Operation and Maintenance Considerations for Hydrocarbon Remediation Systems

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Strategies for Today's Environmental Partnership

American Petroleum Institute

Strategies for Today's Environmental Partnership

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Manufacturing, Distribution and Marketing Department

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Operation and Maintenance Considerations for Hydrocarbon Remediation Systems

SECTION 1—INTRODUCTION

Limited guidance is currently available regarding operation and maintenance (O&M) procedures necessary to achieve and maintain optimal performance of petroleum hydrocarbon remediation systems. O&M is extremely critical in optimizing effective system performance. Costs for O&M can vary significantly depending on the type of system and the operating environment. Since long-term O&M costs can be the most expensive item associated with a corrective action project, it is important to consider O&M requirements when selecting remediation technologies and to plan and execute routine O&M procedures. API Publication 1628E addresses routine O&M procedures, rehabilitation, troubleshooting, and comparisons that are useful as guidance in selecting appropriate remediation and treatment systems for removal of Light Non-aqueous Phase Liquids (LNAPL) and for remediation of groundwater and soil containing concentrations of chemical(s) of concern above site target levels.

1.1 Common O&M Problems

Typically, O&M problems can be linked to one of three major categories; (a) inadequate routine monitoring/adjustment, (b) the physical environment within which the system is exposed, and (c) poor system design. Any of these factors can result in a significant increase in costs associated with O&M, which can often be prevented.

Routine O&M monitoring and system adjustment can provide for optimal operation of hydrocarbon remediation systems. Common problems associated with inadequate routine evaluations include the following:

a. Loss of plume containment.
b. Inefficient recovery of LNAPL.
c. Water discharge violations.
d. Other permit violations.
e. Excessive power usage and utility costs.
f. Extended remediation time.
g. Changing regulatory requirements.

In many cases, the physical environment in which the remediation equipment and systems are exposed can cause major O&M problems. When these conditions are persistent, O&M requirements become more difficult and complex, and associated costs escalate accordingly. Examples of the more common problems associated with the physical environment include the following:

a. Temperature/weather extremes.
b. Inorganic scaling.
c. Iron bacteria and other biofouling.
d. Security problems.

O&M considerations should be incorporated during system design in order to select the most appropriate system for meeting the specific conditions of a particular site. Examples of design issues that can affect O&M include the following:

a. Withdrawal and/or treatment approach not suited to site;
b. Incorrect pump sizing.
c. Equipment not compatible.
d. Poor well design.

1.2 O&M Planning

Considering the preceding discussion, proper planning of O&M considerations during conceptual and detailed system design is critical for optimizing system performance and cost-effectiveness. The key to successful planning for system O&M lies with developing basic guidelines and consistency. During design, the following basic guidelines should be considered and incorporated into an organized O&M plan:

a. Identify O&M requirements and potential problems.
b. Develop an O&M data collection checklist.
c. Establish O&M frequency.
d. Develop a plan for routine data evaluation.
e. Compare O&M data evaluation with design criteria.
f. Modify system operation based on the preceding comparison.

The following sections of this publication provide general guidance that will be useful for preparing O&M plans and implementing O&M programs. Guidance is provided concerning routine O&M data collection/evaluation criteria for LNAPL recovery systems, groundwater recovery systems, soil remediation systems, and groundwater and air treatment systems. Correction of maintenance problems, including rehabilitation and troubleshooting guidelines for recovery and treatment systems is addressed. Finally, a comparison of O&M requirements and the level of effort for different remedial approaches is presented. This information will be particularly helpful in designing systems to reduce long-term O&M costs.

SECTION 2—ROUTINE O&M REQUIREMENTS

2.1 An O&M Plan

Prior to implementing a remediation system, an O&M plan should be prepared. An O&M plan should be sufficiently detailed to be used as a guide in the operation and routine maintenance of the system by personnel who have little prior knowledge of the system or its operation.

At a minimum, O&M plans should include (a) a general process description, where the separate subsystems of the remedial system are described; (b) an operations section, which includes safety issues, system start-up procedures, system optimization procedures, system operational indicators, and an O&M checklist for data collection; (c) a maintenance section which outlines routine and scheduled maintenance procedures and sampling requirements and includes tables to aid in troubleshooting system malfunctions; and (d) an updated procedures section, in which changes in O&M procedures will be documented. Equipment manufacturers' manuals and bulletins, system sampling procedures, operator logs, and pertinent engineering drawings should also be included in the plan.

The following sections provide guidance on routine O&M data collection and evaluation criteria for different aspects of hydrocarbon recovery systems.

2.2 LNAPL Recovery Systems

The first goal for hydrocarbon release remediation is to prevent further LNAPL migration and to recover as much of the mobile LNAPL as possible while minimizing residual losses. This procedure generally involves source removal or mitigation and the installation of a system of trenches, sumps, or withdrawal wells from which LNAPL is skimmed and/or pumped with groundwater to maintain hydraulic control of the plume of dissolved chemical(s) of concern in the groundwater.

