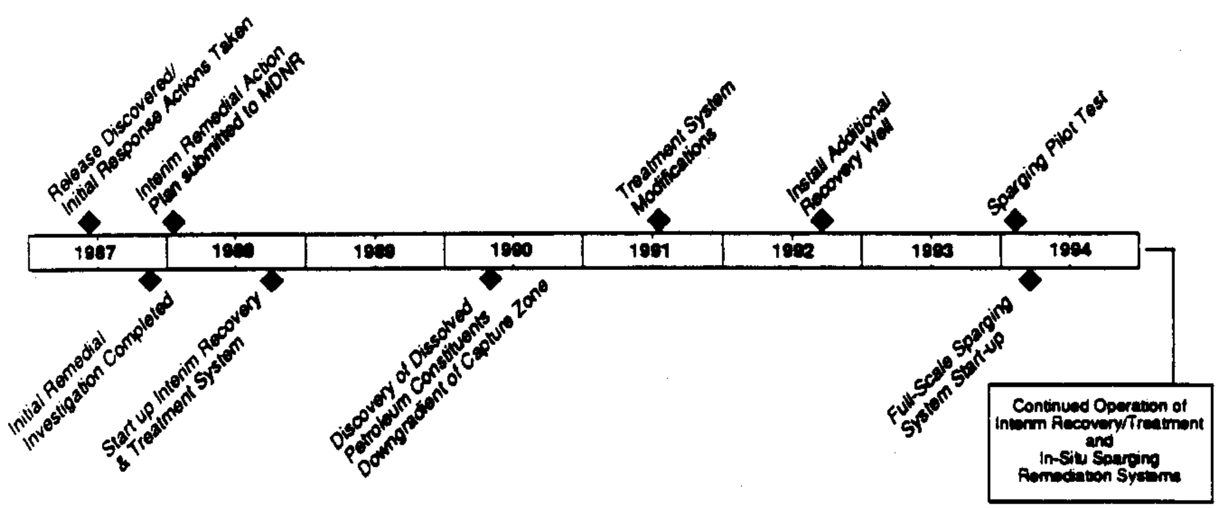
• Air permits were not required by the MDNR for the air sparging system.

• Petroleum constituents in groundwater led to the installation of point-of-use drinking water treatment systems for two residences. A positive pressure ventilation system was installed to prevent petroleum vapors from entering the basement of one of the residences.

• New water supply wells were installed for a nearby farmer. The wells replaced the pond downgradient of the Constantine site as a source for agricultural irrigation water.

SCHEDULE

Major Milestones



LESSONS LEARNED

Implementation Considerations

• An understanding of the extent of contamination at this site evolved over a period of 5 years of investigation, monitoring, and remediation. Defining the extent of contamination was focused on determining the need for remediation in specific areas of the site, selecting and designing remedies, and evaluating the effectiveness of implemented actions.

• Initiating an interim remedial action provided for hydraulic containment and recovery of free-phase petroleum product and containment of a substantial portion of petroleum constituents dissolved in groundwater while the full extent of contamination and supplemental remedial actions were defined.

• Although the interim system operated a high percentage of the time, downtime and low flow rates caused by operating problems resulted in a partial loss of full hydraulic containment of the dissolved - phase contamination.

• Leasing the activated carbon system and carbon provided the flexibility to modify the treatment system in response to changing operating conditions and supplier performance.

Technology Limitations

• Regular treatment of recovery wells to remove solids buildup on intake screens and pump intakes (redevelopment and chemical treatment) is required to maintain adequate capture zone(s) at the Constantine site.

• Olephyllic/hydrophobic filter-skimmers were initially used to recover free product. Frequent maintenance was required due to solids buildup, and they were eventually replaced with free product recovery pumps.

• Paddle wheel-type flow sensors are less than ideal for this site due to in-line solids buildup.

• Carbon system operation is hydraulically limited by solids build-up. Laboratory analysis indicated the reddish/brown solids causing the fouling was mainly biomass (primarily aerobic iron and slime forming bacteria) bound with inorganic matter (iron, silica, sulfur, aluminum and calcium). Daily backwashing of the carbon vessels is required to maintain flow adequate for sustaining hydraulic containment.

• Activated carbon efficiency is limited by suspended solids buildup. Bag filters have only been partially successful in controlling the suspended solids loading to the carbon adsorbers. New methods to control influent solids are regularly evaluated.

• Granular activated carbon is inefficient in removing MTBE as compared to BTEX. An engineering analysis performed subsequent to installing the interim remediation system indicated that air stripping followed by aqueous phase activated carbon may be a more cost-effective technique for treating water with elevated MTBE concentrations.

• BTEX concentrations in groundwater near the source of contamination did not decrease substantially over a 5 (plus) year period. Pump and treat systems appear limited in their ability to restore groundwater quality due to ongoing solubilization of constituents from free product and residual contamination in saturated zone soils.

Future Technology Selection Considerations

• A phased approach to investigation and remediation at this site was beneficial. Early action to control contaminant migration in groundwater, when properly designed and implemented, can reduce the extent, duration and cost of clean up.

• The Constantine site SPDES permit restricted the volume of groundwater that could be extracted and treated, limiting the ability to modify system operation to expand the capture zone. Discharge permits for groundwater treatment systems should provide for sufficient capacity to accommodate modest increases in flow to achieve remediation objectives.

LESSONS LEARNED (Continued)

Future Technology Selection Considerations

- Substantial attention is paid to the design and construction of groundwater pump and treat systems. Greater attention should be paid to operation and maintenance, including periodic evaluation of the performance of subsurface and above ground system components (e.g., capture zone analyses, contaminant transport evaluation, treatment system removal efficiency, etc.), to ensure project objectives are met.

