DEVELOPMENT OF A SHUTDOWN PROCESS FOR REMEDIATION SYSTEMS

OPERABLE UNIT 3

FORT WAINWRIGHT, ALASKA

ESM 684 Project

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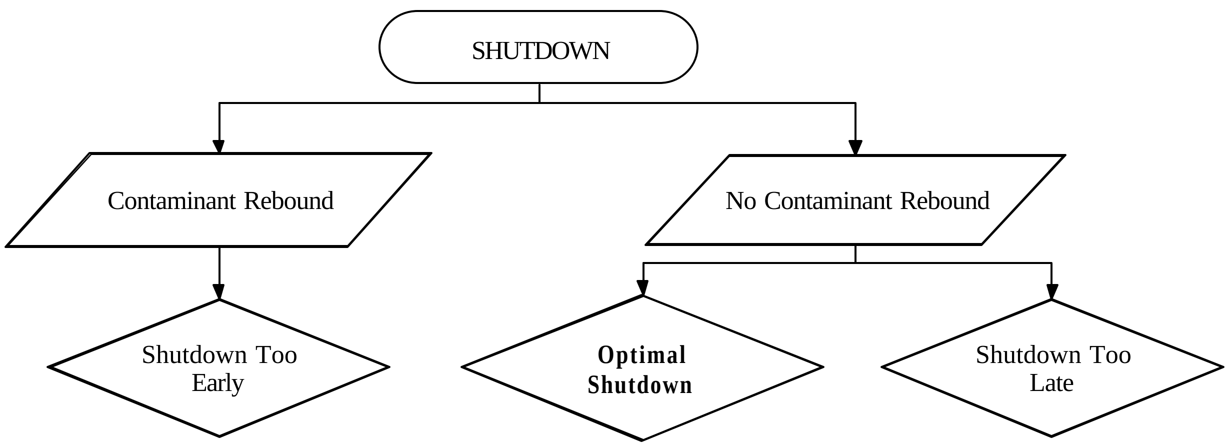
1.0 INTRODUCTION

As a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) National Priority List site, Fort Wainwright, Alaska, has undergone extensive remedial investigation and subsequent treatment to restore contaminated soil and groundwater to safe levels. Treatment systems were installed at various contaminated areas beginning in the mid-1990's and now, several years later, an approach must be developed to bring these systems off-line.

The purpose of this paper is to develop a methodology for shutting down treatment systems, including determining the optimal time to shutdown a treatment system and the steps to take following the shutdown. Shutting down a treatment system at the most appropriate time is the critical factor, as demonstrated below. If contaminants rebound, the system was shut down prematurely; however, if contaminants do not rebound, the system may have been run longer than necessary.



In developing a methodology, both the remedial progress of the treatment systems to-date and the projected future effectiveness of the systems must be considered. The following critical factors were examined in the development of a shutdown process:

- The treatment systems' operational history (Section 2);
- Remedial progress of the treatment systems, including whether cleanup goals have been achieved (Section 3);
- The cost-effectiveness of continuing operation of the systems (Section 4); and
- Development of appropriate post-shutdown monitoring/sampling programs (Section 5).

This paper focuses on two representative treatment systems, Valve Pit C, which is currently in the shutdown process, and Eight-Car Header, which is scheduled for shutdown in the immediate future. The shutdown process methodology developed for these two systems will be used in the decision-making process for the shutdown of other treatment systems throughout Fort Wainwright, and the lessons learned during their shutdowns will help refine post-shutdown monitoring/sampling programs.

2.0 BACKGROUND

This section presents an overview of the historical activities conducted on Fort Wainwright that led to releases of contaminants. It also summarizes remedial activities that have been undertaken to cleanup soil and groundwater, concentrating on Valve Pit C and Eight-Car Header.

2.1 Fort Wainwright

Fort Wainwright, located in Fairbanks, Alaska, occupies 918,000 acres and has been an active military reservation since the 1940's. Originally known as Ladd Air Field, the facility has served as a training site for both the Army and the Air Force. Currently, the post is utilized by the Army for arctic training of light infantry. The post not only serves as a training center, but also contains military-family housing, recreational facilities, a hospital, shopping centers, and numerous other administrative buildings.

Fairbanks Fuel Terminal, a former fuel distribution system for military facilities throughout interior Alaska, operated on Fort Wainwright from the 1940's to 1980's. Components of this system included: the Railcar Off-Loading Facility (ROLF), where fuel was delivered to the post via railway and unloaded; the Birch Hill Tank Farm, where fuel was stored in above ground storage tanks; and a network of distribution piping extending from the ROLF and Birch Hill to several fueling points. Releases of petroleum hydrocarbons have been historically documented in conjunction with the Fairbanks Fuel Terminal (E&E, 1995). In addition, releases, spills, and leaks of fuels and other hazardous substances and pollutants have been documented in conjunction with underground and aboveground storage tanks, fueling stations, and maintenance facilities at various locations throughout post.

Due to the releases of these contaminants into the environment, Fort Wainwright was placed on the CERCLA National Priority List (NPL) in 1990. In 1992, pursuant to listing as a CERCLA NPL site, the U.S. Army, Alaska (Army) entered into a Federal Facilities Agreement with the Environmental Protection Agency (EPA) and the Alaska Department of Environmental Conservation (ADEC) to address cleanup of the contaminated sites. Source areas throughout Fort Wainwright were divided into five operable units for further investigation and potential remedial activities; the remainder of this paper will focus on Operable Unit 3 (OU3).

2.2 Operable Unit 3

A Remedial Investigation/Feasibility Study (RI/FS) was conducted for source areas within OU3 in 1995. The Record of Decision (ROD), prepared following completion of the RI/FS, specified that remedial actions be undertaken to treat soil and groundwater contamination with the objective of achieving Federal Safe Drinking Water Act levels. The ROD also specified air sparging (AS) and soil vapor extraction (SVE) as the remedial technologies to be implemented at all OU3 source areas. An AS system injects air below the water table in order to volatilize contaminants in the groundwater, while a SVE system removes soil vapors from the vadose zone above the water table. These two technologies work in conjunction with one another to remove contamination from the subsurface and enhance natural biodegradation by providing an aerobic environment.

Installation of the AS/SVE treatment systems began in 1996, subsequent to the signing of the ROD. Treatment systems have been operating successfully throughout OU3 since installation, and many of the systems have been expanded and/or modified. Currently, two AS/SVE systems and one AS system are operating in the Birch Hill Tank Farm, three AS/SVE systems are operating at the ROLF, and three AS/SVE systems are operating at former valve pits associated with the Fairbanks Fuel Terminal (FES, 2002a). Two of these systems will be examined in depth; the Valve Pit C treatment system, located at Valve Pit C in the ROLF, and the Eight-Car Header treatment system, located in the central ROLF.

2.3 Valve Pit C and Eight-Car Header

Valve Pit C and Eight-Car Header were chosen as representative treatment systems for developing a shutdown process methodology due to their remedial progress to-date and the Army's future plans for these sites.

2.3.1 Valve Pit C

The Valve Pit C (VPC) treatment system was installed and began operation in the summer of 1996 and was expanded in the summer of 1997. In order to prevent freezing of the vapor extraction lines, the system is only operated during the summer months. From August 1998 to July 1999, VPC was shutdown for a rebound evaluation, a study to observe whether contaminant concentrations will increase when the system is non-operational for an extended period of time. The system was shutdown for a second rebound evaluation in September 2001 and remains off. The data collected during these rebound evaluations make VPC an ideal candidate for analysis in the development of a shutdown process.

During periods of operation, the system was monitored monthly. During these monitoring events, vapor samples from the SVE exhaust were collected, individual SVE lines were field-screened for organic vapors and oxygen content, and system operating parameters were recorded. Baseline groundwater monitoring of the Valve Pit C treatment area was conducted in June 1996, before treatment system installation, and groundwater monitoring was conducted a minimum of three times a year through 2000, followed by twice a year in 2001. The VPC Gantt Chart, Figure 1 (located at the end of the document), shows the system's operational periods, rebound evaluations, and monitoring schedule through 2002. Table 2-1 presents background statistics on VPC.

Table 2-1

Treatment Area Coverage	6,640 square feet
Operational Time (through 2002)	21,242 hours
Number of AS probes	10
Number of VE probes	4
Number of Groundwater Monitoring Points	7

2.3.2 Eight-Car Header

The Eight-Car Header (Eight-Car) treatment system was installed and began operation in the summer of 1998. The system has operated continuously since installation, with the exception of minor shutdowns for sampling and maintenance activities. Eight-Car is also equipped with an oxidizer, which controls SVE exhaust emissions by treating the exhaust stream prior to release to the atmosphere. Eight-Car was chosen as a prototype treatment system for analysis of a shutdown process because the Army has plans to shutdown this treatment system in fall 2002 in order to conduct a rebound evaluation at a system where groundwater contaminant concentrations have decreased to below cleanup levels.

The system is monitored monthly to collect vapor samples from the SVE exhaust and the oxidizer exhaust, to field-screen individual SVE lines for organic vapors and oxygen content, and to record system operational parameters. Baseline groundwater monitoring of the Eight-Car treatment area was conducted in April 1998, before treatment system installation, and groundwater monitoring was conducted a minimum of three times a year through 2000, followed by twice a year in 2001 and 2002. The Eight-Car Gantt Chart, Figure 2 (located at the end of the document), shows the system's operational timeframe and monitoring schedule through 2002. Table 2-2 presents background statistics on Eight-Car Header.

Table 2-2

Treatment Area Coverage	193,580 square feet
Operational Time (through 2002)	28,362 hours
Number of AS probes	199
Number of VE probes	60
Number of Groundwater Monitoring Points	8

3.0 REMEDIATION STATUS

This section analyzes the contaminant reduction at Valve Pit C and Eight-Car Header since installation of the treatment systems and compares current contaminant concentrations to cleanup goals established in the ROD. Based on these analyses, a flow chart is developed to help determine whether remediation has been successful.

3.1 Cleanup Goals

The following remedial objectives for OU3 were established in the ROD (U.S. Army, 1996):

- Restore groundwater to drinking water quality within a reasonable time frame;
- Reduce further migration of contaminated groundwater;
- Prevent use of groundwater with contaminants at concentrations above Safe Drinking Water Act levels; and
- For petroleum-contaminated soil, prevent migration of contaminants from soil into the groundwater that would result in groundwater contamination and exceedances of Federal Safe Drinking Water Act standards.

An institutional control policy for OU3 was established to prevent use of contaminated groundwater and soil. Specific cleanup goals for contaminants of concern in groundwater at OU3 source areas were based on Federal Safe Drinking Water Act levels and are summarized in Table 3-1 below.

Table 3-1

Contaminant of Concern	Cleanup Goal (mg/L)
Benzene	5
Toluene	1,000
Ethylbenzene	700
1,2-Dibromoethane (EDB)	0.05
1,2-Dichloroethane (DCA)	5
1,2,4-Trimethylbenzene (1,2,4-TMB)	1,850[1]
1,3,5-Trimethylbenzene (1,3,5-TMB)	1,850[1]

[1]Cleanup goals for TMB's at OU3 were recently increased from levels originally established in the ROD, through an agreement by the EPA, ADEC, and Army.

The ROD specified that remediation systems would be operated until these groundwater cleanup goals are achieved, and that natural attenuation would then be relied upon to reduce groundwater concentrations to Alaska Water Quality Standards. Although specific cleanup goals for soil were not established in the ROD, it stated that because soils are acting as a continuing source of contamination to the groundwater, active remediation of the soils would continue until Safe Drinking Water Act levels are consistently met. The ROD also stated that the groundwater remediation goals are expected to be achieved in five to ten years.

3.2 Remedial Progress

The following sampling and monitoring results were evaluated to track remedial progress of the treatment systems:

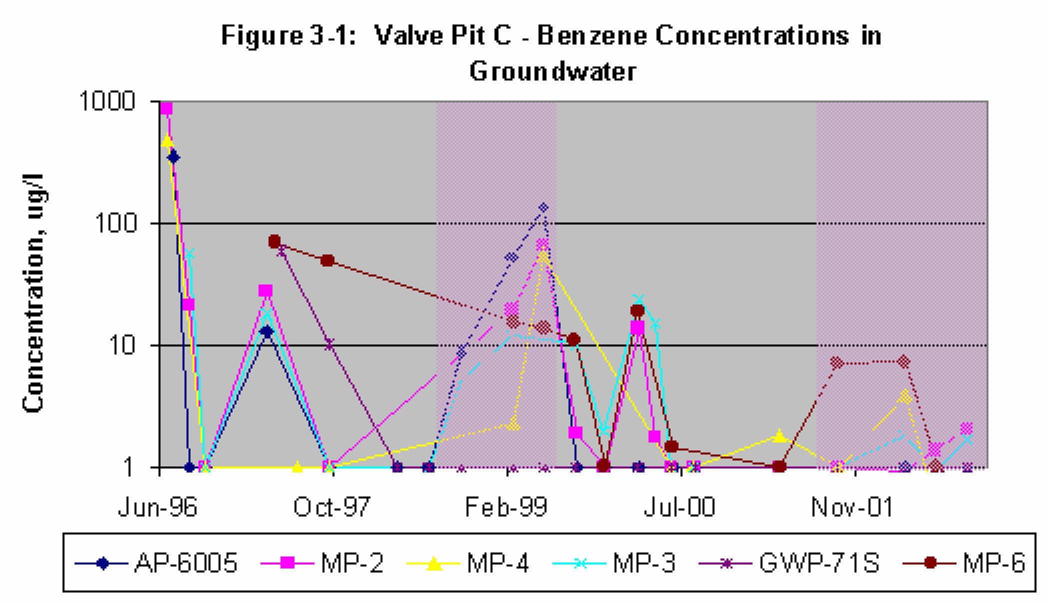
- Groundwater contaminant concentrations at locations within and downgradient of the treatment areas;
- Soil gas concentrations, including oxygen content, from soil gas probes and individual SVE lines;
- Vapor concentrations in the SVE system exhaust;
- The removal efficiency of the SVE system; and,
- The potential for biodegradation during system operation and shutdowns.

Although soil sampling results are available, trends in the soil concentrations will not be discussed, both because limited soil data has been collected and because the ROD states that soil must be remediated until groundwater cleanup goals are achieved.

3.2.1 Valve Pit C

Groundwater

Toluene and ethylbenzene have not been detected above ROD cleanup goals at VPC since the summer of 1996, and EDB, DCA, and TMB's have never been detected above cleanup goals at VPC. Therefore, trend analysis of groundwater contaminant concentrations will focus on benzene. Groundwater analytical concentrations at VPC during 2001 and 2002 are included in Table A-1 of the Appendix. Benzene concentration trends at six different sampling locations from 1996 to 2002 are depicted in Figure 3-1.



