

COST AND PERFORMANCE REPORT

Pump and Treat and *In Situ* Bioremediation
of Contaminated Groundwater
at the Libby Groundwater Superfund Site
Libby, Montana

September 1998



Prepared by:

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

SITE INFORMATION

Identifying Information:

Libby Groundwater Site
Libby, Montana

CERCLIS #: MTD980502736

ROD Date: December 30, 1988

ESD Date: (1) September 4, 1993, (2) January 22, 1997

Treatment Application:

Type of Action: Remedial

Period of operation: September 1991 - Ongoing (Performance data collected through December 1996)

Quantity of material treated during application: As of December 31, 1996, 15.1 million gallons of groundwater were treated.

Background [1,2]

Historical Activity that Generated Contamination at the Site: Lumber Mill - Wood Preserving

Corresponding SIC Code: 2491 (Wood Preserving - Creosote & Pentachlorophenol)

Waste Management Practice That Contributed to Contamination: Improper storage and disposal of wood preserving products.

Location: Libby, Montana

Operations:

- The Libby, Montana site has been used as a lumber mill and wood-treating facility since 1946. From 1946 to 1969, the site used various compounds, including creosote and pentachlorophenol (PCP) in their wood-treating facility. The mill was operated by the St. Regis Company until 1985 when it was purchased by Champion International.
- The area around the facility includes residential areas and businesses. The site is bordered on the west by Flower Creek, on the east by Libby Creek, and on the north by the Kootenai River. The contaminated soil and source area is within the confines of the site. The groundwater contamination extends into the City of Libby, located less than 1,000 feet downgradient.

- In 1979, homeowners detected a creosote odor in their well water. EPA monitoring in 1981 confirmed groundwater contamination from the Libby site.
- The site was placed on the National Priorities List (NPL) on September 8, 1983.
- Source removal activities included the excavation of approximately 67,000 cubic yards of soil and debris. The rock and debris were physically separated from the soils, resulting in 45,000 cubic yards of contaminated soils, which were treated through land treatment.
- A Phase IV remedial investigation/feasibility study (RI/FS) report was prepared by Woodward-Clyde Consultants in July 1986. Field operations were conducted from May 1985 to February 1986. The September 1986 Record of Decision (ROD) provided an alternate water supply to residents whose wells were contaminated through a Buy Water Plan. In a second ROD in December 1988, final remedial actions for contaminated groundwater included pump and treat and *in situ* bioremediation.
- An Explanation of Significant Differences (ESD) was issued in 1997 to change the remedial goals to reflect new information on exposure levels for several contaminants of concern.



SITE INFORMATION (CONT.)

Background (Cont.)

Regulatory Context:

- In 1983, St. Regis and EPA signed an Administrative Order on Consent for the company to study contamination at the site. Champion International purchased the St. Regis Corporation in 1985 and has taken over its obligations to the Order. In 1989, EPA and Champion signed a Consent Decree in which the company agreed to pay the U.S. Government past and future oversight costs and to complete implementation of the remedial action. A construction completion approval was obtained in late 1993.
- A ROD for the Upper Aquifer operable unit was signed on December 30, 1988.

- Site activities are conducted under provisions of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA) §121, and the National Contingency Plan (NCP), 40 CFR 300.

Remedy Selection:

The remedy for contaminated groundwater includes *in situ* bioremediation and groundwater extraction and treatment via an oil water separator and an above-ground fixed-film bioreactor.

Site Logistics/Contacts

Site Lead: PRP

Oversight: EPA

Remedial Project Manager:

Jim Harris*
U.S. EPA - Region 8
301 S. Park Dr.
P.O. Box 10096
Helena, MT 59626
(406) 441-1150 ext. 260

State Contact:
Neil Marsh
Montana Department of Environmental Quality
(MDEQ)
Remediation Division
(406) 444-0487

* Indicates primary contacts.

Treatment System Design:

Woodward-Clyde Consultants
4582 South Ulster Street
Stanford Place 3, Suite 1000
Denver, CO 80237

Facility Operations:

Ralph Heinert*
Champion International Corporation
Corporate Environmental
Highway 2 South
P.O. Box 1590
Libby, MT 59923
(406) 293-6238 phone
(406) 293-5415 fax



MATRIX DESCRIPTION

Matrix Identification

Type of Matrix Processed Through the Treatment System: Groundwater

Contaminant Characterization

Primary Contaminant Groups: Polycyclic aromatic hydrocarbon (PAH) compounds and pentachlorophenol (PCP).

The contaminants described here are limited to those found in the Upper Aquifer. Contamination has migrated to the Lower Aquifer but remedial actions are limited to the Upper Aquifer. Remediation of the Lower Aquifer was addressed in a 1993 ESD.

- The primary contaminants of concern include PAH compounds (both carcinogenic and noncarcinogenic) and PCP (Appendix A presents the levels of contaminants of concern detected in private groundwater wells in 1986).
- Maximum concentrations found during the 1986 RI/FS were: pentachlorophenol (3,200 µg/L), acenaphthene (100 µg/L), naphthalene (500 µg/L), acenaphthylene (200 µg/L), and benzo(a)anthracene (1 µg/L) [1].
- The areal extent of the contaminated groundwater plume was estimated in 1992 to be 1.2 miles long and cover approximately 232 acres [3]. The contaminant plume was estimated to contain as much as 2.2 million gallons of free product [4]. Figures 1 through 3 depict the areal extent of groundwater contamination from carcinogenic PAHs, noncarcinogenic PAHs and PCP, respectively, as measured in July 1992.
- Nonaqueous phase liquids (NAPLs), both dense and light, have been consistently observed in monitoring wells in the source area and downgradient of the intermediate injection system. In a 1997 report, site engineers stated that the NAPL in the upper aquifer appears to exist as free-phase product in small pools, trapped between strata or as a residual phase trapped in pore spaces [4].