The operation of withdrawal systems to recover LNAPL will vary depending on site-specific conditions and the objectives of the remediation program. Sometimes skimming or pumping LNAPL from trenches, sumps, and wells without pumping groundwater can be an effective technique for layers of LNAPL that are relatively static and remain in the vicinity of the release. In most cases, however, concurrent groundwater withdrawal will be required to maintain containment of the plume and to increase the hydraulic gradient to enhance the recovery of LNAPL.

Concurrent pumping of groundwater from trenches, sumps, or wells must be carefully controlled by monitoring plume conditions and adjusting withdrawal rates to limit plume migration and excessive drawdown. If groundwater pumping rates are too low, there is a risk of losing plume containment. On the other hand, if groundwater pumping rates are too high, LNAPL recovery will generally diminish due to an increasing volume of LNAPL that will be lost to residual saturation throughout the cone of depression; this is often referred to as the *smear zone*. Thus, for a given well or trench configuration, groundwater pumping rates should be established to meet the criteria of plume containment and LNAPL recovery maximization.

Since many different pumping configurations may satisfy the requirements of plume control, some additional criteria must be used to optimize system operation while keeping maintenance costs to a minimum. Depending on unit treatment costs and remediation objectives, minimizing groundwater withdrawal for the duration of the remediation period, maximizing total LNAPL recovery, or maximizing the LNAPL recovered per volume of groundwater pumped may be rational criteria.

During recovery system design, consideration must be given to total groundwater withdrawal rates and total LNAPL recovery. For a given recovery system, pumping rates will be designed to control LNAPL migration, and recoverable LNAPL volume will be estimated to determine the design that will yield the maximum recovery. Maximum LNAPL recovery will be obtained by minimizing the total drawdown over the zone of the LNAPL plume, while maintaining plume control around the plume perimeter. For the same total pumping rate, LNAPL recovery will generally increase with the number of wells. The economically optimum number of wells will depend on the tradeoff between costs of well installation and operation versus the benefit gained by reducing the amount of LNAPL lost to residual saturation.

2.2.1 DATA COLLECTION AND EVALUATION OF LNAPL RECOVERY SYSTEMS OVERVIEW

Routine O&M data collection and evaluation of LNAPL recovery systems are essential for ensuring that remediation design criteria are satisfied in a cost-effective manner. Data collection criteria are outlined in the following section.

2.2.2 DATA COLLECTION AND EVALUATION OF LNAPL RECOVERY SYSTEMS

After design and installation of a recovery system, the operating system must be monitored to enable adjustments to be made to maintain system effectiveness. Periodic measurements should be made of the following parameters:

a. Cumulative LNAPL recovered.
b. LNAPL and groundwater recovery rates.
c. LNAPL thickness at individual observation wells.
d. Corrected groundwater table elevations for each observation well.

e. Pump settings relative to LNAPL elevation.
f. General equipment condition and power usage.
g. Pump/well efficiency data.
h. Line pressures.

The frequency of routine O&M data collection and monitoring will vary depending on several factors, including size and complexity of the recovery system, operating conditions, equipment reliability, remote monitoring capability, and regulatory requirements. Most of the major aspects of LNAPL recovery systems should be monitored and evaluated at least monthly; however, some large systems may require weekly or even more frequent attention. Testing other elements, such as specific capacity and pump efficiency, might be performed on a semi-annual basis. Again, the frequency of monitoring and data collection will be very site- and goal specific.

A consistent procedure for data evaluation is just as critical as collecting the data. Monitoring data should be evaluated to determine whether the LNAPL plume is being contained and whether LNAPL recovery is being maximized as efficiently as possible. Evaluation of system performance should include noting any trends, patterns, or anomalies, such as unusual groundwater fluctuations, major changes in LNAPL thickness or distribution, and the relationship of such patterns to hydrologic impacts, subsurface preferential pathways, or other site features. Examples of data evaluation procedures are outlined in the following.

2.2.2.1 System Downtime Summary

All downtimes, along with corrective measures taken to bring the system back on-line, should be reviewed. Examples include high tank shutoff; compressor or pump failures; plugging of discharge lines, wells, infiltration galleries, filters, or flow meters; or other system problems. Any system problems that are occurring repeatedly or that have historically caused other shutdowns of the system should also be reviewed. This information will allow for evaluation of the overall system operation record to ensure maximum operating efficiency.

2.2.2.2 LNAPL Information

LNAPL thickness, the method of recovery, and the volume of LNAPL recovered should be evaluated for a particular time period. The total volume of LNAPL recovered since system start-up should also be evaluated to determine any single significant recovery event that may have occurred. The data should be tabulated and graphed for each LNAPL recovery location and should include volume recovered, LNAPL thickness, and groundwater flow rates and elevations. Additionally, a plot of total LNAPL recovered versus time should be evaluated. Review of these data plots will allow evaluation of the effectiveness of, and the necessity for, continued LNAPL recovery. An example plot of cumulative recovery versus time for different water pumping rates is shown on Figure 1.