As seen in the graph above, benzene concentrations have decreased by at least two orders of magnitude at monitoring points within the treatment system area (AP-6005, MP-2, MP-4, and MP-3) and by at least one order of magnitude at downgradient monitoring points (GWP-71S and MP-6). A linear regression of these six monitoring points indicates that the average benzene concentration has decreased by 18 micrograms per liter (ìg/L) per year since installation of the treatment system.

Since VPC has gone through one rebound evaluation from August 1998 to July 1999 and is currently in the process of going through a second rebound evaluation, groundwater contaminant concentrations during shutdown periods can also be analyzed. Benzene concentrations during rebound evaluations, when the treatment system was off, are depicted in the shaded areas in Figure 3-1.

As seen above, benzene concentrations generally rebounded, or increased, after treatment system shutdowns. During the first yearlong rebound evaluation, benzene concentrations increased an average of 52 ìg/L per year at monitoring points within the treatment system area and 75 ìg/L per year at one downgradient monitoring location. During the second yearlong rebound evaluation, concentrations increased at a much lower rate. Benzene concentrations increased an average of 0.14 ìg/L per year at monitoring points within the treatment area and 0.78 ìg/L per year at one downgradient monitoring location. Data from these rebound trend analyses will be used to predict rebound concentrations for the Eight-Car Header treatment system. However, it should be noted that other factors, such as seasonal trends and groundwater elevations, could potentially contribute to fluctuations in groundwater concentrations.

Soil Gas

Soil gas concentrations were monitored monthly in VPC's four individual SVE lines since treatment system installation. Organic vapor concentrations and oxygen contents of the SVE lines, measured during system operation, are included in Table A-2 of the Appendix. Only one soil gas probe is available at VPC, and field-screening measurements were not collected from this probe until 1998; therefore, soil gas probe concentrations were not analyzed for VPC.

Organic vapors in the SVE lines were measured in percentage of the lower explosive limit (LEL) from 1996 through 1998. During 1999, 2000, and 2001, organic vapor concentrations were measured in parts per million (ppm), a smaller scale than LEL. Overall, vapor concentrations in the SVE lines greatly decreased in the first two years of operation, and remained low for the remaining four years of system operation.

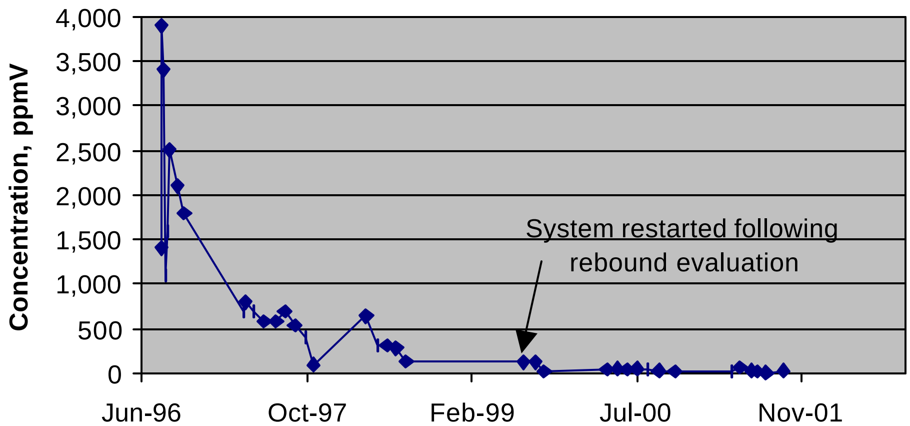
- Percent LEL dropped dramatically in SVE line 1 and SVE line 2 from system startup through 1998, peaking at 37 percent in the summer of 1996 and decreasing to zero percent by the summer of 1998.
- Percent LEL was initially five percent when SVE line 3 and SVE line 4 were installed in July 1997 and dropped to zero percent by August 1998.
- Readings fluctuated from 1999 to 2001, but all ppm readings were below the typical range for one percent LEL.

The soil gas concentrations do not point out any hot spots, areas within the treatment system exhibiting above average contaminant concentrations. Oxygen concentrations in the SVE lines show no discernible pattern.

SVE Vapor Exhaust

Vapor samples were collected from the SVE system exhaust monthly during VPC system operation, and samples were analyzed for total non-methane organic compounds (TNMOC) and for individual volatile organic compounds (VOC). Analytical vapor concentrations are included in Table A-3 of the Appendix and Figure 3-2 below shows the change in TNMOC concentrations since system startup.

Figure 3-2: Valve Pit C - TNMOC Concentrations in Vapor

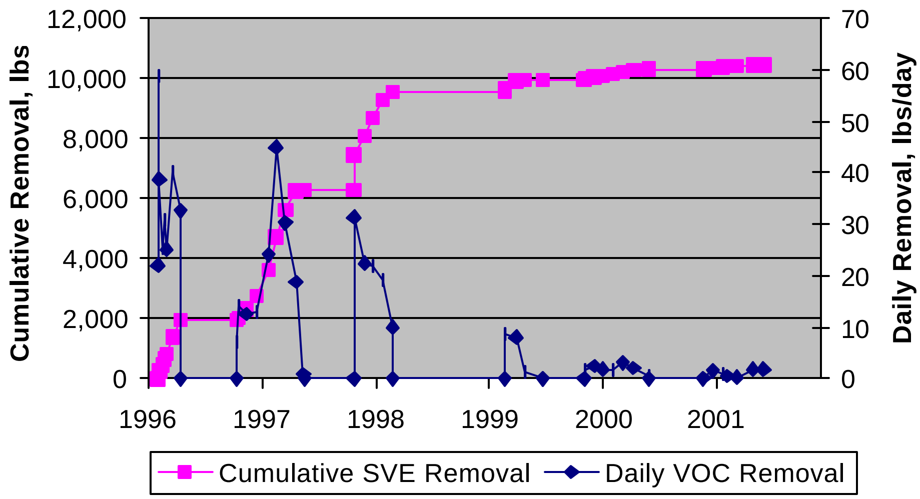


A trend analysis of the TNMOC concentrations over time indicates that the data approximate an exponential decrease over time rather than a linear decrease. The exponential trend analysis resulted in a high r^2 value of 0.90, indicating that an exponential relationship is a good fit. It should also be noted that vapor concentrations did not rebound in 1999 after the system was shutdown for a year. VOC concentrations show similar trends. Benzene, toluene, ethylbenzene, and xylenes (BTEX) concentrations peaked in August 1996 and have decreased by at least three orders of magnitude since system installation.

System Removal Efficiency

During monthly monitoring events, the SVE flow rate and system operational time were recorded. These measurements, along with the SVE exhaust gas analytical concentration, were used to calculate the daily mass removal of hydrocarbons by the treatment system. VPC has removed approximately 10,500 pounds of hydrocarbons over the life of the system. Figure 3-3 below shows trends in the daily and cumulative SVE removal rates.

Figure 3-3: Valve Pit C - Hydrocarbon Removal



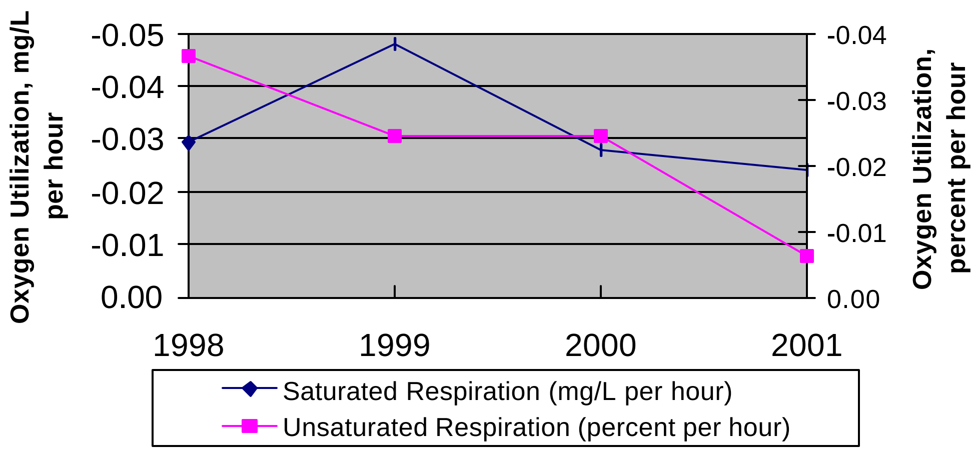
For the first two years of system operation, the daily removal rate decreased sharply and the cumulative removal increased rapidly. A linear regression shows that the cumulative removal increased by approximately 358 pounds per month from August 1996 to August 1998 (r^2 value is 0.94.) When the system was restarted after the 1998 to 1999 rebound evaluation, daily removal rates were an order of magnitude less and cumulative removal only increased approximately 24 pounds per month (r^2 value is 0.89). Overall, 90 percent of the VPC hydrocarbon removal was accomplished in the first two seasons of operation, and the remaining nine percent was removed during the final two seasons of operation.

Biodegradation

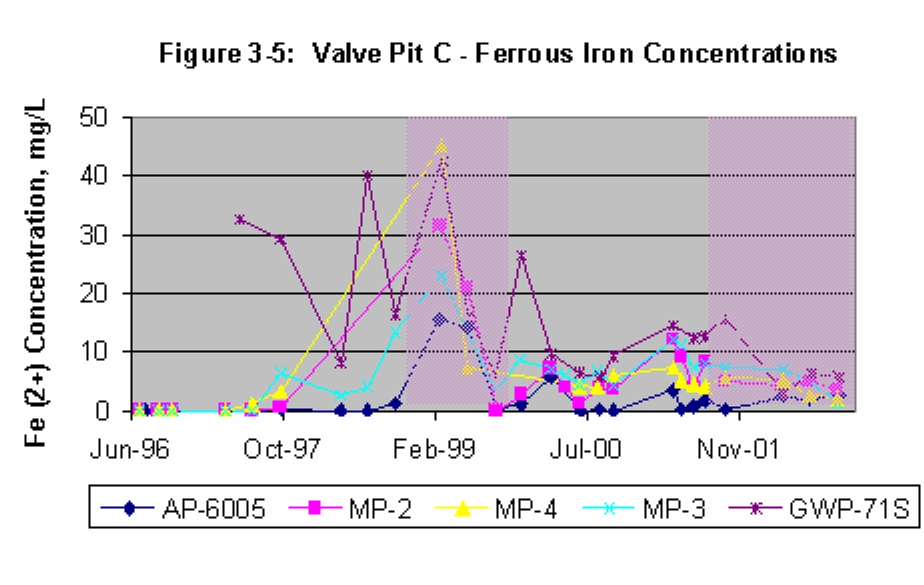
Biodegradation is the conversion or breakdown of hydrocarbons by microbial processes. It has been determined during previous investigations on Fort Wainwright that the primary mechanisms of biodegradation in these treatment areas are aerobic respiration, the production of ferrous iron (ferric iron reduction), and sulfate reduction. Aerobic respiration is the primary mechanism for biodegradation when the system is operating and providing a supply of oxygen to the subsurface. When the system is turned off, oxygen levels deplete and ferric iron followed by sulfate become the predominant electron acceptors in the biodegradation of hydrocarbons.

Respiration testing, in the saturated (below water) and unsaturated (vadose) zones, was conducted in conjunction with groundwater sampling events during system operation to measure aerobic respiration rates. Respiration testing consists of measuring the dissolved oxygen (DO) concentration in groundwater and the percent oxygen in soil gas while the system is operating, followed by monitoring of the decline in DO and percent oxygen for approximately one week following shutdown of the treatment system. Both saturated and unsaturated oxygen utilization rates have decreased from 1998 to 2001 at VPC. Annual estimated aerobic biodegradation has also decreased from 209 pounds of hydrocarbons destroyed in 1998 to 25 pounds destroyed in 2001. The decline in oxygen utilization rates is depicted in Figure 3-4 below.

Figure 3-4: Valve Pit C - Aerobic Respiration Rates



Both ferrous iron and sulfate concentrations in groundwater are measured by field-screening techniques during groundwater sampling events to help determine the potential for anaerobic biodegradation. During the first contaminant rebound study, it was determined that ferrous iron concentrations below 5 milligrams per liter (mg/L) indicate that sufficient ferric iron is available for anaerobic biodegradation. Trends in ferrous iron concentrations indicate that, as expected, concentrations increase when the system is turned off, as ferric iron is reduced to ferrous iron in the biodegradation process, and decrease when the system is turned back on, as ferrous iron is oxidized back into ferric iron. However, ferrous iron concentrations have generally decreased over time and did not increase as significantly during the second rebound evaluation. Trends in ferrous iron concentrations at five sampling locations are depicted in Figure 3-5 below.



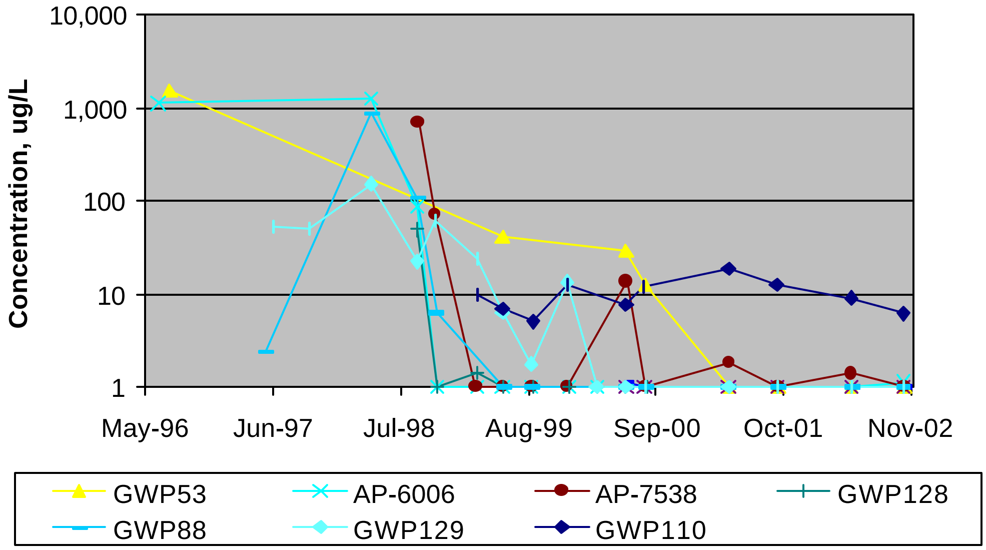
Sulfate concentrations have not shown a significant trend. The decreases in aerobic respiration rates and ferrous iron concentrations both lead to the conclusion that the biodegradation rate at VPC has decreased over time. This may be attributed to both a decrease in hydrocarbon contaminant concentrations, leaving less organic compounds available for microorganisms to convert, and poor airflow in the AS probes, resulting in insufficient subsurface oxygen for respiration and for oxidation of ferrous iron into ferric iron. Groundwater electron acceptor concentrations (DO, ferrous iron, and sulfate) at VPC since treatment system installation are included in Table A-4 of the Appendix.