Matrix Characteristics Affecting Treatment Costs or Performance

Hydrogeology:

Groundwater is present at this site in a highly transmissive aquifer, and is encountered at approximately 10 to 20 feet below land surface (bls). Groundwater flows through the alluvial valley formed by the Kootenai River. To identify different zones of contamination, the aquifer has been divided into two primary units. The upper aquifer, also referred to as the upper saturated unit, is formed of highly transmissive deposits of unconsolidated, interbedded gravel, sand, and clay. The upper aquifer extends to 60 to 70 feet bls and flows from the site north and northwest toward the City of Libby. The deposits are predominantly clean to silty gravel and sand with occasional interbedded layers approximately 2 to 10 feet thick containing clay and silt. From 70 to 110 feet bls, the deposits consist of silt and clay with interbedded layers of clean to silty gravel and sand. These deposits form a discontinuous aquitard, separating the upper aquifer from the lower. The lower aquifer is found at approximately 110 feet bls and extends to approximately 160 to 180 feet bls. The lower aquifer is composed of clean to silty gravel and sand layers, interbedded with clay and silt layers, extending to bedrock [2].



MATRIX DESCRIPTION (CONT.)

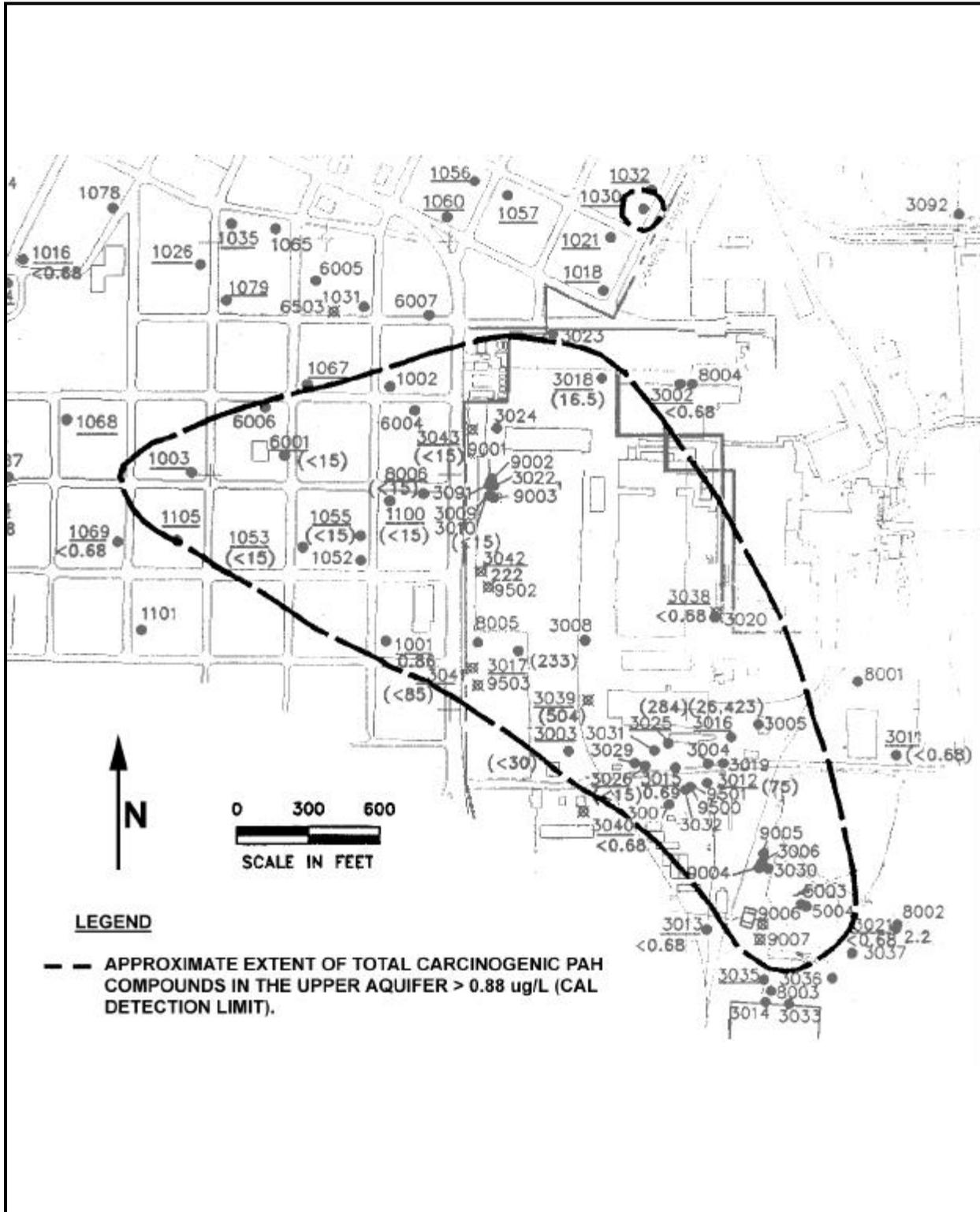


Figure 1. Distribution of Total Carcinogenic PAHs in Upper Aquifer (July 1992) [2]



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MATRIX DESCRIPTION (CONT.)