2.2.2.3 Plume Containment

To ensure that the plume is being effectively contained, groundwater elevations, LNAPL thickness, and LNAPL distribution data should be evaluated; this is an important aspect of evaluating system performance. An analysis of system capture *(capture zone analysis)* should then be performed. This evaluation can be accomplished by flow net analysis, analytical approaches, or models.

2.2.2.4 Well/Pump Efficiency

Routine monitoring of pumping rates and water levels can provide indications of well and pump efficiency problems. However, in some cases well and pump efficiency or capacity tests should be conducted and evaluated at least semi-annually. The results of each test should be compared to the original performance tests conducted after system installation. Each well/pump should be redeveloped/reconditioned if the production rate decreases below 75 percent of the original test rate. Procedures for conducting well and pump performance tests are provided in Tables 1 and 2, respectively.

Well and pump efficiency testing provides a method to determine decreased pump performance. There are several causes for a decreased performance, including biofouling, scaling, silting, and deterioration of equipment due to exposure to hydrocarbons. Rehabilitation alternatives for dealing with these problems are presented in the following sections. Other data collection/evaluation checks that should be performed to ensure proper O&M include the following:

a. Gauge the well depth to check for accumulations of sand or silt.
b. Check water/LNAPL level versus pumping rate to evaluate potential screen plugging problems.
c. Conduct motor resistance and amperage tests on all pump motors.
d. Check switchgear, motor starters, and electrical circuits;
e. Remove, inspect, clean, and replace interface detection probes.
f. Repair, as necessary, pump hoses, safety cables, and electrical power cables.

2.3 Groundwater Recovery Systems

2.3.1 GENERAL

Most hydrocarbon recovery sites require concurrent withdrawal of groundwater. The objectives of pumping groundwater may be (a) to contain LNAPL, (b) to enhance LNAPL recovery, (c) to contain hydrocarbons dissolved in groundwater, (d) to recover/treat groundwater with concentrations of the chemical(s) of concern above site target levels, and (e) to dewater zones for application of soil vapor extraction. A spe-