3.2.2 Eight-Car Header

Groundwater

Toluene and ethylbenzene have not been detected above ROD cleanup goals since the summer of 1998, and EDB, DCA, and TMB's have never been detected above cleanup goals at Eight-Car. Therefore, trend analysis of groundwater contaminant concentrations will focus on benzene. Groundwater analytical concentrations at Eight-Car during 2001 and 2002 are included in Table A-5 of the Appendix. Benzene concentration trends at seven different sampling locations through 2002 are depicted in Figure 3-6 below.

Figure 3-6: Eight-Car Header -
Benzene Concentrations in Groundwater



Benzene concentrations have significantly decreased, by up to four orders of magnitude at monitoring points within the treatment system area (GPW-53, AP-6006, AP-7538, and GWP-128) and by three orders of magnitude at both downgradient monitoring points (GWP-88 and GWP-129). Benzene concentrations did not exceed the cleanup goal at any of these monitoring locations in 2001 or 2002. However, benzene steadily remains above the cleanup goal at an upgradient monitoring location, GWP-110. A linear regression of the six monitoring points within and downgradient of the treatment system indicates that the average benzene concentration has decreased by 106 ìg/L per year since installation of the treatment system. However, this is only an approximation, as some of the trends in benzene concentrations from individual monitoring points are better fitted to an exponential decrease over time.

Soil Gas

Eight-Car is comprised of 60 individual SVE lines distributed throughout five different areas, or treatment zones. Soil gas concentrations at each SVE line and at each zone's manifold were measured monthly during treatment system operation. In addition, soil gas concentrations in soil gas probes installed throughout the treatment area were measured during each sampling event. Organic vapor concentrations and oxygen contents measured in the zone manifolds, which represent the combined concentrations from the SVE lines within the respective zones, are included in Table A-6 of the Appendix.

Organic vapors in the SVE lines were generally measured as percentage of the LEL. Overall, concentrations rapidly decreased for approximately the first year of treatment system operation and then tapered off during the next three years.

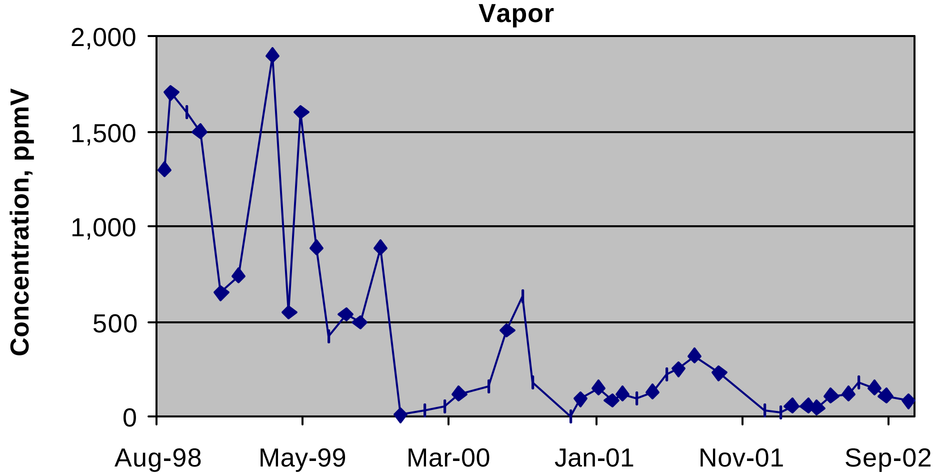
- During the summer of 1998, following treatment system installation, the LEL ranged from 52 percent in Zone 1 to 26 percent in Zone 4.
- Concentrations rapidly decreased through the fall of 1999, and in September 1999 measurements fell below 10 percent LEL in each zone.
- Concentrations fluctuated below 10 percent LEL, with an overall slight decreasing trend, throughout 2000, 2001, and 2002.
- The highest reading in 2002 was four percent LEL in Zone 3; however, at least one percent LEL was measured in each zone.
- Soil gas concentrations appear to be highest in the summer months and decrease over the winter months.

Although soil gas concentrations from the zone manifolds don't clearly show hot spots, measurements from individual SVE lines can be studied to reveal several hot spots, or more contaminated areas, remaining in the soil. Oxygen concentrations in the zone manifolds and in soil gas probes show no discernible patterns. Although organic vapors in soil gas probes have not been tracked at Eight-Car in the past, they will be measured and recorded during future shutdown periods.

SVE Vapor Exhaust

Vapor samples were collected from the SVE system exhaust and the oxidizer exhaust monthly during Eight-Car system operation, and samples were analyzed for TNMOC and VOC. Analytical vapor concentrations are included in Table A-7 of the Appendix, and Figure 3-7 below shows changes in TNMOC concentrations since system startup.

Figure 3-7: Eight-Car Header - TNMOC Concentrations in Vapor

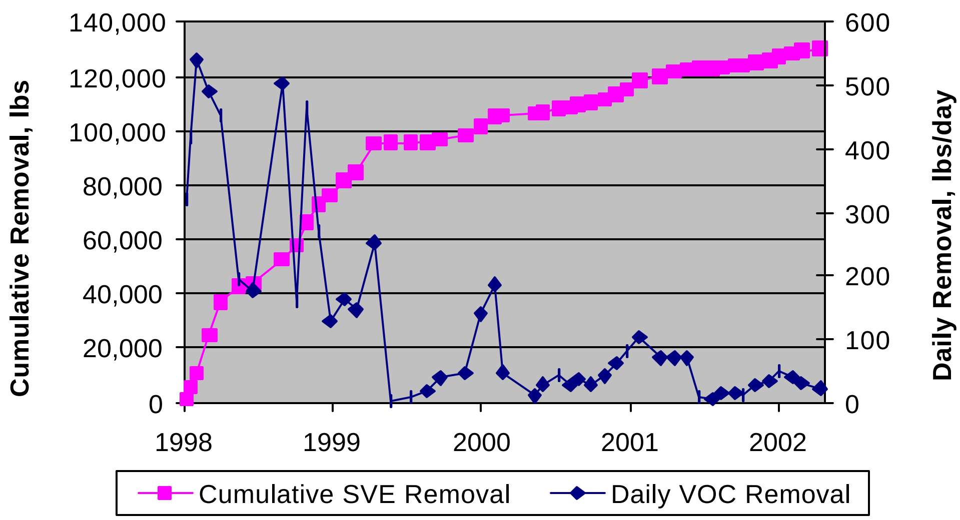


The graph shows that concentrations have decreased by an order of magnitude since system startup. A linear regression results in an approximate decrease in the TNMOC concentration of 300 parts per million by volume (ppmV) per year. It is also apparent from the graph above that SVE exhaust concentrations peak in the summer and reach a minimum in the winter. TNMOC concentrations during 2002 ranged from 24 ppmV in January to 180 ppmV in July. VOC concentrations show similar trends; BTEX concentrations have decreased by two orders of magnitude since system startup.

System Removal Efficiency

Eight-Car has removed approximately 130,255 pounds of hydrocarbons over the life of the system. Figure 3-8 below shows trends in the daily and cumulative SVE removal rates.

Figure 3-8: Eight-Car Header - Hydrocarbon Removal

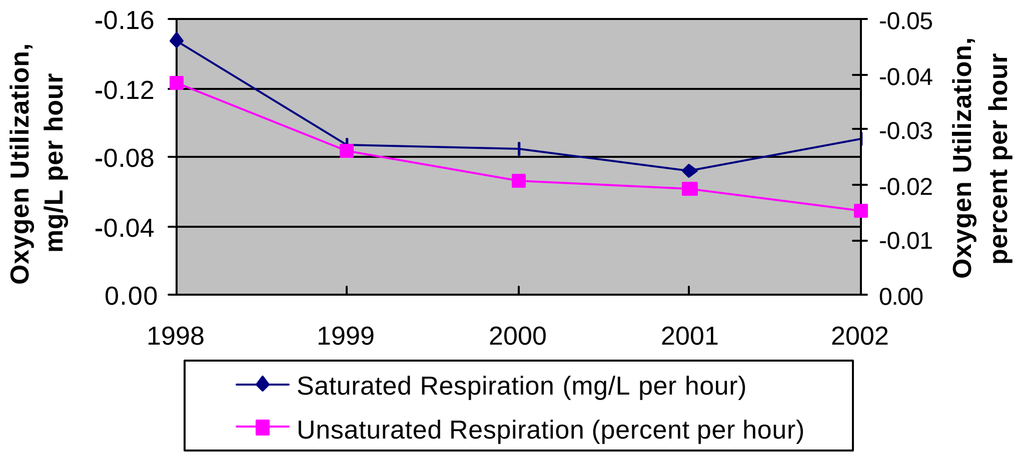


The daily hydrocarbon removal rate at Eight-Car has decreased from an annual maximum of 541 pounds per day in August 1998 to an annual maximum of 48 pounds per day in July 2002. A linear regression shows that the cumulative removal has increased by approximately 2,066 pounds per month since system startup (r^2 value is 0.85.) However, studying the cumulative removal by year results in an approximate increase of 5,550 pounds per month through 1999 (r^2 value is 0.97), followed by an approximate increase of 1,098 pounds per month from 2000 through 2002 (r^2 value is 0.98.) A comparison of the r^2 values reveals that the second yearly regression analysis is much more representative. Overall, 74 percent of the Eight-Car hydrocarbon removal was accomplished in the first two years of operation, and the remaining 26 percent was removed during the last two years of operation.

Biodegradation

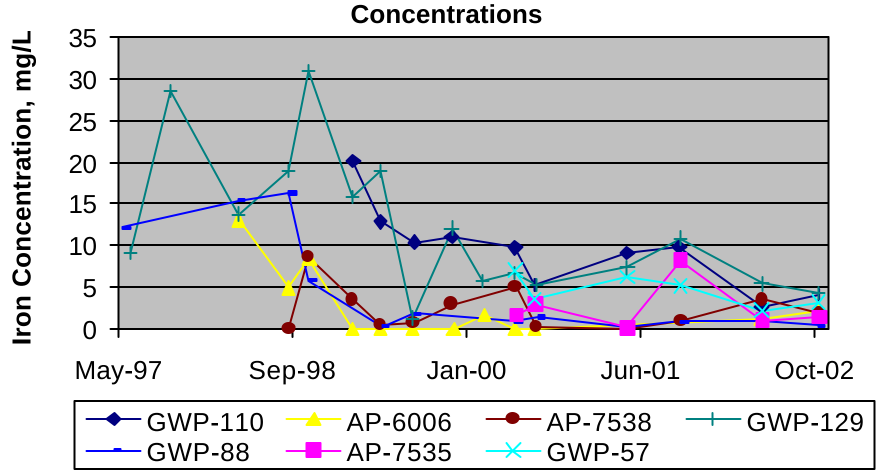
Respiration testing, in the saturated and unsaturated zones, was conducted during each groundwater sampling event at Eight-Car to measure aerobic respiration rates. Both saturated and unsaturated oxygen utilization rates have generally decreased from 1998 to 2002. Monthly estimated aerobic biodegradation has also decreased from approximately 434 pounds of hydrocarbons destroyed per month in 1998 to 295 pounds destroyed per month in 2002. The decline in oxygen utilization rates is depicted in Figure 3-9 below.

Figure 3-9: Eight-Car Header - Aerobic Respiration Rates



Both ferrous iron and sulfate concentrations were field-screened during groundwater sampling events to help determine the potential for anaerobic biodegradation. Ferrous iron concentrations in wells within, downgradient, and upgradient of the treatment system have decreased since the system began operation in August 1998. With the exception of one sampling location, GWP-53, ferrous iron concentrations were below 5 mg/L within the treatment area in 2002. Ferrous iron concentrations outside the treatment area, in upgradient probe GWP-110 and downgradient probe GWP-129, remain higher. Trends in ferrous iron concentrations at seven sampling locations are depicted in Figure 3-10 below.

Figure 3-10: Eight-Car Header - Ferrous Iron Concentrations



Sulfate concentrations have not shown a significant trend. The decrease in aerobic respiration rates over time may be due to both a decrease in contaminant concentrations and a loss in the effectiveness of the AS probes to aerate the subsurface. However, low ferrous iron concentrations within the treatment area indicate that there is sufficient oxygen available to oxidize ferrous iron into ferric iron, creating a favorable environment for anaerobic biodegradation. Groundwater electron acceptor concentrations (DO, ferrous iron, and sulfate) at Eight-Car since treatment system installation are included in Table A-8 of the Appendix.

3.3 Remediation Flow Chart

Based on the above analyses of remedial progress at Valve Pit C and Eight-Car Header, a flow chart was developed to help assess whether remediation has been successful and can be considered essentially complete. The remediation flow chart developed for this paper is presented as Figure 3-11 at the end of this section.

There are three key steps incorporated into the flow chart: groundwater contaminant concentrations, secondary indicators, and other factors. Groundwater is the most critical factor, because it has specific cleanup goals that were established in the ROD. In assessing the remedial progress in regards to groundwater contamination, the following three questions should be asked:

- Have ROD cleanup goals been achieved? If so, are concentrations consistently below cleanup goals during system operation and during rebound evaluations? If not, are exceedances localized in one area?
- Have contaminant concentrations decreased over time? What are the overall trends and did the trends continue during any system shutdowns?
- Has free-phase floating product been eliminated within the treatment area?

If answers to each of these questions are positive, then groundwater remediation can be considered successfully completed.