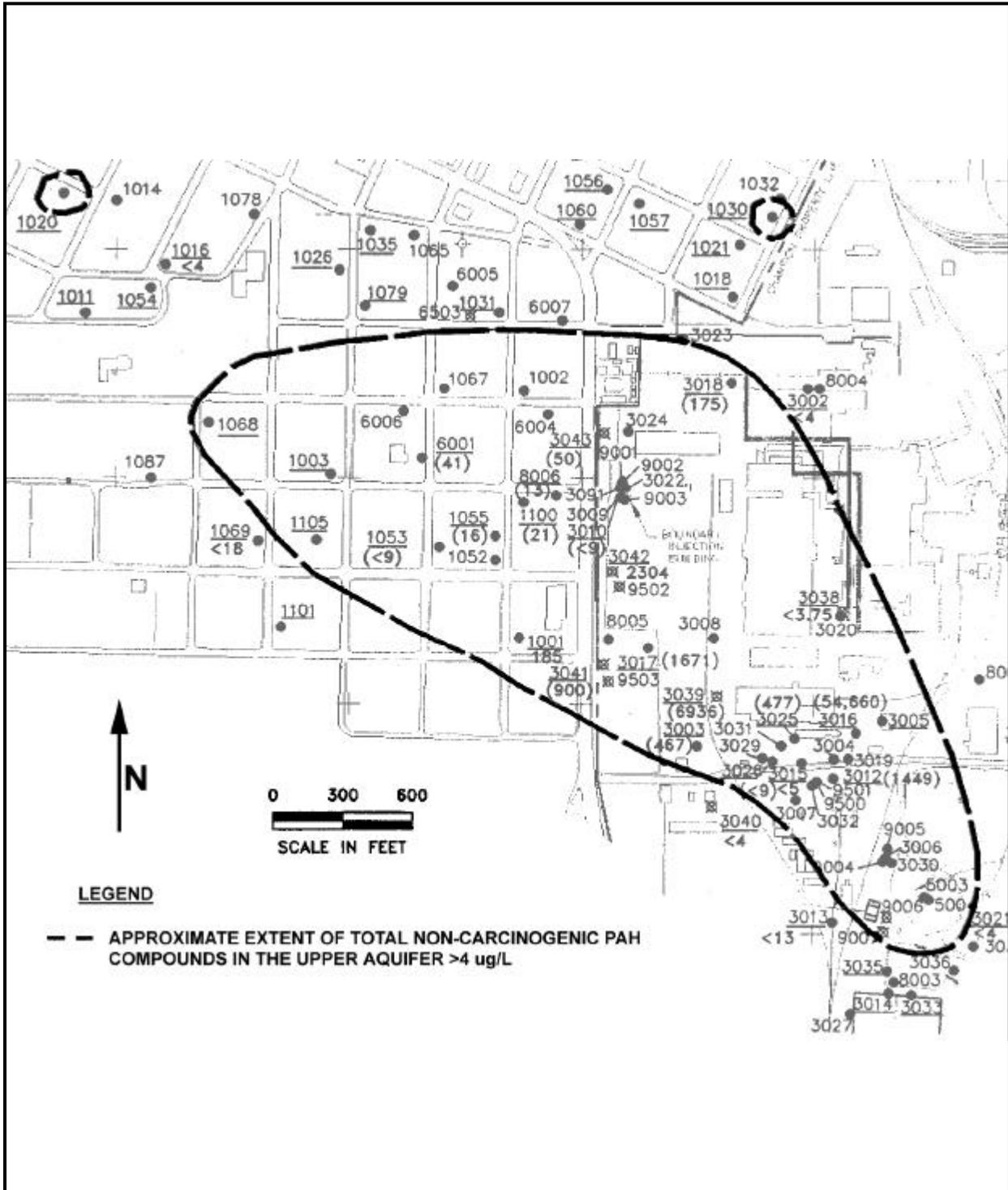


Figure 2. Distribution of Total Noncarcinogenic PAHs in Upper Aquifer (July 1992) [2]

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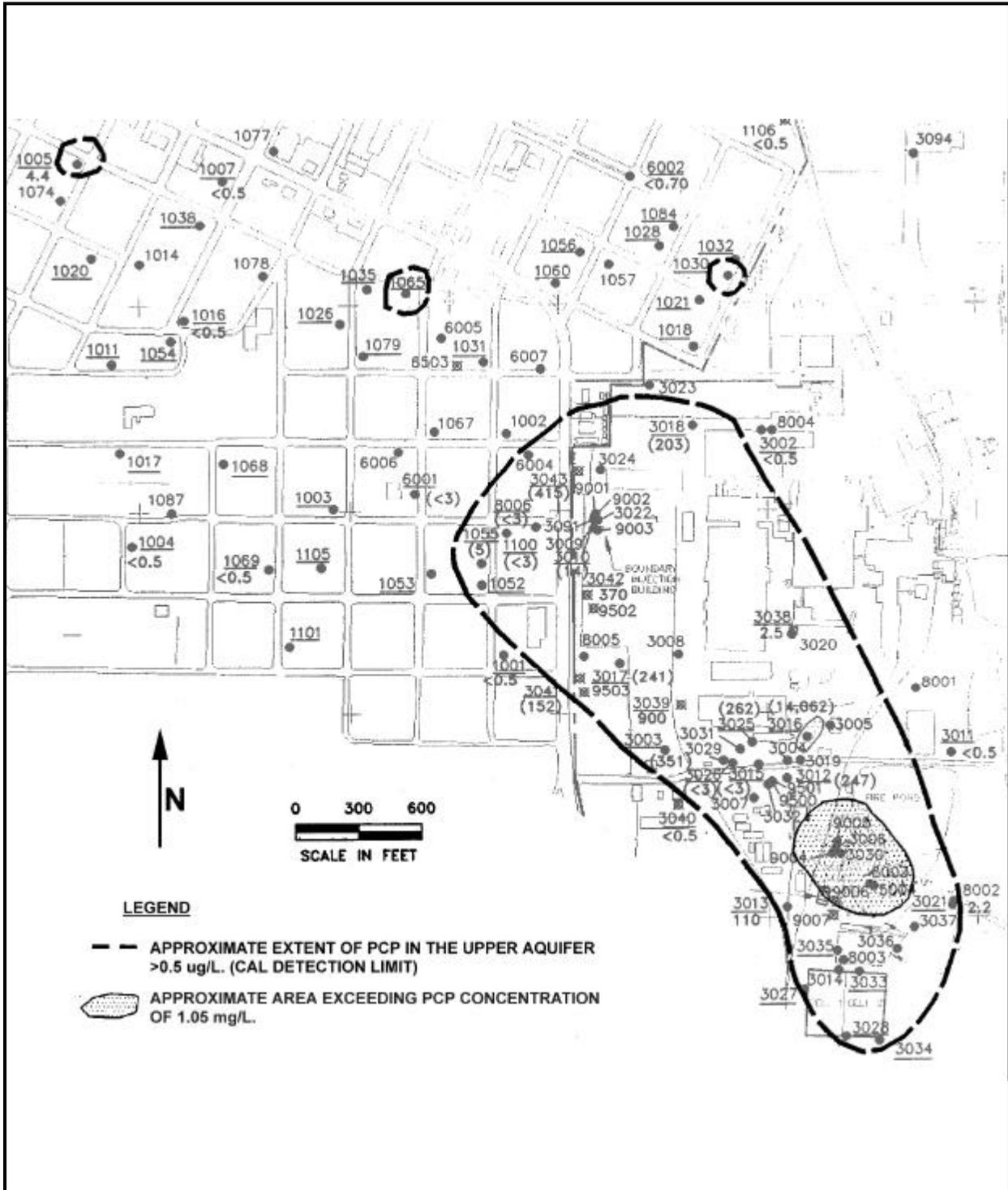


Figure 3. Distribution of PCP in Upper Aquifer (July 1992) [2]

MATRIX DESCRIPTION (CONT.)

Matrix Characteristics Affecting Treatment Costs or Performance (Cont.)