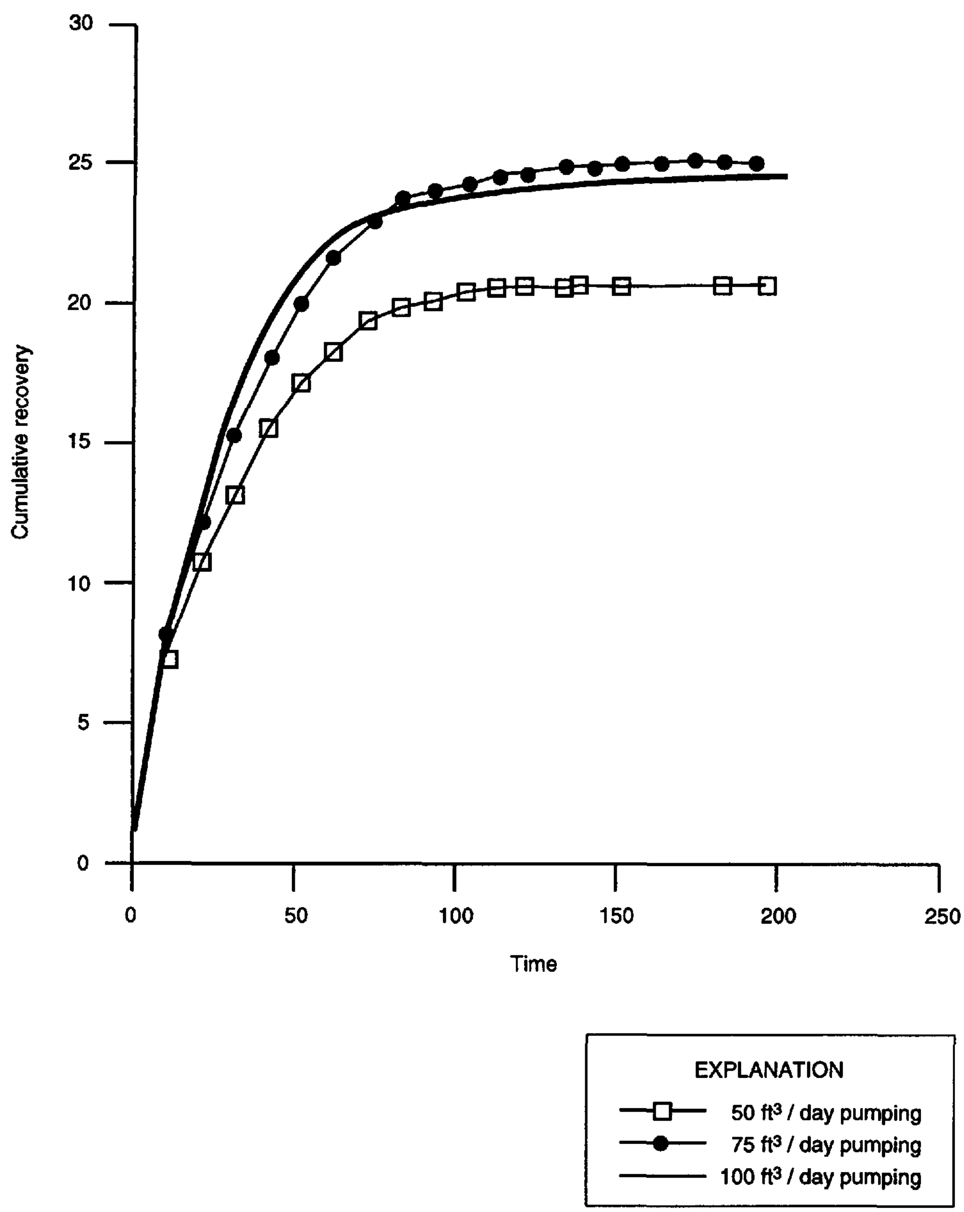

Figure 1—Cumulative Recovery vs. Time for Different Water Pumping Rates

cific site may incorporate any or all of these goals for groundwater withdrawal. Regardless of the goals, when groundwater withdrawal is required, withdrawal rates should be minimized to the extent possible while still meeting the hydraulic control goals.

Based on the hydrogeologic properties of the site and the hydrocarbon properties, calculations should be made to determine the following:

a. The capture zone of the recovery system.

b. The configuration of the system required to contain and remove the dissolved and LNAPL.

The capture zone is the zone of hydraulic influence within which LNAPL and groundwater will flow to the recovery point. The groundwater pumping rate and system location should create a capture zone that will encompass the LNAPL and dissolved plumes, based on site target levels.

Groundwater discharge from a recovery system should be carefully controlled so that water withdrawal is minimized and LNAPL withdrawal is maximized. Lower pumping rates cause reduced drawdown and limit the vertical section of the aquifer exposed to contact with LNAPL, which will reduce the vertical extent of the LNAPL. In many instances, multiple wells pumping at lower individual rates will be more effective than fewer wells pumping at higher rates.

Considering the preceding discussion, routine O&M data collection and evaluation of groundwater recovery systems are essential for ensuring that design criteria and target levels

Table 1—Well Efficiency Test Procedures

Step Performed	Steps
✓	Shut in well 24 hours prior to the test.
✓	Install temporary well flow meter.
✓	Measure and record the following:
✓	- Length from pump suction depth to well datum at top of casing (TOC).
✓	- Distance from center of discharge pipe to center of pressure gauge dial.
✓	- Distance from TOC to center of discharge pipe.
✓	Calibrate well pressure gauge or replace with a calibrated test gauge.
✓	Begin test by measuring the depth to well liquids from TOC using an interface probe; record time, the depth to oil (DTO), and the depth to water (DTW).
✓	Close the discharge flow valve, start the well pump, and open the discharge flow valve to get a steady flow rate (approximately one-quarter of total flow rate capacity) measured through the flow meter.
✓	Check DTO and DTW and maintain steady flow rate until these parameters stabilize.
✓	Record time, flow rate, discharge pressure, DTO, and DTW.
✓	Perform a step test on the well by increasing the well flow in increments of approximately one-quarter of the total flow rate capacity and repeating the previous two measurement procedures until the well has reached its maximum flow rate.
✓	Estimate the specific capacity by dividing each flow rate by the corresponding drawdown. Plot DTO and DTW versus rate and compare with previous test results.

Notes: 1. The well tests should be performed only when the recovery system is in operation.

2. Maintenance of the well/pump system should be considered if the current test results show a decline in the specific capacity of the well of 25 percent or greater below original test results.

Table 2—Pump Efficiency Test Procedures

Step Performed	Steps
✓	Calculate the total pump discharge head (Ht) for each step of the test: $Ht = hs + d1 + hg + hpg + Vd^2/64.4$ *Where:* hs = distance from top of casing (TOC) or measuring point to well pumping liquid level (feet). d1 = distance from TOC or measuring point to center line of discharge pipe (feet). hg = discharge pressure [gauge reading in pounds per square (psi) multiplied by 2.31] (feet). hpg = distance from center line of discharge pipe to center of pressure gauge (feet). Vd = flow velocity in discharge pipe (feet/second).
✓	Each step of the test represents a point on the pump performance curve (total head vs. flow rate); compare the test results to the manufacturers' pump performance curve and also to the original pump performance curve; test points that fall below these performance curves indicate the pump is operating inefficiently and may require maintenance attention.

Note: Use the data generated during well testing (see Table 1).

are satisfied in a cost-effective manner. Data collection and evaluation criteria are outlined in the following section.