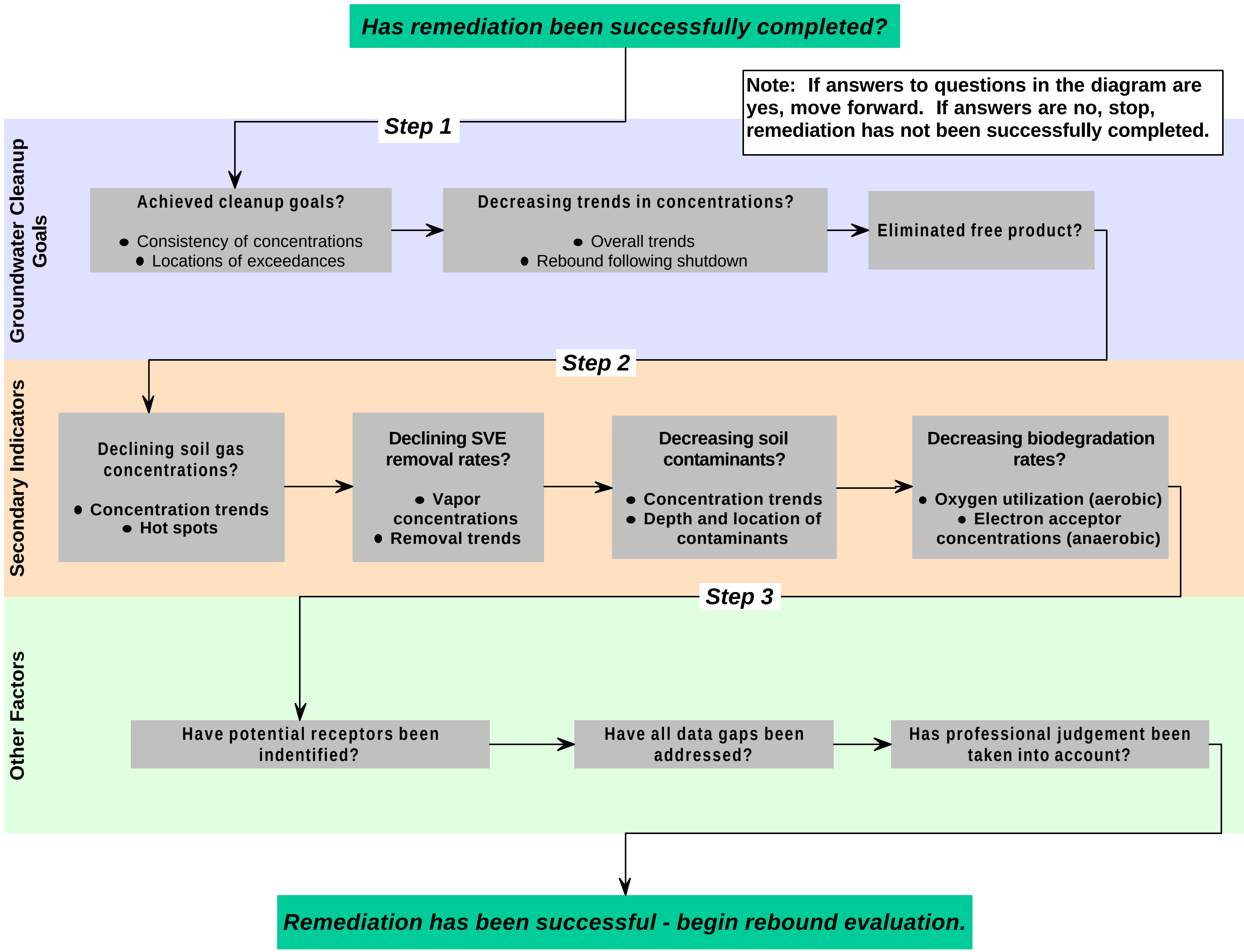
Secondary indicators can also be essential in determining the success of a treatment system. Although specific cleanup goals were not established in the ROD for these secondary indicators, they are a direct indication of whether the system is removing contamination and thereby reducing groundwater concentrations. In assessing the remedial progress of a treatment system, the following questions should be asked:

- Are soil gas concentrations decreasing, and do soil gas concentrations indicate any remaining hot spots within the treatment area?
- Are SVE exhaust vapor concentrations decreasing, and has SVE removal efficiency decreased over time?
- What are the depth and location of remaining contaminants in the soil, and are the concentrations at these locations decreasing?
- Are biodegradation rates, both aerobic biodegradation during system operation and anaerobic biodegradation during system shutdowns, decreasing?

The answers to each of these questions will not only help evaluate the overall effectiveness of the treatment system, but will also reveal whether a system is continuing to be efficient in its current mode of operation. For example, trends in contaminant concentrations may show that the system has effectively reduced contamination over time; however, they may also reveal that the reductions in concentrations have been decreasing over time, indicating that the system efficiency is decreasing.

Once the tangible results of monitoring and sampling have been reviewed, other factors that rely on professional judgment must be considered. First, the proximity of the treatment area to sensitive receptors, such as rivers or drinking water sources, must be factored into the decision to shutdown a treatment system. Although the cleanup goals established in the ROD pertain to groundwater within OU3, a more conservative approach may be appropriate for areas near sensitive receptors. Also, any data gaps in the treatment area must be realized. If samples have not been collected from a certain area or analyzed for a specific compound, more monitoring may be required before a decision can be made. Finally, professional judgment from a party familiar with the site and the treatment system is invaluable in the decision-making process.

Figure 3-11: Remediation Flow Chart



4.0 COST EFFECTIVENESS

Along with evaluating whether remediation has been successful, another consideration in the shutdown process is to determine the cost effectiveness of shutting down a treatment system. In this section, costs for continuing operation of the Valve Pit C and Eight-Car Header treatment systems are analyzed, based upon estimated system operational costs and long-term monitoring costs.

4.1 Objectives

The purpose of this analysis is to minimize future costs, while meeting remediation goals established in the ROD. In order to minimize future costs, the following objectives must be met:

- Minimize the total number of years the treatment system must remain operational;
- Minimize the number of rebound evaluations that must be conducted; and
- Therefore, minimize the timeframe before long-term monitoring is completed.

Minimizing the years of system operation and subsequent years of rebound evaluations both involve shutting down a treatment system at the optimal time. Turning a treatment system off before remediation goals are met will only prolong years of operation, as the system will have to be restarted after the rebound evaluation and a year of active treatment will be lost. Turning a treatment system off long after remediation goals are met will result in unnecessary operational costs. Minimizing the timeframe before long-term monitoring is completed also involves shutting down a system at the optimal time. Assuming that long-term monitoring will occur for ten years after the final rebound evaluation, starting long-term monitoring as soon as possible will minimize future costs.

Therefore, the key component of cost minimization is to turn the treatment system off at a time when contaminant concentrations have been sufficiently reduced so that they will not rebound above cleanup goals when the system is shut down. As part of this cost analysis process, developed to help minimize future treatment costs, the cost per pound of hydrocarbon removal over time was considered and future cost scenarios were examined.

4.2 System Costs

Before analysis, the costs associated with operating and monitoring a treatment system must be established. System operational costs and long-term monitoring costs for VPC and Eight-Car are presented below. All costs are present worth values in 2002.

4.2.1 System Operational Costs

System operational costs include annual operations, maintenance, and monitoring costs associated with running the treatment systems. These costs will be incurred each year that the treatment system is operational. Capital costs of installing the treatment systems will not be considered, as they are sunk costs, and it is assumed that the system has negligible salvage value. Table 4-1 below presents annual operation costs for VPC and Eight-Car (FES, 2002b).

Table 4-1

Cost Category	Valve Pit C	Eight-Car Header
System Operation	$4,940	$9,880
Maintenance	$3,840	$9,960
System Monitoring	$8,400	$22,800
Groundwater Sampling	$7,560	$8,640
Reporting	$6,500	$9,500
Total Annual Cost	$31,240	$60,780

System operation costs include weekly system checks. Since VPC is not equipped to run in the winter, it is assumed that this system will run for 26 weeks a year. It is assumed that Eight-Car will run for 52 weeks a year. Maintenance costs include routine monthly maintenance and more comprehensive semi-annual maintenance. System monitoring costs include monthly system monitoring, to record system parameters and collect SVE exhaust gas analytical samples, and semi-annual respiration testing. Groundwater sampling costs include sampling seven and eight wells at VPC and Eight-Car, respectively, for volatile organic compounds. Reporting costs include annual monitoring reports and meetings with clients. All costs consist of labor hours, administrative costs, and outside contractor/laboratory expenses.

4.2.2 Long-Term Monitoring Costs

Long-term monitoring costs include the costs of groundwater sampling, soil gas monitoring, and subsequent reporting. These costs will be incurred each year the system is non-operational, both during rebound evaluations and after the system has been decommissioned. Table 4-2 below presents long-term monitoring costs for VPC and Eight-Car (FES, 2002b).

Table 4-2

Cost Category	Rebound Evaluation		After Decommissioning	
	Valve Pit C	**Eight-Car**	**Valve Pit C**	**Eight-Car**
Groundwater Sampling	$15,120	$17,280	$3,780	$4,320
Soil Gas Monitoring	$320	$960	$0	$0
Reporting	$8,000	$8,000	$3,200	$3,200
Total Annual Cost	$23,440	$26,240	$6,980	$7,520

It is assumed that groundwater sampling will occur quarterly during rebound evaluations and annually after the systems have been decommissioned, and all samples will be analyzed for volatile organic compounds (CH, FES, VOOM, 2002). Soil gas monitoring will occur quarterly during rebound evaluations. Monitoring reports will be submitted annually. All costs consist of labor hours, administrative costs, and outside contractor/laboratory expenses.

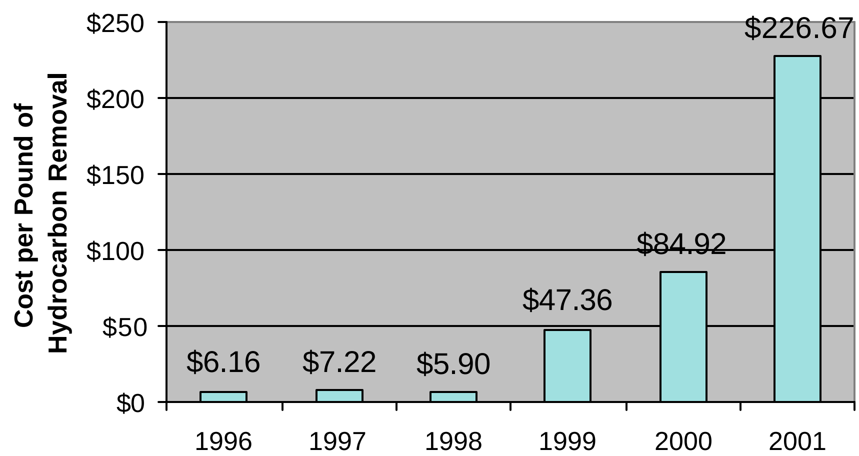
4.3 Cost Analysis

The cost analyses conducted for VPC and Eight-Car consisted of studying past unit costs and analyzing future costs.

4.3.1 Past Unit Costs

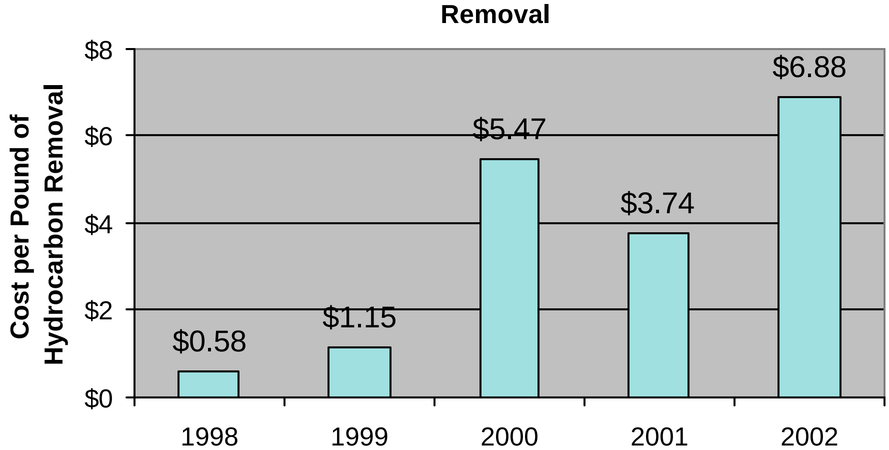
The first step in the cost analysis was to study the cost per pound, or unit cost, of contaminant removal since the treatment systems were installed. Although these past unit costs will not directly affect the shutdown process, since they are sunk costs, they can be used as a comparison tool when assessing the continuing cost effectiveness of a treatment system. Figures 4-1 and 4-2 below present the system operational cost per pound of hydrocarbon removal each year for VPC and Eight-Car, respectively.

Figure 4-1: Valve Pit C - Operational Cost vs. Removal



Since the VPC treatment system did not operate the entire 26 weeks that the annual operational costs were based upon in 1996, 1998, and 1999, annual system operational costs were modified to reflect the costs for the actual amount of time the system operated each year. The graph above clearly shows that the cost per pound of hydrocarbon removal began to steeply rise in 1999, after the system was restarted following the first rebound evaluation. Overall, the cost per pound of removal rose from a minimum of $5.90 per pound in 1998 to $226.67 per pound in 2001, an increase of over 3,700 percent.

Figure 4-2: Eight-Car Header - Operational Cost vs. Removal



Since the Eight-Car treatment system only operated for approximately five months of 1998 and 10 months of 2002, the annual system operational costs were decreased to reflect the actual amount of operational time for those years. The graph above shows that the cost per pound of removal has not increased as rapidly as it did for VPC. The cost per pound has increased from a minimum of $0.58 per pound in 1998 to $6.88 per pound in 2002, an increase of over 1,100 percent. It should also be noted that the cost of removal prior to shutdown was two orders of magnitude greater at VPC, $226.67 per pound at VPC compared to $6.88 per pound at Eight-Car.

4.3.2 <u>Future Cost Scenarios</u>

The second step in the cost analysis was to examine possible cost scenarios for VPC and to analyze future cost scenarios for Eight-Car. The purpose of analyzing the cost scenarios is to develop a methodology for determining cost differences associated with shutting down a treatment system at different times. Cost scenarios for Valve Pit C are presented on Table 1 and future cost scenarios for Eight-Car Header are presented on Table 2. For comparison purposes, all costs were converted to present worth value in 2002, using an interest rate of eight percent.

Valve Pit C

Since VPC is completing its second rebound evaluation and groundwater concentrations have not rebounded above remedial goals, it is assumed that this treatment system can move into the long-term monitoring phase. Therefore, the actual cost scenario can be examined for this treatment system. Table 1 (located at the end of the document) shows the actual VPC cost scenario and the costs that would have been incurred for two different scenarios.

Conducting the first rebound evaluation from 1998 to 1999 did not significantly affect the overall costs for this treatment system. Without the first rebound evaluation, the total cost would have been less than one percent greater if the system was operated each year through 2001. If the first rebound evaluation had not been conducted and the system was operated through 2000, the total cost would have been approximately ten percent less. Since VPC is a relatively small treatment system, operational costs are only slightly greater than rebound evaluation costs; therefore, shutting the system down at different times does not cause a vast difference in the total costs.

Eight-Car Header

Future cost scenarios for Eight-Car were developed with the assumption that the first rebound evaluation will take place in 2003. Scenarios were then developed for one to five additional years of system operation with varying years of rebound evaluations, from only one rebound evaluation before long-term monitoring to a rebound evaluation after each year of treatment. Table 2 (located at the end of the document) shows the future Eight-Car costs for 16 different scenarios.