Table 1 presents technical aquifer information.

Table 1. Technical Aquifer Information

Unit Name	Thickness (ft)	Conductivity (ft/day)	Average Velocity (ft/day)	Flow Direction
Upper Aquifer	15-70	100 - 1,000	3-10	North-Northwest
Lower Aquifer	160-180	100	<3	North-Northwest

Source: [5,6]

TREATMENT SYSTEM DESCRIPTION

Primary Treatment Technology

Supplemental Treatment Technology

In situ bioremediation and pump and treat (P&T) consisting of an oil/water separator followed by two fixed-film bioreactors in series

None

System Description and Operation

Tables 2 and 3 provide technical information about the extraction and injection wells used at this site, respectively.

Table 2. Extraction Well Data

Well Name	Unit Name	Depth (ft)	Design Yield (gal/min)
9006	Deeper portion of Upper Aquifer	67-73	16
9008	Deeper portion of Upper Aquifer	76	6

Note: Average system extraction rate was 6.6 gpm (currently operating at 16 gpm).

Source: [5,6]



TREATMENT SYSTEM DESCRIPTION (CONT.)

System Description and Operation (Cont.)

Table 3. Injection Well Data

Well Name	Unit Name	Depth (ft)	Design Injection Rate (gal/min)
Intermediate Injection System			
3004-1	Upper Aquifer	18-21	27
3004-2	Upper Aquifer	34-37	2
3007-1	Upper Aquifer	20-23	3
3007-3	Upper Aquifer	42-45	1
9500	Upper Aquifer	45-65	10
9501	Upper Aquifer	18-38	50
Boundary Injection System			
9001	Upper Aquifer	25-40	67
9502-1	Upper Aquifer	20-40	50
9502-2	Upper Aquifer	46-56	50
9503-1	Upper Aquifer	19-39	50
9503-2	Upper Aquifer	45-55	15

Source: [5,6]

System Description

- The remedial strategy at this site was to address the source area by removing NAPL and to stimulate bioremediation in the downgradient upper aquifer plume. An Applicable or Relevant and Appropriate Requirements (ARAR) waiver has been granted for the lower aquifer due to the technical impracticability of remediating NAPLs and the low likelihood that the lower aquifer poses a risk to human health and the environment [6].
- There are three components to the upper aquifer remedial system at the Libby site: source area extraction system, intermediate injection system, and boundary injection system shown in Figure 4. The components were constructed in phases beginning in late 1989 and were finished in early 1993 [4,5].
- The source area extraction and treatment system consists of extraction wells, an oil/water separator, nutrient addition, and two fixed-film bioreactors, operated in series. The system extracts heavily contaminated groundwater from the upper aquifer, separates the NAPL from the water in the oil/water separator, adds nutrients to the extracted groundwater, and then treats the dissolved-phase contamination in bioreactors. From the bioreactors, the effluent is discharged to infiltration trenches. The objective of the system is to remove NAPL from the upper aquifer to improve the performance of the naturally occurring *in situ* biodegradation downgradient of the source area [5].



TREATMENT SYSTEM DESCRIPTION (CONT.)

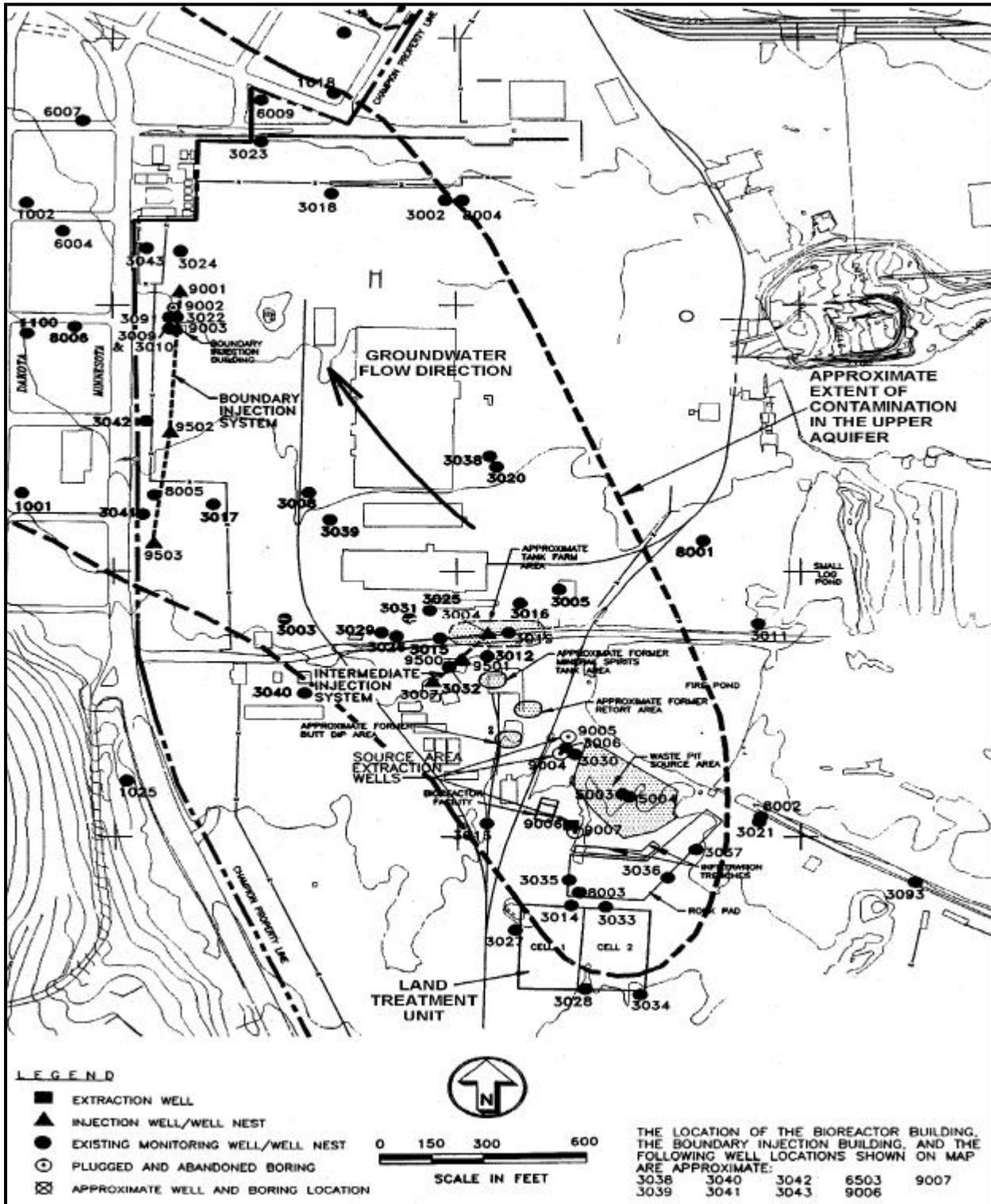


Figure 4. Locations of Remedial System Components [6]

TREATMENT SYSTEM DESCRIPTION (CONT.)