2.3.2 DATA COLLECTION AND EVALUATION OF GROUNDWATER RECOVERY SYSTEMS

Most of the data collected during routine monitoring discussed in Section 2.2 will also apply to evaluating groundwater recovery systems. A groundwater recovery-system design will vary from site to site depending on the objectives, target levels, and the site-specific hydrogeologic conditions. The focus of routine data collection and evaluation should be to ensure that the system is meeting the design objectives and the permit requirements in a cost-effective manner. After design and installation of a recovery system, the operating system must be monitored to enable adjustments to be made to maintain system effectiveness. Data collection requirements include the following:

a. Actual and corrected groundwater table elevations for each recovery and monitoring well.
b. Water quality from selected wells.
c. Pumping rates for individual wells.
d. System pumping rate.
e. Power usage.
f. General equipment condition (pumps, controls, treatment system).
g. Pump/well efficiency data.
h. Line pressures.
i. LNAPL information.

Data collection frequency will vary from site to site depending on several factors, including the size and complexity of the recovery system, operating conditions, equipment reliability, remote monitoring capability, and regulatory requirements. Specific factors that will usually dictate monitoring frequency for groundwater recovery systems include the following:

a. Degree of groundwater table fluctuations or other hydrogeologic conditions that could significantly alter flow patterns over short time frames.
b. Pumping rate fluctuations or related factors that could result in a loss of plume containment.
c. Aquifer sensitivity.
d. Regulatory requirements.

In the absence of complicating site conditions, data necessary to evaluate flow patterns and optimum pumping rates should be collected and evaluated at least monthly.

As with LNAPL recovery systems, evaluation of system performance should include evaluating any trends, patterns, or anomalies, such as unusual groundwater fluctuations, and the ways such patterns affect the performance of the recovery system. The data evaluation should determine if the system is operating as designed to meet the program objectives (i.e., plume containment/recovery, pumping rates minimized). Complete evaluations will allow for system adjustments to be made for system optimization.

Plume containment and pumping optimization are probably the most important data evaluation goals. Data evaluation procedures should include the following:

a. System performance summary.
b. LNAPL recovery and dissolved hydrocarbon concentration information.
c. Plume containment evaluation (capture zone analysis).
d. Well/pump efficiency evaluations.
e. Other system checks (i.e., power usage, silting problems).

These data evaluation procedures are essentially the same as those discussed in the previous section on LNAPL recovery systems (see 2.2–2.2.2.3).

2.4 Soil Remediation Systems

2.4.1 OVERVIEW

There are several alternatives for remediating soils containing petroleum hydrocarbons above site target levels, ranging from physical excavation with surface disposal/treatment to in-situ techniques. By far the most common techniques are in-situ vapor extraction and bioremediation.

Vapor extraction is accomplished by increasing the movement of air through the hydrocarbon-containing soils in the unsaturated zone to remove volatile hydrocarbons. This technique is often referred to as *soil venting* or *soil vapor extraction.* Bioremediation techniques for soil remediation are commonly accomplished by *bioventing,* which is a method closely related to soil venting. The purpose of bioventing is to move air through the hydrocarbon-containing soils to provide an oxygen supply to stimulate bioremediation processes. The operational difference between soil venting and bioventing is that soil venting typically operates at higher air flow rates to enhance volatilization of residual volatile hydrocarbons; whereas bioventing systems operate at lower air flow rates to promote biodegradation by maintaining aerobic conditions and moisture content.

A soil venting/bioventing system consists of three basic components:

a. Subsurface vapor extraction wells.
b. Blower fan/vacuum pump (to draw air through the soil).
c. Vapor management and treatment system.

The vapor extraction wells provide conduits for air movement to and from the soils containing concentrations of chemical(s) of concern above site target levels to the surface and may consist of slotted casing or well screen. Fan systems include an explosion-proof motor and a spark-resistant blower. Vacuum pump systems include an explosion-proof motor and a liquid-ring vacuum pump or regenerative blower.

Venting systems can be used effectively in a wide variety of situations. The rates of recovery and applicability to a given site depend primarily on the properties of the formation and the volatility/biodegradability of the hydrocarbons. Venting systems should be monitored regularly to ensure that the system is operating as designed and to maximize operational efficiency. Procedures for data collection and evaluation are outlined below.

2.4.2 DATA COLLECTION/EVALUATION OF SOIL REMEDIATION SYSTEMS

Venting system O&M monitoring is performed to determine the amount and movements of chemical(s) of concern in the subsurface before, during, and after remediation. The overall goals of a monitoring program are (a) to assess site conditions to determine remediation approach, (b) to evaluate the progress of in-situ treatment and ensure the system is operating according to design, and (c) to document site conditions following treatment. A number of options are available for monitoring venting systems, including measuring the following parameters:

a. Vapor flow rates—Measurements can be made by a variety of flow meters, including pitot tube, orifice plates, and rotometers.
b. Vacuum readings—Measurements can be made with manometers and magnehelic gauges. Pressure should be monitored at each monitor location while ensuring that a good seal is maintained so as not to alter in-situ vacuum measurements.
c. Vapor concentrations and composition—Vapor concentrations can be measured by an on-line total hydrocarbon analyzer calibrated to a specific hydrocarbon or by periodic measurements with field instrumentation. This information can be combined with vapor flow rate data to calculate removal rates (mass/time) and the cumulative amount of chemical(s) of concern removed. Compositional measurements of hydrocarbon vapors should be made periodically. Soil-gas measurements should be made periodically at different radial distances using soil-gas probes to monitor the reduction in the vapor concentrations of the chemical(s) of concern.