While the obvious conclusion from Table 2 is that the total years should be minimized, other conclusions can be drawn. First, it is most economical to conduct a rebound evaluation only after there is a possibility that the system will not have to be restarted. Each rebound evaluation that results in turning the treatment system back on increases the total years and, hence, increases the total cost. For example, if Eight-Car has to be restarted and operated for one additional year after the rebound evaluation in 2003, the total future cost will be $137,292. However, if the system were operated during 2003 and successfully turned off in 2004, the total cost would be $122,036, or 11 percent less (this cost is not shown in Table 2, as it is not a possible future scenario).

Also, as the years of treatment system operation increase, one additional year of operation has less of an affect on the total cost. For example, the incremental cost increase of operating the system for five years with only one additional final rebound evaluation versus operating the system for four years with a rebound evaluation after each year of treatment is $9,163. Comparatively, the incremental cost increase of operating the system for two additional years with only one final rebound evaluation versus operating the system for only one more year with a final rebound evaluation is $43,739.

4.4 Optimal Shutdown Time

As demonstrated in the above sections, the key to cost minimization is turning a treatment system off at a point in time when contaminant concentrations have been sufficiently reduced so that they will not rebound. While this is not an exact science, an educated guess can be made based on system monitoring results and data collected during rebound evaluations at similar treatment systems.

For Eight-Car, data from rebound evaluations at VPC were compared to Eight-Car monitoring results to estimate the expected rebound. The expected benzene rebound at Eight-Car was estimated based on the observed benzene rebound during the first rebound evaluation at VPC; benzene concentrations are expected to increase 52 ìg/L at monitoring points within the treatment system and 75 ìg/L at downgradient monitoring points (see Section 3.2.1). However, many differences between VPC and Eight-Car could have a large influence on the rebound, as outlined in Table 4-3 below.

Table 4-3

Difference	Valve Pit C	Eight-Car Header
Pre-Treatment benzene concentrations	437 ìg/L within treatment area, 65 ìg/L downgradient	870 ìg/L within treatment area, 509 ìg/L downgradient
Upgradient benzene concentrations	Below cleanup goals	Exceed cleanup goals with no decreasing trend (indicating upgradient source)
Operational time	12 months prior to first shutdown, 28 months prior to second shutdown	51 months
SVE vapor concentrations	Exponential decrease	Linear decrease
Cost per pound of hydrocarbon removal	$226.67 prior to final shutdown	$6.88 prior to 2003 rebound evaluation

Although Eight-Car has been operating much longer than VPC, the other differences indicate that Eight-Car may be more likely to have a greater contaminant concentration rebound after system shutdown. In addition, Eight-Car is a much larger treatment system with a greater areal extent of contamination. For these reasons, it is most likely not the optimal time to shutdown Eight-Car Header. Assuming the system will have to be restarted after the 2003 rebound evaluation, an additional year will have been added, not minimizing the total cost. However, information gathered during this rebound evaluation will be invaluable in assessing the optimal time to shutdown other treatment systems on Fort Wainwright.

This methodology of studying unit contaminant removal costs over time, calculating future cost scenarios, and estimating the optimal time for shutdown based on past results should be employed on a case-by-case basis. As each treatment system will have unique operational and long-term monitoring costs, total costs will vary. However, the objective will always be to minimize the total cost by turning a treatment system off at a time when contaminant concentration are no longer expected to rebound.

As more treatment systems on Fort Wainwright go through shutdowns and subsequent rebound evaluations, such as Eight-Car Header in 2003, more information will become available for comparison purposes. The ultimate goal should be to gather enough rebound evaluation data in order to predict the chance of contaminant rebound at other treatment systems. This chance of rebound can then be weighed against future costs to determine whether or not it is the optimal time to shutdown.

5.0 SHUTDOWN MONITORING PROGRAM

Once the decision to shutdown a treatment system has been made, a monitoring program must be established to track contaminant concentrations both during the rebound evaluation and during the long-term monitoring phase. The purpose of this monitoring is to study whether groundwater contaminant concentrations will remain below cleanup goals when the treatment system is not operating. If contaminant concentrations increase above cleanup goals, an operational decision must be made.

5.1 Rebound Evaluation

Rebound evaluation monitoring should be conducted on a quarterly basis and consist of groundwater sampling and soil gas monitoring (CH, FES, and VOOM, 2002). Figure 3 (located at the end of the document) depicts the shutdown process monitoring schedule for Eight-Car Header during the 2003 rebound evaluation.

Quarterly monitoring was chosen as a more conservative sampling frequency than the semi-annual sampling conducted during system operation due to the unknown nature of the potential contaminant rebound. Groundwater samples should be analyzed for volatile organic compounds, in order to monitor the contaminants of concern with established cleanup goals, and field-screened for ferrous iron and sulfate, in order to track the potential for anaerobic biodegradation. Soil gas monitoring should consist of measuring organic vapors and oxygen content in soil gas probes located throughout the treatment area. In the event that groundwater contaminant concentrations increase and exceed cleanup goals, the soil gas monitoring will help pinpoint hot spots within the treatment area that may be causing groundwater exceedances.

5.2 Long-Term Monitoring

Long-term monitoring should be conducted annually and consist of groundwater sampling. Once the rebound evaluation groundwater monitoring has shown that concentrations do not appear to be increasing above cleanup goals, a less conservative sampling frequency is appropriate. Similar to rebound evaluation monitoring, groundwater samples should be analyzed for volatile organic compounds and field-screened for ferrous iron and sulfate.

5.3 Operational Decision

The results from quarterly monitoring during the rebound evaluation will be used to make a decision concerning the operation of the treatment system. Monitoring results will be evaluated after each sampling event and these evaluations will lead into an operational decision made at the end of the year, as shown on Figure 3. As discussed above, the treatment system should be turned back on at the end of the yearlong rebound evaluation if groundwater contaminant concentrations have increased above cleanup goals and/or concentrations are showing a significant increasing trend. However, the decision to restart the treatment system does not necessarily have to be straightforward; different operational scenarios can be considered. Different available operational modes include:

- Restarting the entire treatment system;
- Restarting specific zones within the treatment system;
- Restarting the treatment system in air sparge mode only; and
- Restarting specific zones in air sparge mode only.

If groundwater contaminant concentrations have increased above cleanup goals throughout the treatment area, restarting the entire system is most likely the best option. However, if concentrations have only increased in specific zones within the treatment area or if soil gas monitoring results indicate that hot spots within the treatment area may be responsible for contaminant concentration increases, resuming treatment in these more contaminated areas should be considered. This reduced area treatment will focus air sparging and soil vapor extraction capabilities in the areas of greater contamination, resulting in more effective treatment.

Restarting the treatment system in air sparge mode only should be considered if contaminant concentrations rebound but monitoring results indicate that the remaining contamination is present predominantly in the groundwater rather than the soil. The soil vapor extraction system would remain shutdown and, therefore, soils in the unsaturated zone would not be actively treated. Operation of the air sparge system in the saturated zone, below the water table, would help reduce dissolved contaminant concentrations in the groundwater. Similarly to full-scale treatment, operation of only the air sparge system could also be employed on a zone-by-zone basis.

6.0 CONCLUSIONS

The methodology developed in this paper for shutdown of the Valve Pit C and Eight-Car Header treatment systems can be applied to the shutdown process for other treatment systems on Fort Wainwright, AK. Since individual treatment systems will have unique characteristics, including varying degrees of remedial progress and differing associated costs, a generic shutdown process cannot be developed. However, this methodology can be utilized at other treatment systems to help make decisions regarding system shutdown.

As demonstrated for VPC and Eight-Car, the developed shutdown process consists of four steps:

1) Review the operational history of the treatment system to gain background knowledge of the site characteristics and contaminants along with an understanding of the treatment system itself.

2) Assess the remedial progress of the treatment system. The flow chart developed in Section 3.3 of this paper lays out the framework for determining whether remediation has been successful and a rebound evaluation should begin. The most important factor in remedial progress is whether or not groundwater cleanup goals have been achieved. Other factors that should be considered include soil gas concentrations, system contaminant removal, soil contaminant concentrations, and biodegradation rates. Finally, professional judgment from an individual familiar with the treatment system must be considered.

3) Consider the cost-effectiveness of continued treatment. The following steps were developed in order to minimize future costs: study unit contaminant removal costs over time; calculate and compare future cost scenarios; and estimate the optimal time for shutdown based on data from other treatment systems' rebound evaluations.

4) Once the decision to shutdown a treatment system has been made, employ a monitoring program to evaluate contaminant concentrations while the system is off. The monitoring program should consist of groundwater sampling and soil gas monitoring, and the results should be interpreted and used to make a decision regarding the future operation of the treatment system.

As more treatment systems on Fort Wainwright go through the shutdown process, additional data will be gathered concerning contaminant rebound during system shutdown. Subsequently, as more insight is gained into the potential rebound, the estimation of an optimal shutdown time will become more accurate and cost minimization will become more achievable. In other words, each shutdown will improve the decision-making process for future shutdowns. Therefore, it is recommended that rebound evaluation data continue to be gathered and studied in order to improve the shutdown process and refine post-shutdown monitoring programs for similar treatment systems operating on Fort Wainwright.

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Tables

Table 1 - Cost Scenarios
Valve Pit C

Scenario					Total Cost (Present Worth in 2002)
Description	**Years of Operation**	**Years of Rebound Study**	**Years of Long-Term Monitoring**	**Total Years**	
Actual operational scenario, 1996 - 2002, with long-term monitoring through 2012	4	2	10	16	$286,307
Operational scenario without first rebound evaluation and with operation through 2001	5	1	10	16	$287,278
Operational scenario without first rebound evaluation and with operation through 2000	4	1	10	15	$259,161

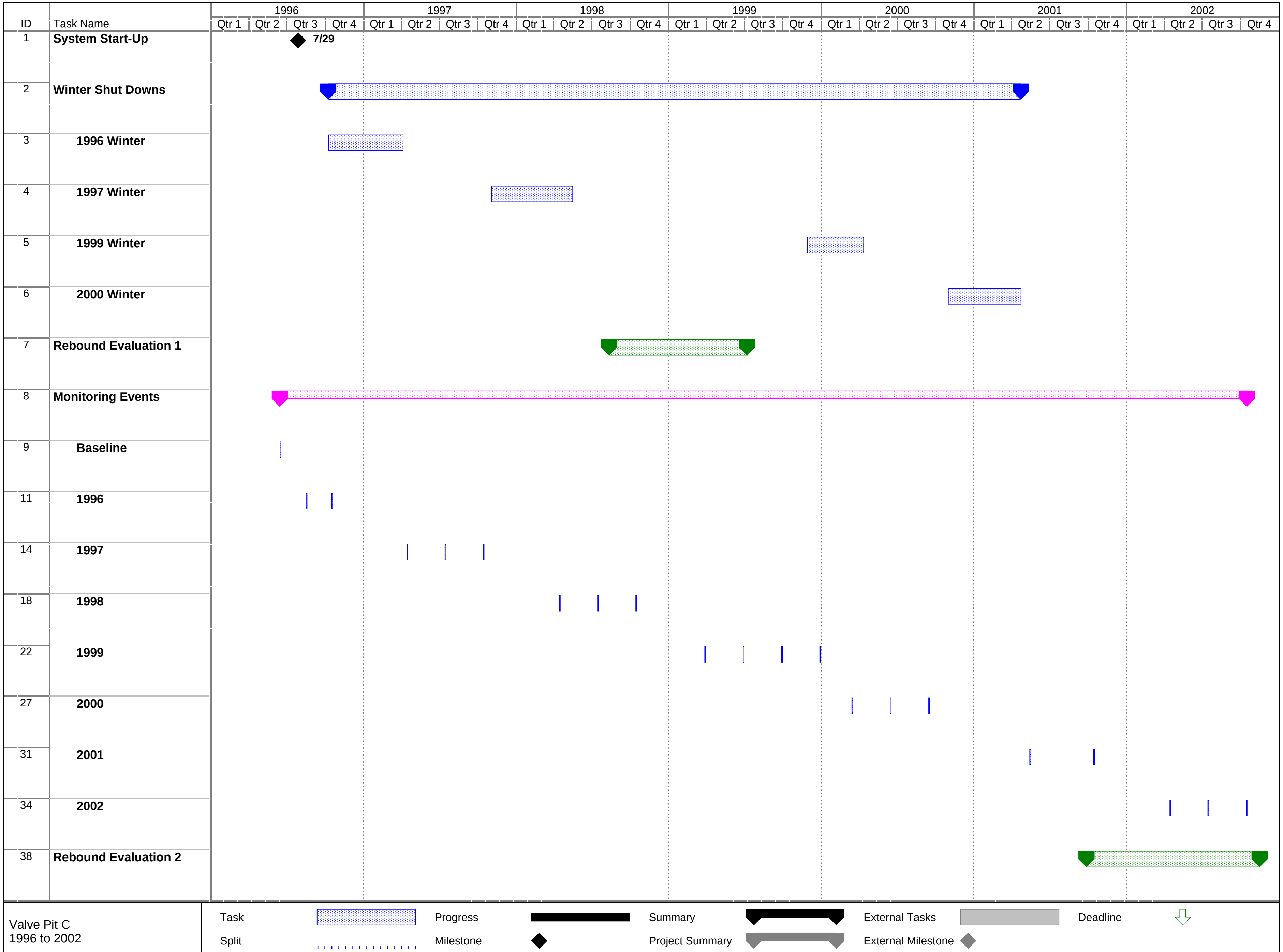
Note: An interest rate of 8% was assumed for present worth calculations.

Table 2 - Future Cost Scenarios
Eight-Car Header

Scenario					Total Cost (Present Worth in 2002)
Description	**Years of Operation**	**Years of Rebound Study**	**Years of Long-Term Monitoring**	**Total Years**	
Rebound evaluation in 2003, followed by 10 years of long-term monitoring	0	1	10	11	$71,018
Rebound evaluation in 2003, followed by an additional year of operation in 2004, and a subsequent rebound evaluation in 2005	1	2	10	13	$137,292
Two years of additional system operation required	2	2	10	14	$181,031
	2	3	10	15	$194,111
Three years of additional system operation required	3	2	10	15	$221,530
	3	3	10	16	$233,641
	3	4	10	17	$242,824
Four years of additional system operation required	4	2	10	16	$259,029
	4	3	10	17	$270,243
	4	4	10	18	$278,746
	4	5	10	19	$284,588
Five years of additional system operation required	5	2	10	17	$293,751
	5	3	10	18	$304,134
	5	4	10	19	$312,007
	5	5	10	20	$317,416
	5	6	10	21	$320,394

Notes: The cost scenarios assume that a rebound evaluation will occur during 2003.
Rebound evaluations may occur as often as after each year of operation or only after the final year of operation.
An interest rate of 8% was assumed for present worth calculations.