System Description and Operation (Cont.)

- Five extraction wells were installed at different depths in the upper aquifer in the source area. Four of these wells were completed as two-well pairs, with one well of each pair screened in the shallow portion of the upper aquifer and the other well screened in the lower portion. This well design allows flexibility in selecting the best pumping scenario. As of 1998, only two wells remain in service, extracting approximately 16 gpm.
 - The extracted groundwater flows to a 10,000-gallon oil/water separator where floating and sinking NAPLs are removed. The tank is eight feet in diameter and 26 feet long. From the separator, the process water flows to the bioreactors. Liquid nutrients are added to the process water before it enters the bioreactors. Oxygen is added through an aeration system within each bioreactor [5].
 - The bioreactor units consist of two 10,000-gallon tanks filled with a polyethylene media. The process water from the oil/water separator is heated in the first bioreactor to 22° Celsius to stimulate biological activity. The polyethylene media is designed to provide surface area on which the biofilm forms. Contaminants are adsorbed onto the biofilm where they become a food source for the microbes. Byproducts of aerobic biodegradation are carbon dioxide, water, and additional biomass [5].
 - The first reactor reduces the concentrations in the process water by 70 to 80 percent. The process water then flows to the second tank where most of the remaining contaminants are removed. The elevated level of oxygen in the bioreactors re-oxygenates the effluent before it is discharged to the infiltration trenches [5].
 - The *in situ* bioremediation system consists of two gravity injection systems--the intermediate and boundary injection systems--through which oxygen and nutrients are added to the Upper Aquifer.
- The intermediate injection system consists of six wells, and the boundary injection system consists of three wells [4, 5].
- The source of water for injection is an on-site pond. Hydrogen peroxide was initially used to oxygenate the water and was added at a rate of 100 mg/L. However, when the boundary system was installed in early 1993, alternative oxygenation methods were investigated to lower costs of operations. As a result, a U-Tube oxygenator system and a bubbleless aeration system were installed. Based on its success, this method also replaced the hydrogen peroxide method used in the intermediate injection system [5].
 - Nutrients (nitrogen and phosphorous) are added to the water for the intermediate injection system to maintain levels of 2.4 mg/L and 1 mg/L, respectively in the injection water [5]. During the design of the boundary system, it was found that sufficient levels of nutrients already were present in the groundwater, originating from natural sources or migrating from the intermediate system wells; therefore, the addition of nutrients was not necessary for this system.
 - The monitoring plan at this site requires sampling of the extraction well system, the *in situ* system, and the monitoring wells for the intermediate and boundary systems. Water levels, concentrations of contaminants, and geochemical parameters, such as temperature, dissolved oxygen levels, and nutrients, are monitored. Twenty-three wells are sampled annually for PAHs and PCP. Twenty-one wells are monitored monthly for dissolved oxygen and water levels [5].
 - There is an on-site laboratory that performs wet chemistry. Most PAH and PCP analyses are performed on site, but some contaminant analyses are performed by an off-site commercial laboratory for quality assurance purposes [5]. Dissolved oxygen (DO) analyses are performed in the field with direct reading instruments.



TREATMENT SYSTEM DESCRIPTION (CONT.)

System Description and Operation (Cont.)

System Operation

- Quantity of groundwater pumped from aquifer from 1992 to 1996:

Year	Total Volume Pumped (gal)	Average Pump Rate (gal/min)
1992	4,355,000	8.4
1993	2,620,000	5.6
1994	1,100,000	2.2
1995	3,470,000	6.6
1996	3,520,000	7.5
Total	15,065,000	6.1

Source: [2, 6, 7, 8, 9]

- The source area extraction system has operated nearly continuously since operations began. There were some interruptions to system operations because of several failures of the Protec pump, such as drive-rod breakage and gear box failure. The percentage of time that the system has operated ranges from 89 to 100 [6].
- The intermediate and boundary injection systems have been in near-continuous operation from mid-1990 through December 1996 [2, 6, 7, 8, 9].
- The intermediate injection system operates at an average rate of 70 gpm, and nutrients are added to the injection water to maintain levels of approximately 2.4 mg/L nitrogen and 1 mg/L phosphorus. The level of DO is maintained at approximately 40 mg/L [2,6,7,8,9].
- The boundary injection system operates at an average rate of 232 gpm; no nutrients are added. Dissolved oxygen levels are maintained at approximately 51 mg/L [2,6,7,8,9].
- PAH removal occurs primarily in the first fixed film bioreactor; PCP removal occurs primarily in the second reactor [4].
- During 1992, a study was performed to optimize the temperature of the bioreactors to lower the cost of their operation. The results indicated that there was no difference in performance between 22° and 30° Celsius. The temperature in the bioreactors was lowered to 22° Celsius [6].
- During the summers of 1992 and 1993, efforts were made to expand the capacity of the source area treatment system. Two different fixed film bioreactors were tested and both were successful in expanding the treatment capacity. However, it was determined that it was more cost-effective to improve the efficiency of the system by improving the performance of the oil/water separator. Consequently, the tests on the growth bioreactors were stopped, and several studies were undertaken to improve the performance of the separator. [6]
- Studies to improve the performance of the oil/water separator included adding dissolved-air flotation and flocculation, and lengthening retention times. The studies showed that the performance of the separator improved when droplet size increased. A positive-displacement, progressive-cavity pump was installed, which increased NAPL droplet size by reducing the extent of shearing produced by the pump [6].
- A review of the monitoring data from the intermediate injection system wells in 1992 revealed a negative correlation between DO levels and concentrations of PCP and PAHs. On this basis, samples taken from intermediate system wells from 1993 onward were analyzed for DO, and not PCP and PAHs. If DO levels change significantly, samples will be analyzed for PCP and PAHs to directly measure the change in groundwater quality [6].