- The potential impact of solids buildup due to biomass growth and oxidation of inorganics should be addressed in the design of groundwater pump and treat systems.

- Ultrasonic flow meters should be considered for use in groundwater pump and treat systems where solids buildup is of concern.

- Alternative treatment systems (i.e., air stripping followed by aqueous-phase activated carbon polishing) should be considered for sites where efficient removal of MTBE is required prior to discharge.

ANALYSIS PREPARATION

This analysis was prepared by:

Stone & Webster Environmental Technology & Services

245 Summer Street
Boston, MA 02210
Contact: Bruno Brodfeld (617) 589-2767

CERTIFICATION

This analysis accurately reflects the performance and costs of the remediation:

x Paul F Ressmeyer

Paul F. Ressmeyer
Remedial Project Manager
Amoco Corporation

SOURCES

Major Sources For Each Section

Site Characteristics:	Source #s (from list below) 1, 5, 7, and 23
Remediation System:	Source #s 1, 2, 3, 5, 7, 9, 17, 18, 20, 21, and 23
Performance:	Source #s 5, 6, 7, 10, 12, 14, 16, 17, 19, and 23
Cost:	Source #s 11, 13, 22, and 23
Regulatory/Institutional Issues:	Source #s 4, 5, 7, 8, 15, and 23
Schedule:	Source #s 5, 7, 19, 22, and 23
Lessons Learned:	Source #s 5, 6, 7, 10, 12, 14, 17, and 23

Chronological List of Sources and Additional References

1. *Design Basis for Constantine Remediation System*, prepared by Groundwater Technology, Inc., Undated.

2. *Plans and Specifications for Interim Remediation System*, prepared by Groundwater Technology, Inc., Undated.

3. *Operational and Maintenance Information for the Interim Groundwater Remediation and Hydrocarbon Treatment System* - Amoco, Florence Township near Constantine, Michigan, prepared by Groundwater Technology, Inc., March 8, 1988.

4. *NPDES Permit No. MI0046159* - AMOCO Oil Co. - Constantine, Michigan, Water Resources Commission, issued September 30,1987, modified September 21,1989.

5. *Data Package*, prepared by J. W. Aiken and D. A. Schumacher, ENSR Consulting and Engineering, June 17, 1992.

6. *August 1991 Quarterly Monitoring Report* - Constantine, Michigan Site, Document 0350-020-400, prepared for AMOCO Corporation, prepared by ENSR Consulting and Engineering, May 1992.

7. *Remediation Plan for Constantine, Michigan, Document Number 0350-024-141*, prepared by ENSR, January 1992.

8. *MERA Operational Memorandum #8 - Type B Criteria, Rules 299.5709, 299.5711(2), 299.5711(5) and 299.5713, Interoffice Memorandum*, prepared by Alan J. Howard, Michigan Department of Natural Resources, January 8, 1992.

9. *Summary of Recovery Well Installations at Constantine, Letter to Mr. Paul Ressmeyer, Amoco Corporation*, prepared by Mr. David A. Schumacher, ENSR Consulting and Engineering, March 26,1992.

10. *November 1991 and February 1992 Quarterly Monitoring Report - Constantine, Michigan Site Document No. 0350-020-110*, prepared by ENSR Consulting and Engineering, May 1992.

11. *Irrigation Well Drilling at Constantine, Letter to Mr. Paul Ressmeyer, Amoco Corporation*, prepared by Messrs. Joseph W. Aiken and David A. Schumacher, ENSR Consulting and Engineering, June 17, 1992.

12. *Spent Granular Activated Carbon: Foulant Analysis, Constantine Site, Michigan; Project 2112-21-D703, Internal Memorandum to P.F. Ressmeyer, Amoco Corporation*, prepared by V.E. Berkheiser, July 20,1992.

13. *Calgon Carbon Service Agreement, Letter to Paul Ressmeyer, Amoco Corporation*, prepared by M.C. Reiser, January, 1993.

14. *Semi -Annual Monitoring Report, Constantine Michigan, Period of April 1993 through October 1993*, prepared by Amoco Corporation, January 30, 1993.

15. *NPDES Permit No. MI0046159. - Amoco Pipeline Company, 63638; Constantine Road, Constantine, Michigan*, Water Resources Commission, March 18, 1993.

16. *Semi-Annual Monitoring Report - Constantine, Michigan, 9/93 to 3/93*, prepared by Amoco Corporation, June 8, 1993.

17. *AMOCO Constantine Site, Presentation Handout* prepared by Calgon Carbon, June 22,1993.

18. *Work Plan for Remedial Design/Remedial Action - Constantine, MI/* Residuals Management Technology, Inc., August 1993.

19. *AMOCO, Constantine, Michigan - Results of Air Sparging Pilot Test*, Letter to Ms. Lolita M. Anderson, Superfund Coordinator, Amoco Corporation, prepared by Residuals Management Technology, Inc., September 7, 1993.

20. *Project Manual for Amoco Corporation Air Sparging System, Final Design - Phase 1 Constantine, Michigan*, prepared by Residuals Management Technology, Inc., October 1993.

21. *Specifications for AMOCO Corporation Air Sparging System, Final Design - Phase 2, Constantine, Michigan*, prepared by Residuals Management Technology, Inc., October 1993.

22. *Constantine Michigan Air Sparging System - Project Summary*, Letter to Ms. Lolita Anderson, Superfund Coordinator, Amoco Corporation, prepared by Residuals Management Technology, Inc., January 5, 1994.

23. Personal Communications with Mr. Paul F. Ressmeyer, Superfund Coordinator, Amoco Corporation, March through June 1994.