Figures



ID
Task Name
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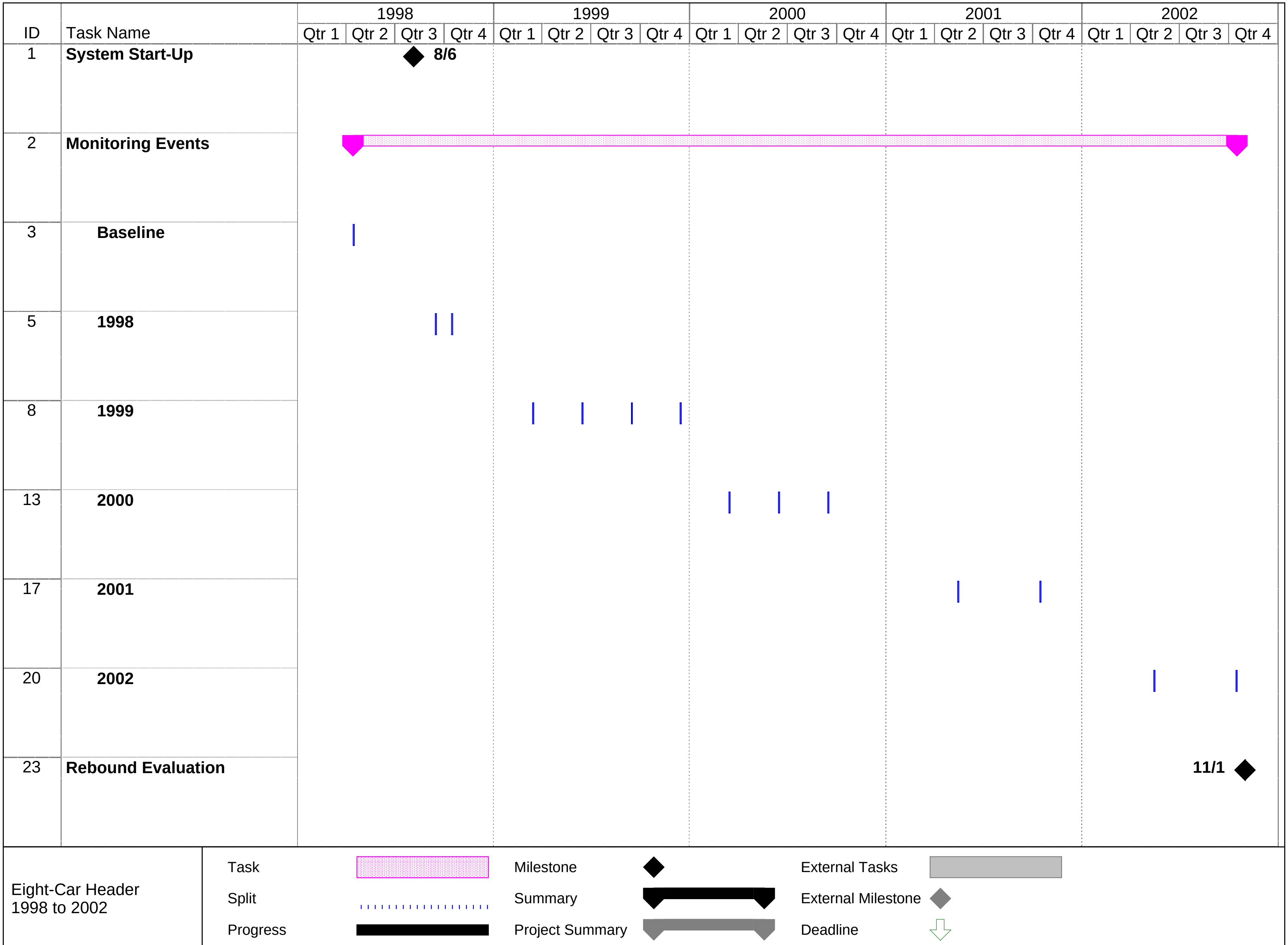
1997
1998
1999
2000
2001
2002
Qtr 1
Qtr 2
Qtr 3
Qtr 4
1 System Start-Up
7/29
2 Winter Shut Downs
3 1996 Winter
4 1997 Winter
5 1999 Winter
6 2000 Winter
7 Rebound Evaluation 1
8 Monitoring Events
9 Baseline
11 1996
14 1997
18 1998
22 1999
27 2000
31 2001
34 2002
38 Rebound Evaluation 2
Valve Pit C
1996 to 2002
Task
Split
Progress
Milestone
Summary
Project Summary
External Tasks
External Milestone
Deadline

Figure 1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1999
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Qtr 1
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Qtr 4
1 System Start-Up
8/6
2 Monitoring Events
3 Baseline
5 1998
8 1999
13 2000
17 2001
20 2002
23 Rebound Evaluation
11/1
Eight-Car Header
1998 to 2002
Task
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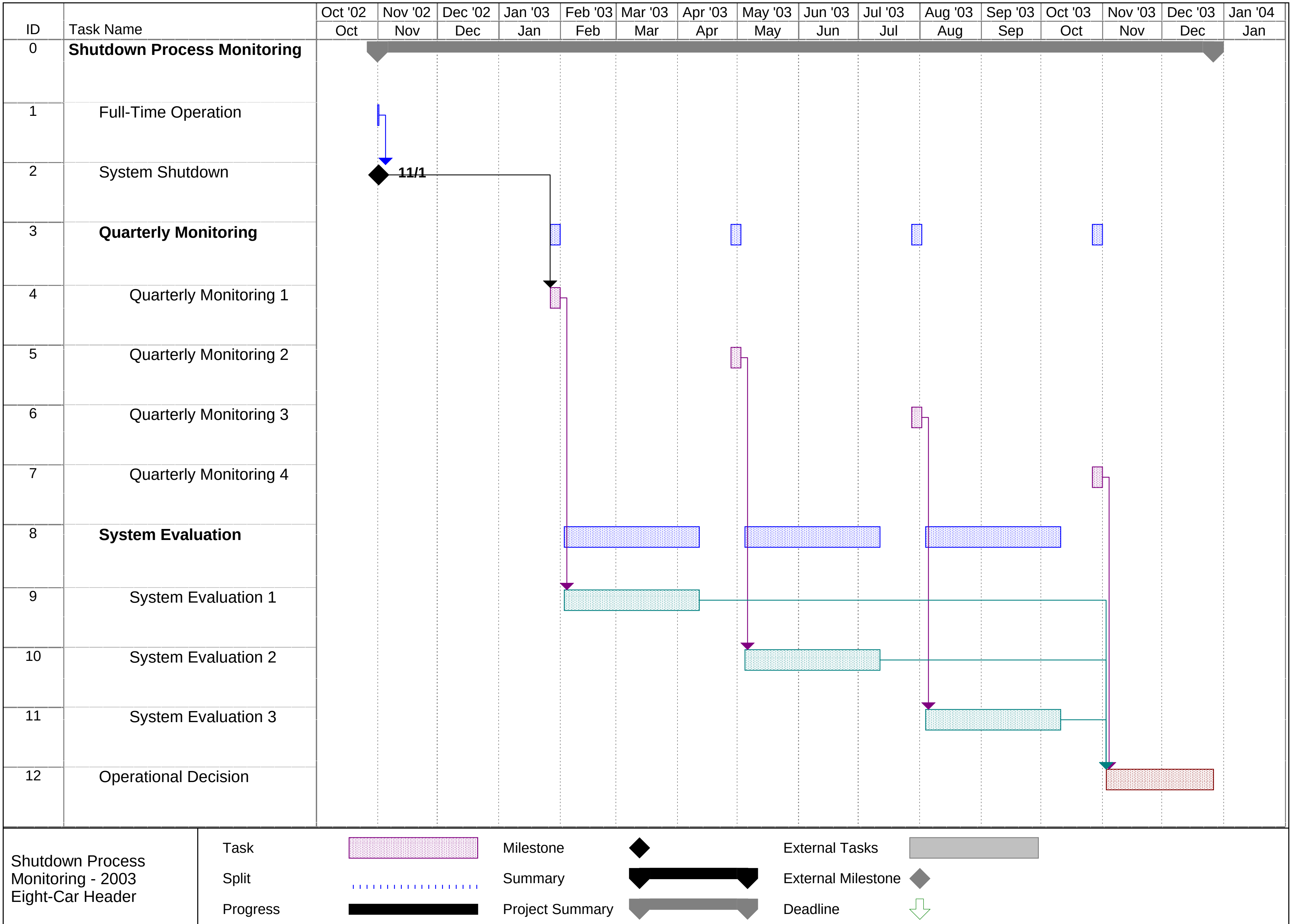
Progress
Milestone
Summary
Project Summary
External Tasks
External Milestone
Deadline

Figure 2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Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan
0 Shutdown Process Monitoring
1 Full-Time Operation
2 System Shutdown
11/1
3 Quarterly Monitoring
4 Quarterly Monitoring 1
5 Quarterly Monitoring 2
6 Quarterly Monitoring 3
7 Quarterly Monitoring 4
8 System Evaluation
9 System Evaluation 1
10 System Evaluation 2
11 System Evaluation 3
12 Operational Decision
Shutdown Process
Monitoring - 2003
Eight-Car Header
Task
Split
Progress
Milestone
Summary
Project Summary
External Tasks
External Milestone
Deadline

Figure 3

Appendix

Table A1 - Groundwater Sample Analytical Concentrations
Valve Pit C

Probe/Well Number	Proximity to Treatment Area	Sample Number	Date	Water Level in feet BTOC	ROD Chemicals of Concern in µg/L						
					Benzene	Toluene	Ethylbenzene	1,2,4-Trimethyl-benzene	1,3,5-Trimethyl-benzene	1,2-Dichloro-ethane	1,2-Dibromo-ethane
ROD CLEANUP LEVELS					5	1,000	700	1,850	1,850	5	0.05
VPC-MP1	Upgradient	01FWF005WA	4/17/2001	20.14	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)
		01FWF008WA	9/28/2001	19.24	ND (0.5)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)
		02FWF007WA	4/10/2002	20.55	ND (0.5)	ND (1)	ND (1)	ND (1)	ND (1)	ND (2)	ND (1)
		02FWF012WA	7/10/2002	16.33	ND (0.5)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)
		02FWF015WA	10/9/2002	18.31	ND (0.5)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)
VPC-MP2	Within Treatment	01FWF002WA	4/17/2001	19.96	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)
		01FWF013WA	10/3/2001	19.18	1.00	13.2	8.92	3.58	1.39	ND (1)	ND (1)
		02FWF004WA	4/10/2002	20.4	0.94	ND (1)	36.2	3.65	ND (1)	ND (2)	ND (1)
		02FWF009WA	7/10/2002	16.08	1.38	ND (1)	44.7	23.6	8.42	ND (1)	ND (1)
		02FWF017WA	10/9/2002	18.18	2.07	ND (1)	69.7	29.1	7.96	ND (1)	ND (1)
VPC-MP3	Within Treatment	01FWF004WA	4/17/2001	20.44	ND (1)	ND (1)	ND (1)	1.82	2.44	ND (1)	ND (1)
	Area	01FWF011WA	10/2/2001	19.52	ND (0.50)	ND (1)	ND (1)	ND (1)	1.39	ND (1)	ND (1)
		02FWF003WA	4/10/2002	20.8	1.85	ND (1)	1.80	1.36	2.41	ND (2)	ND (1)
		02FWF011WA	7/10/2002	16.55	0.94	ND (1)	5.07	5.15	3.19	ND (1)	ND (1)
		02FWF016WA	10/9/2002	18.55	1.69	ND (1)	8.24	1.74	1.01	ND (1)	ND (1)
VPC-MP4	Within Treatment	01FWF003WA	4/17/2001	17.11	1.84	2.08	9.76	29	13	ND (1)	ND (1)
	Area	01FWF012WA	10/3/2001	16.35	ND (5)	ND (10)	ND (10)	24.9	20.1	ND (10)	ND (10)
		02FWF002WA	4/10/2002	17.55	3.93	3.18	12.5	32.3	14.5	ND (2)	ND (1)
		02FWF010WA	7/10/2002	13.30	0.51	1.43	9.40	90.7	43.5	ND (1)	ND (1)
		02FWF018WA	10/9/2002	15.29	0.5	2.63	3.06	71	30	ND (1)	ND (1)
AP-6005	Within Treatment	01FWF001WA	4/17/2001	19.99	ND (1)	ND (1)	ND (1)	1.24	1.05	ND (1)	ND (1)
	Area	01FWF014WA	10/5/2001	19.32	ND (0.5)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)
		02FWF001WA	4/10/2002	20.42	ND (0.5)	ND (1)	ND (1)	ND (1)	ND (1)	ND (2)	ND (1)
		02FWF008WA	7/10/2002	16.19	ND (0.5)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)
		02FWF019WA	10/10/2002	18.25	ND (0.5)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)
VPC-MP6	Downgradient	01FWF007WA	4/18/2001	7.83	ND (1)	ND (1)	ND (1)	12.7	3.09	ND (1)	ND (1)
		01FWF009WA	10/2/2001	6.99	7.03	ND (1)	ND (1)	1.91	ND (1)	ND (1)	ND (1)
		02FWF006WA	4/10/2002	8.71	7.28	ND (1)	6.05	ND (1)	ND (1)	ND (2)	ND (1)
		02FWF014WA	7/11/2002	6.92	1.03	ND (1)	ND (1)	1.19	ND (1)	ND (1)	ND (1)
		02FWF020WA	10/10/2002	6.44	0.61	ND (1)	ND (1)	1.12	ND (1)	ND (1)	ND (1)
GWP71S	Downgradient	01FWF006WA	4/17/2001	12.08	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)
		01FWF010WA	10/1/2001	10.24	ND (0.50)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)
		02FWF005WA	4/10/2002	12.55	ND (0.5)	ND (1)	ND (1)	ND (1)	ND (1)	ND (2)	ND (1)
		02FWF013WA	7/11/2002	8.68	ND (0.5)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)
		02FWF021WA	10/10/2002	10.26	ND (0.5)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)

Notes:
BTOC = Below top of casing
µg/L = Micrograms per liter
ND () = Not detected above method reporting limit in parentheses
ROD = Record of Decision

Source: (FES, 1996 to 2002)