TREATMENT SYSTEM DESCRIPTION (CONT.)

System Description and Operation (Cont.)

- In May 1993, the hydrogen peroxide injection system for the intermediate injection system was replaced with a bubbleless aeration system. The bubbleless aeration system was pilot-tested over the previous year to measure its cost and performance. The site engineer determined that a cost savings could be achieved, without a loss in performance [6].
- In 1996, three of the four original source area extraction wells were abandoned because they were no longer removing NAPL. In December 1996, a fifth well was installed to increase the removal of NAPL from the source area groundwater [6].
- During 1996, the facility operator tested a Protec pump in one extraction well to evaluate the pump's ability to reduce emulsification of NAPL, and improve the performance of the oil/water separator. The original pump operated at 3,450 rpm, a speed at which free product was being emulsified and resisted gravity separation. The Protec pump, operating at 350 rpm, significantly reduces emulsification in the well [7]. The Protec pump, however, has not been able to operate for extended periods of time without malfunctions.
- According to the RPM, a Phase II design report for the upper aquifer was submitted in April 1997 and a Technical Impracticability (TI) report is currently being prepared. At this time, no "additional groundwater treatment activities are anticipated" [11].

Operating Parameters Affecting Treatment Cost or Performance

The major operating parameter affecting cost or performance for this technology is the pumping rate. Table 4 presents the average pumping rate and other performance parameters.

Table 4. Performance Parameters

Parameter	Value	
Average Pump Rate	6.6 gpm	
Performance Standard (Effluent)	Non-carcinogenic PAH Compounds	
	Napthalene	1,460 µg/l
	Acenaphthene	2,100 µg/l
	Fluorene	1,460 µg/l
	Anthracene	11,000 µg/l
	Pyrene	1,100 µg/l
Performance Standard (Effluent)	Carcinogenic PAH Compounds	
	Benzo(a) anthracene	0.1 µg/l
	Chrysene	0.2 µg/l
	Benzo(b)fluoranthene	0.2 µg/l
	Benzo(a)pyrene	0.2 µg/l
	Dibenzo(a,h)anthracene	0.3 µg/l
	Indeno(1,2,3-cd)pyrene	0.4 µg/l
Arsenic	50 µg/l	
Benzene	5 µg/l	
	Pentachlorophenol	1 µg/l
Remedial Goals (Aquifer)	Same as above	

Source: [6]



TREATMENT SYSTEM DESCRIPTION (CONT.)

Timeline

Table 5 presents a timeline for this remedial project.

Table 5. Project Timeline

Start Date	End Date	Activity
7/87	4/88	Pilot scale test for <i>in situ</i> bioremediation conducted
12/88	---	ROD signed
1/90	1/91	Demonstration program for <i>in situ</i> bioremediation conducted
1/90	8/91	Phase I Remedial Design conducted
1991	---	Remedial construction performed
2/91	---	Operations for source area extraction system begun
1996	---	Three wells abandoned; one new well installed; change in pump speed tested
1997	---	ESD signed; remedial goals revised

Source: [2, 4, 6]

TREATMENT SYSTEM PERFORMANCE

Cleanup Goals/Standards [1]

- The remedial goals were revised in the 1997 ESD to reflect a recent risk assessment and updated MCLs. Table 4 presents the revised goals.

Additional Information on Goals [4]

- The cleanup goals for this site were originally established in the December 1988 ROD based on achieving a 10^{-5} risk level in the groundwater. At that time, the limit set for total noncarcinogenic PAHs was 400 ng/L, and 40 ng/L for total carcinogenic PAHs.

Treatment Performance Goals [6]

- The goal of the source area extraction system is to remove oil-contaminated groundwater and NAPL from the area of the waste pit and remove as much NAPL as possible.
- The goal of the *in situ* bioremediation and P&T system is to reduce PAH and PCP concentrations in the upper aquifer to levels below remedial goals.

Performance Data Assessment

Total PAHs include naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(g,h,i)perylene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, dibenzo(a,h)anthracene, indeno(1,2,3-cd)pyrene.

- As of December 1996, concentrations in many parts of the plume had declined to either remedial levels or detection limits. However, there are areas of groundwater

contamination in which levels of PAHs and PCP remain near original levels.

- As discussed in System Operation, DO levels have been monitored to evaluate the extent of the influence of the intermediate injection system and as an indicator measure for PAH and PCP levels in the groundwater. Background levels for DO at this site range from 3.0 mg/L to 4.2 mg/L (DO levels in contaminated groundwater are typically less than 1 mg/L). Decreases in



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TREATMENT SYSTEM PERFORMANCE (CONT.)

Performance Data Assessment (Cont.)

DO levels indicate that increased contaminant concentrations are depleting available DO faster than it can be supplemented from the injection system.

- Figure 5 shows DO concentrations in three of the 18 wells that are used to monitor the progress of the intermediate injection system. These three wells are located within 600 feet of the injection system, which is the limit of the influence of the intermediate injection wells. In these and five other wells, PAH and PCP concentrations have declined to either remedial goals or below detection limits. The spikes and troughs seen in these graphs do not necessarily directly correspond with a decline or increase in PAH or PCP levels. According to the site engineers, an order of magnitude change in DO concentrations is required before a "significant" change in groundwater quality would be indicated [4, 6].
- In the remaining 11 wells used to monitor the performance of the intermediate injection system, PAH and PCP concentrations have shown little decline from original levels [4].
- Figure 6 shows trends in PCP, PAH, and DO levels in one of the wells used to monitor the progress of the boundary

injection system. DO levels in this well and nine other boundary injection system monitoring wells have increased. In most wells, a corresponding decrease in PAH and PCP concentrations, such as that shown in Figure 6, has been observed. By September 1996, PCP and PAH concentrations were not detected in seven and eight of the 10 wells, respectively. However, because the remedial goals for PCP and carcinogenic PAHs are below the on-site laboratory detection limit, data from the on-site laboratory do not indicate whether remedial goals have been met in these wells [4].

- According to the Phase II Design Report, migration in the PAH and PCP plumes had ceased by the end of 1996. The site engineers believe that an equilibrium has been reached between the advection, dispersion, and degradation of PAHs and PCP in the aquifer and the rate of dissolution of those compounds in the source areas [4].
- The source area treatment system removed a total of 37,570 pounds of PAHs from the groundwater from 1992 to 1996. Of the two components of the treatment system, the oil/water separator removed a total of 23,200 pounds of PAHs, while the bioreactor degraded 14,370 pounds [4].