1. Temperature of the soil and ambient air: By monitoring soil temperatures, Conner (1988) predicted that biodegradation was occurring in the soils containing chemical(s) of concern. At locations with large seasonal differences between air and soil temperatures, extraction air temperature is also a qualitative measure of air residence time in the soil.

2. Water-table elevation: For soils with a relatively shallow water table, water-level measurements should be made to help ensure that the zone of interest remains unsaturated and that upwelling of groundwater in the vicinity of the vapor extraction wells is not causing a significant problem.
3. Meteorological data: These measurements include barometric pressure, precipitation, and similar data.

Data collection requirements for a variety of data interpretation/analysis requirements utilizing venting system and related data are presented in Table 3.

Monitoring and evaluation of venting system performance should be conducted frequently enough to accurately represent both the variability in the data set and the overall decline of hydrocarbon removal rates over time. Collection of O&M data on too frequent a basis can generate unneeded quantities of data and will add to the operational costs. Selection of an appropriate monitoring frequency is a compromise between data quantity and project costs, and may be influenced by site-specific factors. Many venting systems are monitored either weekly or monthly; it may be appropriate to monitor weekly (or even daily) during the period following system start-up and then monthly after several weeks.

Soil venting-system performance monitoring is a direct measurement of the rate of hydrocarbon removal by the system. If the system has been properly designed to access all residual hydrocarbon in the vadose zone, the rate of hydrocarbon removal should determine time estimates for system shutdown and site closure.

Hydrocarbon mass removal rate graphs are calculated as a function of the total volatile hydrocarbon concentration of the system effluent, the molecular weight of the calibration gas, and the volume of air extracted per unit time. This format allows easy interpretation of the present and past performance of the system, and provides important information about system efficiency. The relative decline in hydrocarbon mass removal rates, variability of the removal rate data (which may indicate overriding engineering or hydrologic controls on system efficiency), and degree of asymptoticity of the data are easily interpreted from these graphs. An example of a hydrocarbon mass removal rate graph is shown on Figure 2.

Site monitoring for carbon dioxide and oxygen levels using soil vapor probes should be conducted when bioventing systems are operated to evaluate the effects of process changes on microbiological activity in the subsurface. These measurements are simple and relatively inexpensive to conduct and can provide information on the following:

a. Hydrocarbons that have been biodegraded versus volatilized: This information is critical if subsurface conditions, such as soil moisture, are to be manipulated to improve biodegradation, reduce off-gas treatment costs, and maximize semivolatile hydrocarbon removal.

b. Site factors limiting biodegradation: If oxygen and carbon dioxide monitoring indicates low oxygen consumption and carbon dioxide production (and chemical(s) of concern are still present in the subsurface), further site evaluation can be conducted to determine what factors are limiting biodegradation.

c. Subsurface air flow characteristics: Measurement of persistently low oxygen or high carbon dioxide in one or more monitoring wells may indicate an inadequate air supply. The presence of measurable methane, a by-product of anaerobic degradation, is also an indicator that oxygen is limited in the system. In this case, higher extraction rates, more extraction wells, or cycling of passive and active wells to eliminate stagnant air flow zones and low oxygen levels may be needed. The presence of high moisture content or other immiscible fluids should also be considered as adversely affecting air flow.

2.5 Groundwater and Air Treatment Systems

2.5.1 OVERVIEW

Groundwater and air treatment is usually associated with hydrocarbon remediation projects. The design and successful implementation of these treatment systems with respect to cost-effective O&M requires the consideration of several factors including the following:

a. Identification of target compounds to be removed.
b. Background levels of target compounds.
c. Influent concentrations of target compounds.
d. Cleanup objectives.
e. Identification of parameters in the influent stream (typically inorganics) that may inhibit the removal of chemical(s) of concern or cause fouling or corrosion of treatment system components.
f. Influent flow rates.
g. Power requirements.

During design, O&M requirements should be evaluated to ensure that the treatment system selected has the following characteristics:

a. Capability to remove chemical(s) of concern effectively and efficiently.
b. Reliability.
c. Cost-effectiveness.
d. Compatibility with site conditions.
e. Conformance with regulatory requirements.

Typical treatment systems available for the treatment of groundwater and/or air at hydrocarbon remediation sites include oil/water separators, air strippers, bioreactors, carbon systems, and catalytic/thermal oxidation systems.