Table A2 - Soil Gas Measurements
Valve Pit C

Date	Organic Vapor Concentrations				Oxygen Gas Concentrations			
	SVE 1 % LEL/ppmV	SVE 2 % LEL/ppmV	SVE 3 % LEL/ppmV	SVE 4 % LEL/ppmV	SVE 1 %	SVE 2 %	SVE 3 %	SVE 4 %
7/30/1996	22	4	NM	NM	9.2	12.2	NM	NM
8/1/1996	32	1	NM	NM	18.9	20.8	NM	NM
8/5/1996	32	22	NM	NM	19.5	20.3	NM	NM
8/12/1996	28	15	NM	NM	20.1	20.5	NM	NM
8/19/1996	37	13	NM	NM	20.3	20.5	NM	NM
8/26/1996	19	5	NM	NM	20.2	20.4	NM	NM
9/17/1996	24	7	NM	NM	20.1	20.4	NM	NM
10/9/1996	28	11	NM	NM	20.4	20.6	NM	NM
4/5/1997	18	12	NM	NM	10.7	12.3	NM	NM
4/10/1997	23	10	NM	NM	19.3	19.7	NM	NM
5/5/1997	19	10	NM	NM	20.4	20.5	NM	NM
6/7/1997	5	3	NM	NM	19.9	20.3	NM	NM
7/14/1997	NM	NM	5	5	NM	NM	19.7	19.7
8/18/1997	NM	NM	4	3	NM	NM	20.1	19.9
9/8/1997	7	6	2	2	20.1	20.1	19.9	19.9
10/11/1997	7	2	2	2	20.7	20.7	20.8	20.5
11/4/1997	6	5	2	5	20.5	20.7	20.9	19.6
4/13/1998	2	1	2	4	20.8	20.8	20.6	19.8
5/16/1998	1	1	2	2	20.9	20.9	20.5	20.7
6/13/1998	2	1	2	2	20.7	20.7	20.3	20.4
7/13/1998	2	0	0	0	20.2	20.7	20.4	20.3
8/12/1998	0	0	0	0	20.5	20.4	20.4	20.7
8/2/1999	85	86	87	10	20.5	20.7	19.8	20.4
9/7/1999	80	135	82	46	20.9	20.9	20.7	20.9
10/5/1999	168	185	120	68	19.3	20.4	18.1	20.1
11/30/1999	33	NM	31	27	20.9	NM	20.9	20.9
4/11/2000	108	62	77	25	18.4	19.8	19.7	20.9
5/11/2000	51	70	74	27	20.4	20.9	19.5	20.9
6/9/2000	28	NM	16	5	19.8	NM	19.8	20.9
7/11/2000	102	NM	54	0	19.7	NM	19.7	20.7
8/11/2000	91	98	72	9	19.7	20.5	19.6	20.9
9/14/2000	77	78	43	28	20.5	20.9	20.4	20.9
11/1/2000	7	14	NM	15	20.9	20.9	NM	20.9
4/23/2001	119	39	71	Off	15.4	10.8	17.7	Off
5/21/2001	83	77	114	53	20.1	20.8	18.9	19.6
6/22/2001	69	77	63	34	20.1	20.8	19.8	20.2
7/9/2001	67	49	55	26	19.9	20.9	19.8	20.2
8/8/2001	16	16	7	4	NM	NM	NM	NM
9/28/2001	112	111	115	118	19.8	20.2	19.6	19.9

Notes: Organic vapor concentrations were measured as percent of the lower explosive limit (LEL) through 1998. Starting in 1999, organic vapors were measured in a smaller scale, ppm.
% = Percent oxygen concentration
NM = Not measured
ppmV = Parts per million by volume
SVE = Soil vapor extraction line

Source: (FES, 1996 to 2002)

Table A3 - SVE Exhaust Gas Sample Analytical Concentrations
Valve Pit C

	EPA Method TO-12	EPA Method TO-14			
	TNMOC	Benzene	Toluene	Ethylbenzene	Xylenes
Date	ppmV	ppbV	ppbV	ppbV	ppbV
7/30/1996	1,400	1,300	16,000	1,300	14,900
8/1/1996	3,900	3,300	29,000	2,400	20,300
8/5/1996	3,400	4,700	50,000	4,100	27,600
8/12/1996	1,100	1,100	24,000	2,300	14,700
8/19/1996	1,600	350	59,000	6,100	50,000
8/26/1996	2,500	2,000	45,000	3,700	38,000
9/17/1996	2,100	850	34,000	3,000	51,000
10/9/1996	1,800	220	25,000	2,700	45,000
4/5/1997	700	270	2,600	ND (100)	6,400
4/10/1997	800	270	5,900	320	10,900
5/5/1997	690	ND (340)	5,100	1,200	14,600
6/7/1997	580	86	2,200	240	4,800
7/14/1997	580	ND (130)	2,600	300	6,400
8/8/1997	700	ND (200)	2,100	350	8,800
9/8/1997	540	ND (87)	520	170	8,700
10/11/1997	400	ND (40)	400	120	7,800
11/4/1997	91	ND (13)	200	31	2,300
4/13/1998	640	110	910	120	3,800
5/16/1998	320	ND (51)	220	51	3,100
6/13/1998	310	ND (41)	230	49	3,000
7/13/1998	280	ND (100)	170	ND (100)	2,700
8/12/1998	140	ND (42)	ND (42)	ND (42)	1,020
8/2/1999	120	ND (8.1)	ND (8.1)	ND (8.1)	332
9/7/1999	120	ND (13)	ND (13)	ND (13)	368
10/5/1999	19	ND (4.0)	33	ND (4.0)	6
4/11/2000	35	ND (4.9)	ND (4.9)	ND (4.9)	48.8
5/11/2000	50	ND (8.1)	ND (8.1)	ND (8.1)	115
6/9/2000	38	ND (8.1)	ND (8.1)	ND (8.1)	155
7/11/2000	48	ND (5.0)	ND (5.0)	ND (5.0)	143
8/11/2000	45	ND (8.0)	ND (8.0)	ND (8.0)	107
9/14/2000	27	ND (4.1)	ND (4.1)	ND (4.1)	39
11/1/2000	12	ND (4.2)	ND (4.2)	ND (4.2)	11.3
4/23/2001	15	ND (5.6)	ND (5.6)	ND (5.6)	ND (5.6)
5/21/2001	55	ND (8)	ND (8)	ND (8)	ND (8)
6/22/2001	28	ND (4)	ND (4)	ND (4)	5.2
7/9/2001	19	ND (4)	4.1	ND (4)	4.7
8/8/2001	8.7	ND (10)	ND (10)	ND (10)	ND (10)
9/28/2001	27	ND (10)	ND (10)	ND (10)	ND (10)

Notes:
ppbV = Parts per billion by volume
ppmV = Parts per million by volume
EPA = Environmental Protection Agency
ND = Not detected above method detection limit in parantheses
SVE = Soil vapor extraction
TNMOC = Total non-methane organic compounds

Source: (FES, 1996 to 2002)

Table A4 - Groundwater Electron Acceptor Concentrations
Valve Pit C

Probe/Well Number	Treatment System Operation	Date	Dissolved Oxygen in mg/L	Iron (II) in mg/L	Sulfate in mg/L
MP-1	Off	6/25/1996	0.25	NM	NM
	On	8/27/1996	0.90	NM	NM
	On	10/9/1996	2.25	NM	NM
	Off	4/4/1997	0.7	NM	NM
	On	6/29/1997	1.2	4.0	40
	On	10/1/1997	1.2	6.2	30
	Off	4/17/1998	1.55	6.73	39
	On	7/15/1998	2.75	6.05	64
	Off	10/15/1998	1.45	3.65	1
	Off	3/11/1999	0.65	15.85	95
	Off	6/9/1999	0.64	7.1	122
	On	9/9/1999	1.24	2.15	160
	On	11/30/1999	0.90	10.15	84
	Off	3/8/2000	0.01	9.21	63
	On	6/15/2000	1.60	2.8	115
	On	8/11/2000	0.86	6.06	106
	Off	4/17/2001	NM	11.3	114
	On	9/28/2001	0.66	9.75	60
	Off	4/10/2002	0.95	4.26	44
	Off	7/10/2002	0.33	5.14	152
	Off	10/9/2002	0.74	3.48	130
MP-2	Off	6/25/1996	0.30	NM	NM
	On	8/27/1996	4.84	NM	NM
	On	10/9/1996	NM	NM	NM
	Off	4/4/1997	0.38	NM	NM
	On	7/1/1997	NM	NM	NM
	On	10/1/1997	7.0	0.5	195
	Off	3/11/1999	0.51	31.6	102
	Off	6/10/1999	0.41	21.0	50
	On	9/11/1999	4.70	0.0	190
	Off	12/1/1999	1.07	2.75	245
	Off	3/8/2000	0.08	7.3	100
	On	4/24/2000	NM	4.0	84
	On	6/10/2000	0.76	1.35	115
	On	8/15/2000	2.92	3.72	88
	Off	4/17/2001	0.65	12.05	130
	On	10/3/2001	6.00	5.02	42
	Off	4/10/2002	2.74	4.35	41
	Off	7/10/2002	0.35	4.94	86
	Off	10/9/2002	0.40	3.60	0
MP-3	Off	6/25/1996	NM	NM	NM
	On	8/26/1996	1.08	NM	NM
	On	10/9/1996	2.94	NM	NM
	Off	4/4/1997	0.52	NM	NM
	On	7/1/1997	NM	NM	NM
	On	10/1/1997	0.78	6.48	300
	Off	4/17/1998	0.5	2.63	300
	On	7/15/1998	0.99	4.05	215
	Off	10/15/1998	0.1	13.4	187.5
	Off	3/12/1999	0.16	23	70
	On	9/8/1999	13.0	3.3	175
	On	11/30/1999	0.42	8.75	216
	Off	3/8/2000	0.51	7.05	204
	On	4/24/2000	NM	6.15	195
	On	6/10/2000	2.24	4.5	100
	On	8/11/2000	0.69	6.75	129
	Off	4/17/2001	0.29	12.05	225
	On	10/2/2001	6.66	7.26	144
	Off	4/10/2002	2.84	6.99	122
	Off	7/10/2002	0.81	4.98	104
	Off	10/9/2002	3.18	1.38	16

Probe/Well Number	Treatment System Operation	Date	Dissolved Oxygen in mg/L	Iron (II) in mg/L	Sulfate in mg/L
MP-4	Off	6/25/1996	0.25	NM	NM
	On	8/27/1996	0.7	NM	NM
	On	10/9/1996	1.4	NM	NM
	Off	4/4/1997	NM	NM	NM
	On	7/1/1997	3.64	1.15	60
	On	10/1/1997	2.85	3.1	310
	Off	3/15/1999	NM	45.25	175
	Off	6/10/1999	0.39	7.45	108
	On	6/10/2000	0.28	4.2	25
	On	8/10/2000	0.69	4.05	0
	Off	4/17/2001	0.44	7.35	16
	On	10/3/2001	7.65	5.58	23
	Off	4/10/2002	4.5	5.14	13
	Off	7/10/2002	0.30	2.65	12
	Off	10/9/2002	0.63	2.09	3
AP-6005	Off	7/12/1996	0.11	NM	NM
	On	8/26/1996	8.61	NM	NM
	On	10/9/1996	12.24	NM	NM
	Off	4/4/1997	0.67	NM	NM
	On	7/1/1997	NM	NM	NM
	On	10/1/1997	9.41	0.075	390
	Off	12/1/1999	2.21	1.1	270
	Off	3/8/2000	0.05	5.86	528
	On	6/14/2000	5.55	0	120
	On	8/16/2000	8.44	0.11	112
	Off	4/17/2001	0.30	3.48	250
	On	10/5/2001	4.56	0.34	328
	Off	4/10/2002	5.03	2.24	176
	Off	7/10/2002	0.34	1.88	96
	Off	10/10/2002	1.68	2.51	140
MP-6	On	4/28/1997	0.52	13.3	84
	On	7/2/1997	NM	NM	NM
	On	9/30/1997	0.06	460	53
	Off	3/16/1999	0.31	68.25	55
	Off	6/11/1999	0.30	22	29.5
	On	9/7/1999	0.15	9.3	125
	Off	12/1/1999	NM	18.5	50
	Off	3/7/2000	0.21	0.51	55
	On	6/14/2000	NM	3.6	0
	Off	4/18/2001	NM	11.15	5
	On	10/2/2001	0.26	5.54	8
	Off	4/10/2002	1.55	2.66	37
	Off	7/11/2002	0.23	5.82	84
	Off	10/10/2002	1.01	3.19	18
GWP-71S	On	5/19/1997	4.69	32.6	0
	On	10/1/1997	0.46	29.3	48
	Off	4/17/1998	0.26	8.25	90
	On	7/14/1998	0.21	40.25	1
	Off	10/16/1998	0.28	16.45	36
	Off	3/16/1999	0.62	42.5	45
	Off	6/11/1999	0.64	17	35
	On	9/8/1999	0.26	6	115
	Off	12/1/1999	NM	26.4	90
	Off	3/7/2000	0.17	9.66	17
	On	6/12/2000	0.40	6.50	5
	On	8/18/2000	1.66	5.8	46
	Off	4/17/2001	NM	14.6	88
	On	10/1/2001	0.32	15.8	80
	Off	4/10/2002	1.21	2.9	112
	Off	7/11/2002	0.28	6.30	114
	Off	10/10/2002	1.53	5.80	114

Notes: mg/L = Milligrams per liter
NM = Not measured

Source: (FES, 1996 to 2002)