Performance Data Completeness [4]

- A total of 42 monitoring wells are sampled annually for PAHs and PCP.
- Bimonthly DO analyses are performed in each of the monitoring wells. Samples are taken from the influent and effluent of the treatment system on a weekly basis and analyzed for PAHs, PCP, and DO.

Performance Data Quality [4]

Analyses for PAHs and PCP are performed using modified EPA Methods 8100 and 8040, respectively. The on-site laboratory was used for the majority of analyses required for this site.

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



TREATMENT SYSTEM PERFORMANCE (CONT.)

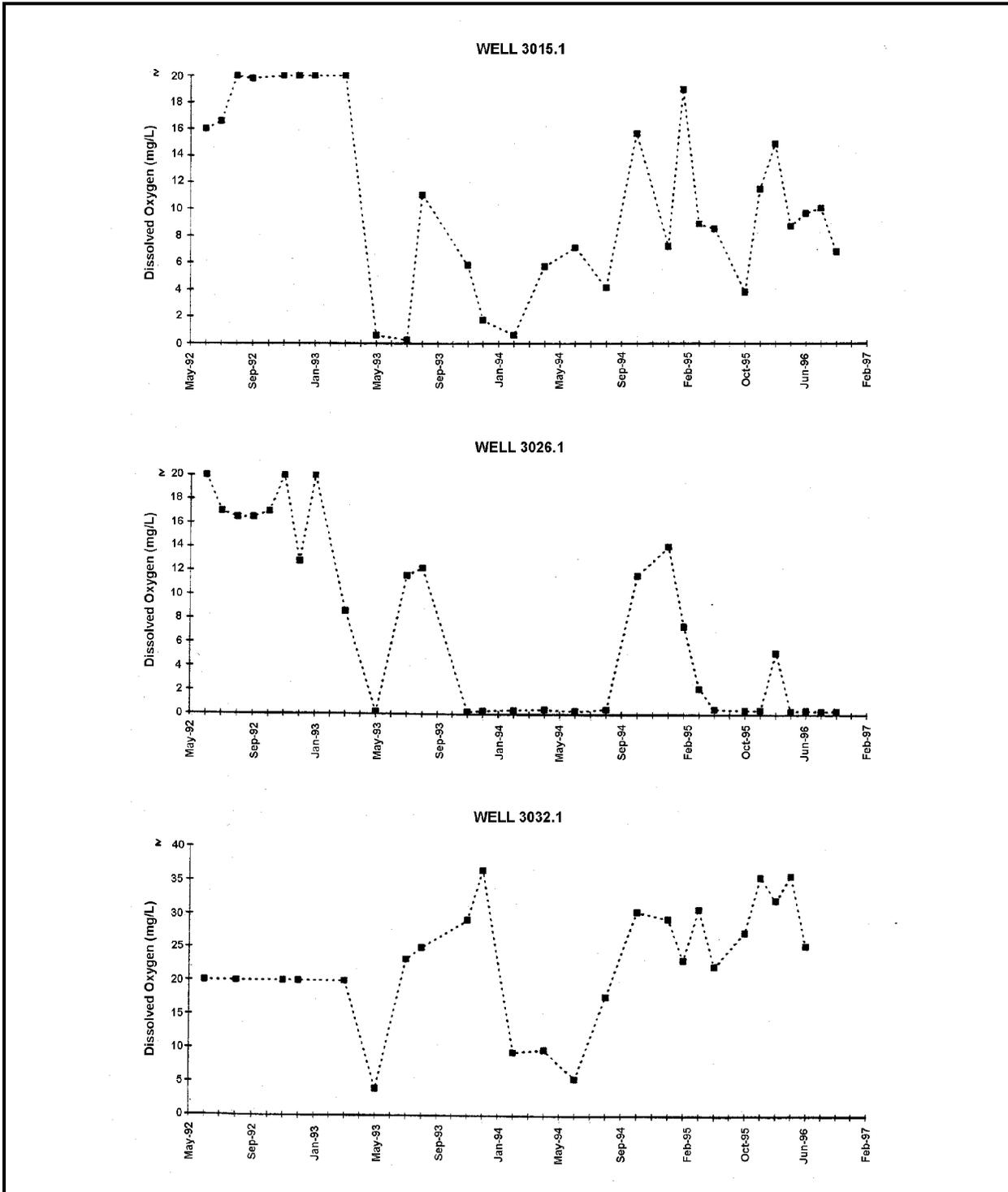


Figure 5. Dissolved Oxygen Concentrations in Three Intermediate Monitoring Wells [6]



TREATMENT SYSTEM PERFORMANCE (CONT.)