Routine O&M data collection and evaluation are essential for ensuring that treatment systems are treating waste

Table 3—Process Monitoring Options and Data Interpretation

Data Interpretation/Analysis Requirement	Data Collection Requirement
Concentration vs. time Composition vs. time Flowrate vs. time Applied pressure/vacuum vs. time Mass removal rate (mass/time)vs. time cumulative removed by volatilization (mass) identify mass transfer limitations	1
Aerobic biodegradation contribution to removal rate [mass/time] vs. time Aerobic biodegradation contribution to cumulative removed (mass)	1, 2, 6[a]
Total remediation costs ($) vs. time Cost per mass of hydrocarbon removed ($/kg-removed) vs. time	1, 2[b], 3
Effect of environmental factors (qualitative)	1, 2[b], 4
In-situ assessment of treatment with time (qualitative areal impact)	1, 2b, 4[a], 5, 6[b], 8[a], 9[c]
Define zone of vapor containment (qualitative areal impact)	1, 5[a], 7, 11[a]
Closure monitoring report	1, 2[b], 3[a], 4[a], 5, 7, 8, 9, 10, 11[a]
Areal impact of air sparging	1, 2, 4[a], 5[a], 6[a], 7, 8[a], 9, 10, 11[a]
Effect of water-table elevation changes	1, 2, 4, 5, 6, 7, 9, 10
Injection/extraction flowrate optimization Flow field definition	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11

[a]Optional, or as required.
[b]Applicable for bioventing applications.
[c]Relevant to air sparging.

Note: Data Collection Requirement Key:
1 = Process monitoring data; extraction/injection flowrate(s) and vacuum(s)/pressure(s), extraction vapor concentration and composition.
2 = Respiratory gas (O_2, CO_2) monitoring of extracted vapor stream.
3 = Cost monitoring; capital, operation and maintenance, and utilities costs.
4 = Environmental monitoring; temperature, barometric pressure, precipitation.
5 = In-situ soil gas monitoring; vapor concentration and composition.
6 = In-situ soil gas monitoring; respiratory gases (CO_2 and O_2).
7 = Subsurface pressure distribution monitoring.
8 = Soil samples.
9 = Groundwater monitoring.
10 = Groundwater elevation monitoring.
11 = Tracer gas monitoring.

streams to acceptable levels as cost-effectively as possible. Data collection criteria are outlined below.

2.5.2 DATA COLLECTION/EVALUATION OF GROUNDWATER AND AIR TREATMENT SYSTEMS

Routine data collection requirements for groundwater treatment systems include the following:

a. Oil/water separation efficiency.
b. Influent concentration (chemical(s) of concern and inorganic parameters that have fouling potential).
c. Effluent concentration.
d. Flow rates.
e. Line pressures.
f. Percent downtime.
g. Equipment condition.
h. Power usage.