Table A5 - Groundwater Sample Analytical Concentrations
Eight-Car Header

Probe/Well Number	Proximity to Treatment Area	Sample Number	Date	Water Level in feet BTOC	ROD Chemicals of Concern in µg/L						
					Benzene	Toluene	Ethylbenzene	1,2,4-Trimethyl-benzene	1,3,5-Trimethyl-benzene	1,2-Dichloro-ethane	1,2-Dibromo-ethane
ROD CLEANUP LEVELS					5	1,000	700	1,850	1,850	5	0.05
GWP110	Upgradient	01FWI003WA	5/2/2001	17.2	**18.8**	522	140	258	91.0	ND (1)	ND (1)
		01FWI010WA	9/28/2001	16.56	**12.6**	347	98.3	174	86.2	ND (5)	ND (5)
		02FWI001WA	5/23/2002	13.19	**9.0**	185	48.6	82.8	84.8	ND (10)	ND (10)
		02FWI009WA	10/31/2002	16.23	**6.2**	209	93.4	156	77.5	ND (10)	ND (10)
GWP53	Zone 1/5	01FWI008WA	5/5/2001	NM	ND (10) J	41.4 J	159 J	558 J	284 J	ND (10) J	ND (10) J
		01FWI016WA	10/5/2001	17.92	ND (2.5)	48.6	103	391	180	ND (5)	ND (5)
		02FWI008WA	5/24/2002	13.88	ND (0.5)	4.71	4.63	17.5	8.01	ND (1)	ND (1)
		02FWI014WA	11/4/2002	16.55	ND (5)	ND (10)	ND (10)	29.9	21.1	ND (10)	ND (10)
AP-6006	Zone 2	02FWI002WA	5/23/2002	13.04	ND (0.5)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)
		02FWI011WA	11/1/2002	16.15	1.13	1	19.3	35	15.4	ND (1)	ND (1)
GWP57	Zone 2	01FWI002WA	5/2/2001	NM	ND (1)	ND (1)	5.16	190	62.4	ND (1)	ND (1)
		01FWI013WA	10/2/2001	15.05	ND (5)	ND (10)	ND (10)	162	32.1	ND (10)	ND (10)
		02FWI003WA	5/23/2002	11.43	ND (0.5)	ND (1)	1.49	87	25.2	ND (1)	ND (1)
		02FWI012WA	11/1/2002	14.5	ND (5)	ND (10)	ND (10)	116	16.4	ND (10)	ND (10)
AP-7538	Zone 3	01FWI006WA	5/3/2001	18.1	1.82	ND (1)	ND (1)	6.04	5.60	ND (1)	ND (1)
		01FWI015WA	10/4/2001	17.48	ND (0.5)	ND (1)	ND (1)	1.86	ND (1)	ND (1)	ND (1)
		02FWI007WA	5/24/2002	13.76	1.39	ND (1)	ND (1)	2.95	9.61	ND (1)	ND (1)
		02FWI015WA	11/4/2002	16.99	ND (0.5)	ND (1)	6.09	10.8	6.20	ND (1)	ND (1)
AP-7535	Zone 4	01FWI007WA	5/3/2001	16.00	ND (10)	ND (10)	ND (10)	42.5	47.9	ND (10)	ND (10)
		01FWI012WA	10/2/2001	15.58	ND (5)	ND (10)	ND (10)	30.8	32.0	ND (10)	ND (10)
		02FWI006WA	5/24/2002	11.86	ND (5)	ND (10)	ND (10)	18.3	24.0	ND (10)	ND (10)
		02FWI016WA	11/4/2002	15.10	ND (0.5)	ND (1)	1.65	10.5	11.1	ND (1)	ND (1)
GWP88	Downgradient	01FWI004WA	5/2/2001	16.13	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)
		01FWI014WA	10/2/2001	14.44	ND (0.5)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)
		02FWI004WA	5/23/2002	10.70	ND (0.5)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)
		02FWI010WA	10/31/2002	13.95	ND (0.5)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)
GWP129	Downgradient	01FWI001WA	5/2/2001	NM	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)
		01FWI011WA	10/1/2001	18.98	ND (0.5)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)
		02FWI005WA	5/23/2002	15.26	ND (0.5)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)
		02FWI013WA	11/1/2002	18.54	ND (0.5)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)

Notes:
BTOC = Below top of casing
µg/L = Micrograms per liter
J = Estimated value
ND () = Not detected above method reporting limit in parantheses
NM = Not measured
ROD = Record of Decision

Source: (FES, 1996 to 2002)

Table A6 - Soil Gas Measurements
Eight-Car Header

Date	Organic Vapor Concentrations					Oxygen Gas Concentrations				
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
	% LEL	% LEL	% LEL	% LEL	% LEL	%	%	%	%	%
8/6/1998	Off	40	Off	26	16	Off	19.2	Off	17.60	27.0
8/17/1998	52	Off	46	Off	32	19.9	Off	19.4	Off	20.2
8/30/1998	32	Off	35	Off	29	19.5	Off	19.6	Off	20.0
9/30/1998	12	Off	9	Off	12	20.2	Off	20.2	Off	20.4
10/27/1998	Off	7	Off	6	Off	Off	20.7	Off	20.2	Off
12/11/1998	3	Off	10	Off	2	20.9	Off	20.9	Off	20.6
1/15/1999	Off	2	24	17	Off	Off	20.9	20.0	19.8	Off
3/25/1999	Off	NM	NM	Off	Off	Off	NM	NM	Off	Off
4/29/1999	Off	8	8	Off	Off	Off	20.3	19.6	Off	Off
5/24/1999	9	7	9	8	Off	20.8	20.6	20.1	19.8	Off
6/23/1999	9	8	10	8	8	20.4	20.1	19.6	18.8	19.7
7/19/1999	7	5	7	7	10	20.1	20.0	19.3	17.7	18.4
8/23/1999	6	5	7	5	10	20.8	20.7	20.3	19.2	19.8
9/21/1999	8	Off	8	12	10	20.5	Off	20.3	18.6	20.2
11/3/1999	0	1	2	3	1	20.9	20.9	19.2	19.4	20.7
12/14/1999	0	0	0	0	0	20.9	20.9	20.9	20.9	20.9
2/1/2000	1	1	0	0	Off	20.9	20.9	20.8	20.8	Off
3/13/2000	9	9	3	2	Off	15.6	18.0	20.6	20.5	Off
4/12/2000	NM	5	0	0	Off	NM	19.1	20.9	20.9	Off
6/12/2000	7	Off	7	3	Off	19.5	Off	19.2	20.7	Off
7/20/2000	4	Off	4	2	6	19.9	Off	19.8	20.2	19.5
8/21/2000	3	Off	4	3	5	20.4	Off	19.3	19.7	19.6
9/11/2000	2	Off	4	3	4	20.7	Off	20.1	19.8	20.2
11/27/2000	350 ppmV	250 ppmV	70 ppmV	40 ppmV	140 ppmV	16.7	17.5	17.1	18.2	18.6
12/18/2000	4	2	Off	0	0	20.0	20.4	Off	20.5	20.2
1/24/2001	1	2	Off	3	3	20.8	20.7	Off	19.5	19.9
2/20/2001	2	3	Off	1	2	20.7	20.9	Off	20.9	20.9
3/12/2001	2	2	Off	0	0	20.5	20.7	Off	20.9	20.9
4/11/2001	3	0	Off	1	0	19.4	20.9	Off	20.9	20.9
5/15/2001	5	3	4	4	NM	19.6	20.7	19.7	19.7	NM
6/13/2001	2	1	5	4	3	20.4	20.6	18.9	19.5	19.9
7/8/2001	4	5	5	6	5	20.2	20.1	19.2	18.5	20.1
8/9/2001	4	5	8	8	6	20.2	20.1	18.1	18.2	19.4
9/28/2001	2	2	3	3	2	19.9	20.0	17.4	18.5	19.5
12/31/2001	0	1	Off	1	2	21.0	20.7	Off	19.1	17.9
1/31/2002	1	0	Off	0	0	20.4	20.4	Off	20.9	20.9
2/24/2002	2	1	1	1	3	20.4	20.9	20.9	20.9	20.4
3/29/2002	1	1	0	0	1	20.8	20.7	20.1	20.9	20.9
4/17/2002	0	0	0	NM	0	20.9	20.9	20.6	NM	20.9
5/17/2002	2	1	0	2	3	20.3	20.8	18.3	20.3	20.1
6/20/2002	3	3	4	2	3	19.7	20.4	18.3	20.1	19.6
7/11/2002	2	1	2	2	2	20.5	20.8	19.3	19.7	20.2
8/13/2002	1	1	1	1	1	20.9	20.9	19.8	20.9	20.9
9/5/2002	1	1	Off	1	1	20.9	20.9	Off	20.9	20.9

Notes: Organic vapor concentrations were generally measured as percent of the lower explosive limit (LEL); however, some were measured in ppm, a smaller scale.
% = Percent oxygen concentration
NM = Not measured
ppmV = Parts per million by volume

Source: (FES, 1996 to 2002)

Table A7 - SVE Exhaust Gas Sample Analytical Concentrations
Eight-Car Header

	EPA Method TO-12	EPA Method TO-14			
Date	TNMOC in ppmV	Benzene in ppbV	Toluene in ppbV	Ethylbenzene in ppbV	Xylenes in ppbV
8/17/1998	1,300	5,100	18,000	1,000	11,400
8/30/1998	1,700	3,900	22,000	1,400	13,300
9/30/1998	1,600	2,200	28,000	3,500	29,800
10/27/1998	1,500	2,400	28,000	4,300	31,000
12/11/1998	650	940	9,600	1,200	11,300
1/15/1999	740	700 J	4,600	660 J	6,700
3/25/1999	1,900	1,800	14,000	2,200	15,400
4/29/1999	550	850	6,400	1,500	11,200
5/24/1999	1,600	990 J	10,000	2,100	21,400
6/23/1999	890	990 J	10,000 J	2,100 J	21,400 J
7/19/1999	420	270	4,800	1,100	12,100
8/23/1999	540	140	2,700	680	7,800
9/21/1999	500	ND (92)	1,900	490	7,000
11/3/1999	890	170	3,300	840	13,500
12/14/1999	8.3	ND (3.7)	20	10	229
2/1/2000	33	21	170	37	620
3/13/2000	53	38	380	88	1,160
4/12/2000	120	15	370	94	2,000
6/12/2000	160	ND (19)	260	51	2,240
7/20/2000	450	ND (220)	940	ND (220)	5,100
8/21/2000	630	ND (37)	670	ND (37)	4,700
9/11/2000	180	ND (13) J	260 J	33 J	2500 J
11/27/2000	48 J	10	110	20	710
12/18/2000	91	ND (19)	66	33	720
1/24/2001	150	36	450	130	1,530
2/20/2001	88	19	420	120	1,360
3/12/2001	120	31 J	420 J	120 J	1,520 J
4/11/2001	96	20	340	130	2,150
5/15/2001	130	ND (9.6)	230	75	2,010
6/13/2001	220	ND (8) J	88 J	ND (8) J	1,440 J
7/8/2001	250	30	160	43	1,550
8/9/2001	320	ND (9.4) J	320 J	65 J	2,700 J
9/28/2001	230	ND (19)	330	75	2,400
12/31/2001	30	ND (9.4)	32	19	320
1/31/2002	24	ND (9.0)	19	ND (9.0)	130
2/24/2002	58	11	150	64	1,080
3/29/2002	58	19	180	47	910
4/17/2002	47	ND (9.4)	84	29	590
5/17/2002	110	ND (10)	70	16	680
6/20/2002	120	ND (10)	330	46	1200
7/11/2002	180	ND (10)	150	26	770
8/13/2002	150	27	200	31	1,010
9/5/2002	110	ND (20)	140	ND (20)	750
10/21/2002	82	ND (15)	180	20	620

Notes:
ppbV = Parts per billion by volume
ppmV = Parts per million by volume
EPA = Environmental Protection Agency
J = Estimated value
ND = Not detected above method detection limit in parantheses.
TNMOC = Total non-methane organic compounds
SVE = Soil vapor extraction

Source: (FES, 1996 to 2002)

Table A8 - Groundwater Electron Acceptor Concentrations
Eight-Car Header

Probe/Well Number	Date	Dissolved Oxygen in mg/L	Iron (II) in mg/L	Sulfate in mg/L
GWP110	3/8/1999	9.42	20.16	0
	5/24/1999	0.41	12.9	0
	8/30/1999	0.3	10.45	1
	12/15/1999	0.24	11.05	11
	6/15/2000	NM	9.7	25
	8/10/2000	0.57	5.35	10
	5/2/2001	0.25	9.15	32
	9/28/2001	0.28	9.84	18
	5/23/2002	0.26	2.78	17
	10/31/2002	2.97	4.1	19
GWP53	7/18/1996	0.45	NM	NM
	4/10/1998	NM	NM	NM
	9/3/1998	NM	NM	NM
	5/25/1999	NM	16.3	130
	6/15/2000	NM	17	8
	8/14/2000	4.83	NM	31
	5/5/2001	2.97	15.8	155
	10/5/2001	2.01	10.08	70
	5/24/2002	0.39	13.44	76
	11/4/2002	5.54	2.53	208
AP-6006	6/13/1996	0.2	NM	NM
	4/10/1998	0.36	13.1	8
	9/1/1998	0.07	5	22
	11/1/1998	6.66	8.5	64
	3/5/1999	1	0.03	NM
	5/24/1999	0.84	0.10	216
	8/25/1999	0.7	0.00	285
	12/21/1999	5.59	0.00	300
	3/17/2000	1.88	1.76	325
	6/14/2000	1.19	0.01	210
	8/11/2000	1.00	0.01	195
	5/23/2002	1.07	1.27	76
	11/1/2002	3.27	2.25	41
GWP57	6/14/2000	2.89	7.05	155
	8/11/2000	0.37	3.65	49
	5/2/2001	0.24	6.3	58
	10/2/2001	0.51	5.2	18
	5/23/2002	0.78	2.26	70
	11/1/2002	4.89	3.19	37
AP-7535	6/19/2000	9.25	1.7	46
	8/12/2000	2.37	3.00	35
	5/3/2001	11.51	0.19	8
	10/2/2001	0.70	8.25	38
	5/24/2002	8.88	1.09	27
	11/4/2002	3.69	1.54	26

Probe/Well Number	Date	Dissolved Oxygen in mg/L	Iron (II) in mg/L	Sulfate in mg/L
AP-7538	9/4/1998	1.73	0	160
	10/29/1998	0.05	8.55	255
	3/4/1999	0.15	3.55	300
	5/27/1999	13.48	0.5	440
	8/28/1999	10.5	0.78	335
	12/14/1999	0.98	2.95	350
	6/16/2000	13.72	5.04	141
	8/14/2000	11.01	0.33	115
	5/3/2001	8.13	0.11	42
	10/4/2001	9.69	0.93	66
	5/24/2002	0.77	3.56	164
	11/4/2002	10.68	1.98	13
GWP88	5/14/1997	0.48	12.2	1
	4/10/1998	0.21	15.4	1
	9/3/1998	1.68	16.3	0
	10/30/1998	2.5	5.85	21
	5/28/1999	2.55	0.37	65
	8/28/1999	7.37	1.87	67
	6/15/2000	NM	1.0	144
	8/17/2000	1.38	1.43	112
	5/2/2001	8.58	0.36	210
	10/2/2001	1.12	0.91	153
	5/23/2002	0.47	0.97	156
	10/31/2002	3.18	0.46	74
GWP129	6/7/1997	0.83	9.2	0
	9/29/1997	0.23	28.5	5
	4/10/1998	0.63	13.8	0
	9/2/1998	0.2	18.9	0
	10/29/1998	0.02	30.9	8
	3/5/1999	0.5	15.75	1
	5/25/1999	0.4	18.9	5
	8/24/1999	0.6	1.34	42
	12/15/1999	0.35	12.1	9
	3/14/2000	0.31	5.85	2.0
	6/15/2000	NM	6.75	10
	8/14/2000	0.6	5.35	0
	5/2/2001	0.52	7.35	27
	10/1/2001	0.27	10.9	14
	5/23/2002	1.27	5.44	25
	11/1/2002	1.89	4.3	10

Notes: mg/L = Milligrams per liter
NM = Not measured

Source: (FES, 1996 to 2002)