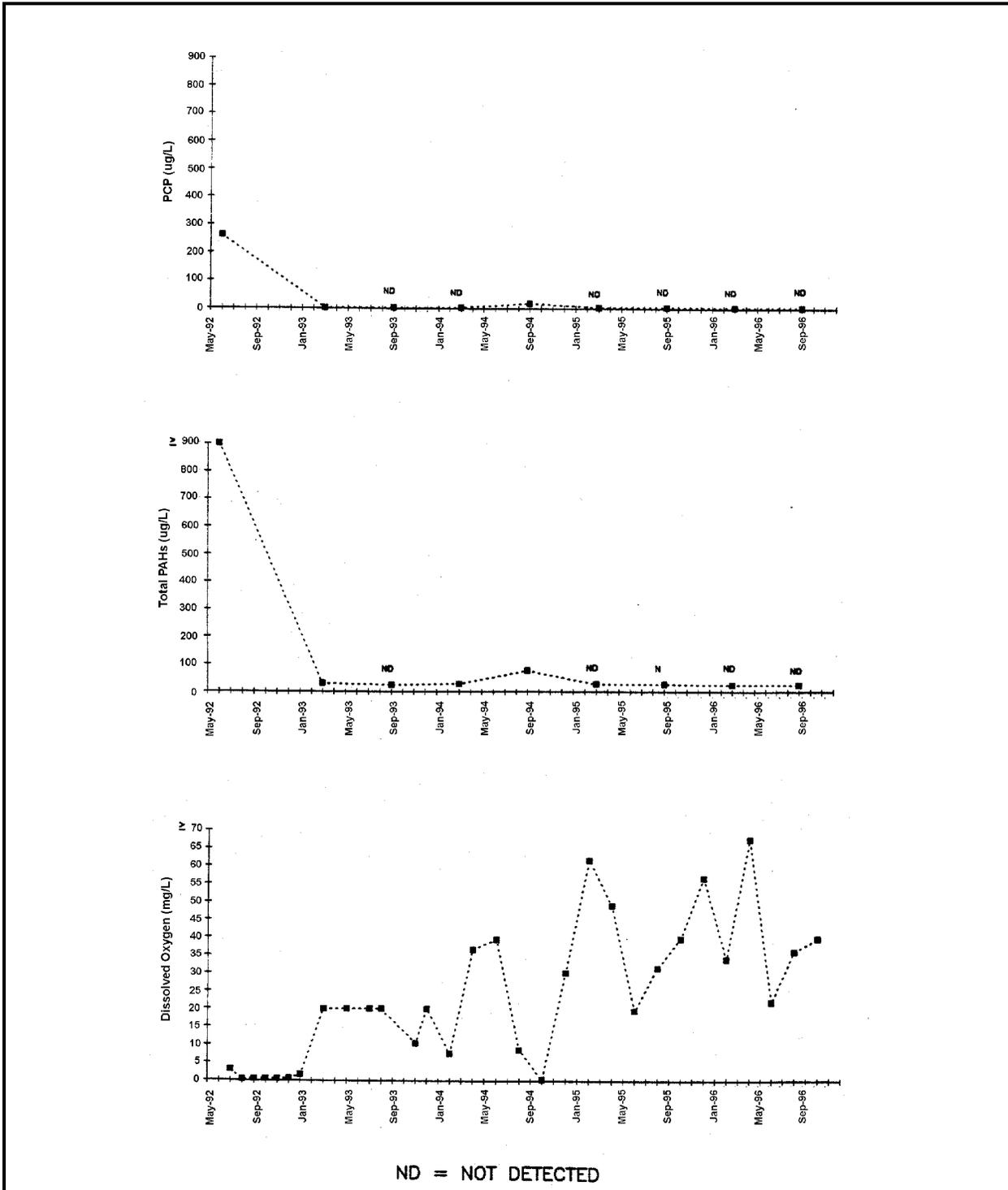


Figure 6. Graphs of PCP, Total PAH, and Dissolved Oxygen in One Boundary Monitoring Well 3042.2 [6]



TREATMENT SYSTEM COST

Procurement Process

Champion International Corporation, in cooperation with EPA Region 8, leads the remedial activities for the Libby Site. Woodward-Clyde Consultants provides design and oversight services for Champion. The remedial activities at the site are part of a performance evaluation of groundwater biological treatment processes (bioremediation) being conducted by the U.S. EPA National Risk Management Research Laboratory (Scott Huling) and Utah State University.

Cost Analysis [10]

- All costs for design, construction and operation of the treatment system at this site are borne by Champion International Corporation.

Capital Costs

<u>Remedial Construction</u>	
Engineering and Site Services	\$1,050,000
Construction	\$700,000
Sample Analysis/Data Management	\$210,000
Drilling and Sampling	\$140,000
Equipment/Supplies	\$910,000
Total Remedial Construction	\$3,010,000

Operating Costs

1989-92 Operations and Services	\$980,000
1993 Operations	\$437,000
1994 Operations	\$363,400
1995 Operations	\$418,200
1996 Operations	\$420,000
Total Operations 1989 - 1996	\$2,618,600
Average Annual Operating Expenses	\$327,300

Other Costs

Remedial Design	\$350,000
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Cost Data Quality

Estimated capital and operating and maintenance cost data were available from Champion International. Limited information on the items included in the total project costs was provided. To date, including RI/FS and EPA oversight, over \$14 million was spent in total for this site.

OBSERVATIONS AND LESSONS LEARNED

- Estimated costs incurred through 1996 were \$5,628,600 (\$3,010,000 in capital costs and \$2,618,600 in operating and maintenance costs). This corresponds to \$374 per 1,000 gallons treated and \$150 per pound of contaminant removed. These costs do not account for the volume of groundwater treated or the mass removed through *in situ* bioremediation. No estimates have been made of the mass of PAHs and PCP that have been degraded through *in situ* bioremediation [10].
- The selection of the Protec pump for the source area extraction wells had an impact on the overall cost of the system. Each pump cost approximately \$10,000, and two were purchased. The pumps cannot be run for extended periods of time without malfunctions, which has interrupted the operation of the source area treatment system. Prior to the use of Protec pumps, standard centrifugal pumps were used at this site. The use of standard centrifugal pumps with rotation speeds of 3450 rpm did not let the oil settle in the extraction wells because droplets were too small [4].



OBSERVATIONS AND LESSONS LEARNED (CONTINUED)

- The adoption of a U-Tube oxygenator system and a bubbleless aeration system for the two injection systems proved to be a cost-effective alteration to the systems [4].
- To avoid clogging with biological growth, two infiltration trenches were constructed and used alternately, allowing one to dry while the other was in use [4].
- According to the 1997 Phase II Design report, the NAPL pools in the upper aquifer will dissolve slowly. The time required to dissolve a NAPL pool depends on the contaminant. According to the Design Report, it would take 270 years to dissolve the PCP, 75 years for naphthalene, and 110,000 years for benzo(a)pyrene [4].
- The site operators believe that no additional modifications could be made to improve the systems performance and to reduce the time required to remediate the intermediate injection area. The individual systems are operating as expected [4].

REFERENCES

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6. 1996 Annual Operations Report For The Upper Aquifer, Woodward-Clyde Consultants, February 1997.
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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.



Appendix A
Contaminants Detected in Private Groundwater Wells As Reported in the 1986 ROD

Contaminant of Concern	Maximum Concentration (µg/L)
Arsenic	5
Zinc	1,400
Copper	160
Chromium	10
Lead	30
Nickel	29
Pentachlorophenol (PCP)	3,200
Napthalene	500
Acenaphthylene	200
Acenaphthene	100
Fluorene	48
Phenanthrene	212
Anthracene	15
Fluoranthene	93
Pyrene	44
Chrysene	5
Benzo(a)anthracene	1
1-methyl napthalene	250
2-methyl napthalene	43
Benzene	20
Toluene	51
Carcinogenic PAHs	93