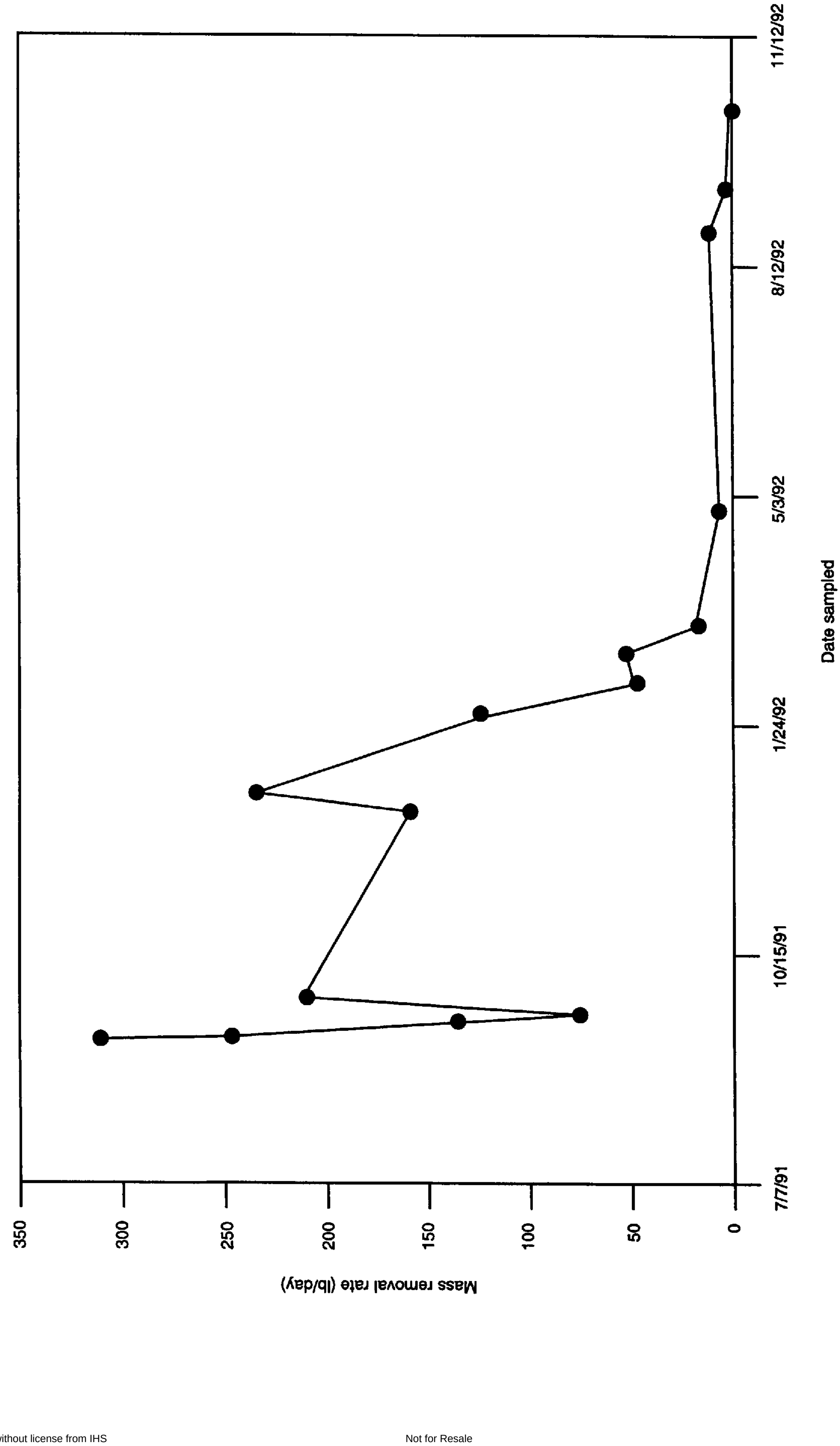

Figure 2—Hydrocarbon Mass Removal Rate vs. Time

Evaluation of routine data is typically accomplished graphically. Influent and effluent concentrations for chemical(s) of concern should be tabulated and graphed versus time. These concentrations are compared with regulatory limits for the chemical(s) of concern. An example of influent/effluent concentration graphs is shown on Figure 3. This graphical approach facilitates interpretation of treatment system efficiency and, will usually allow adequate estimates of time for remediation as trends are developing.

Routine data collection requirements for air treatment systems include the following:

a. Influent concentration [typically collected with a photoionization detector (PID), flame ionization detector (FID), or other field equipment].
b. Effluent concentration.
c. Flow rates (volume for monitoring period).
d. Percent downtime.
e. Equipment condition.
f. Power usage.

The evaluation of these data is also easily accomplished graphically. Air influent and effluent readings for each measuring point (i.e., treatment system off-gas, extraction system off-gas) are plotted graphically and compared with past operational data and allowable discharge limits. The flow rate and effluent concentrations should be used to determine compliance with specific regulatory emissions requirements.

Typical components of treatment systems that require routine checks and maintenance are as follows:

a. *Hydraulic:* high-low-level switches, pressure sensors, flow meters, phase separation probes.
b. *Physical/chemical:* pH meters, conductivity probes, turbidity probes, dissolved oxygen probes.
c. *Electrical:* motors/blowers, circuit breakers, thermal overloads.
d. *Mechanical:* automatic valves.

SECTION 3—REHABILITATION/PROBLEM TROUBLESHOOTING

3.1 General

Several factors cause O&M problems for hydrocarbon remediation systems and lead to the need for rehabilitation to restore operating efficiency. The more common O&M problems are associated with the following factors:

a. Poor design (leading to inefficient operation and frequent maintenance).
b. Inorganic scaling.
c. Iron bacteria/biofouling.
d. Cold weather.

Any of these factors can result in inefficient operation and costly maintenance of either recovery or treatment systems. This section discusses the problems, troubleshooting, and solutions to the O&M problems associated with these factors.

3.2 Poor Design

O&M problems are frequently the result of the decisions, methods, and systems selected during design. These design errors can lead to inappropriate or inadequate systems for site-specific conditions and may require frequent adjustments and maintenance to ensure satisfactory operation. Numerous examples of this type of problem exist; a few common problems, troubleshooting methods, and potential solutions are discussed below.

a. Poor well design: Some well design factors may lead to premature O&M problems (i.e., improper gravel pack sizing or screen size). Many times poor well design is identified through routine monitoring of well efficiency and specific capacity testing. Potential solutions may include more frequent well redevelopment and/or well replacement.
b. Equipment not compatible: It is important to ensure that equipment used for hydrocarbon recovery and treatment systems be compatible with the hydrocarbons it will recover and treat. Equipment not compatible with the specific hydrocarbon may deteriorate rapidly or operate inefficiently. This problem might be recognized during efficiency monitoring or routine checks of equipment condition. Equipment replacement will probably be required.
c. Incorrect pump sizing: Incorrect pump sizing can lead to inefficient flow rates and increased power costs. Testing pump efficiency and comparing actual operating data with manufacturer's recommended performance information can identify this problem. Adjusting operating conditions to appropriate ranges or equipment replacement may be potential solutions.
d. Inappropriate treatment system: If a treatment system is being utilized that is not appropriate for site-specific conditions, then increased O&M may be the result. One example would be a site that uses carbon adsorption where carbon replacement costs far exceed O&M requirements for other applicable alternative treatment methods. Although routine efficiency monitoring and evaluation will likely identify this problem soon after system start-up, this type of problem could be avoided by adequate economic and technical consideration during design. Since treatment requirements are likely to change with time, appropriate measures should be evaluated during design to ensure cost-effective treatment throughout the life of the project.

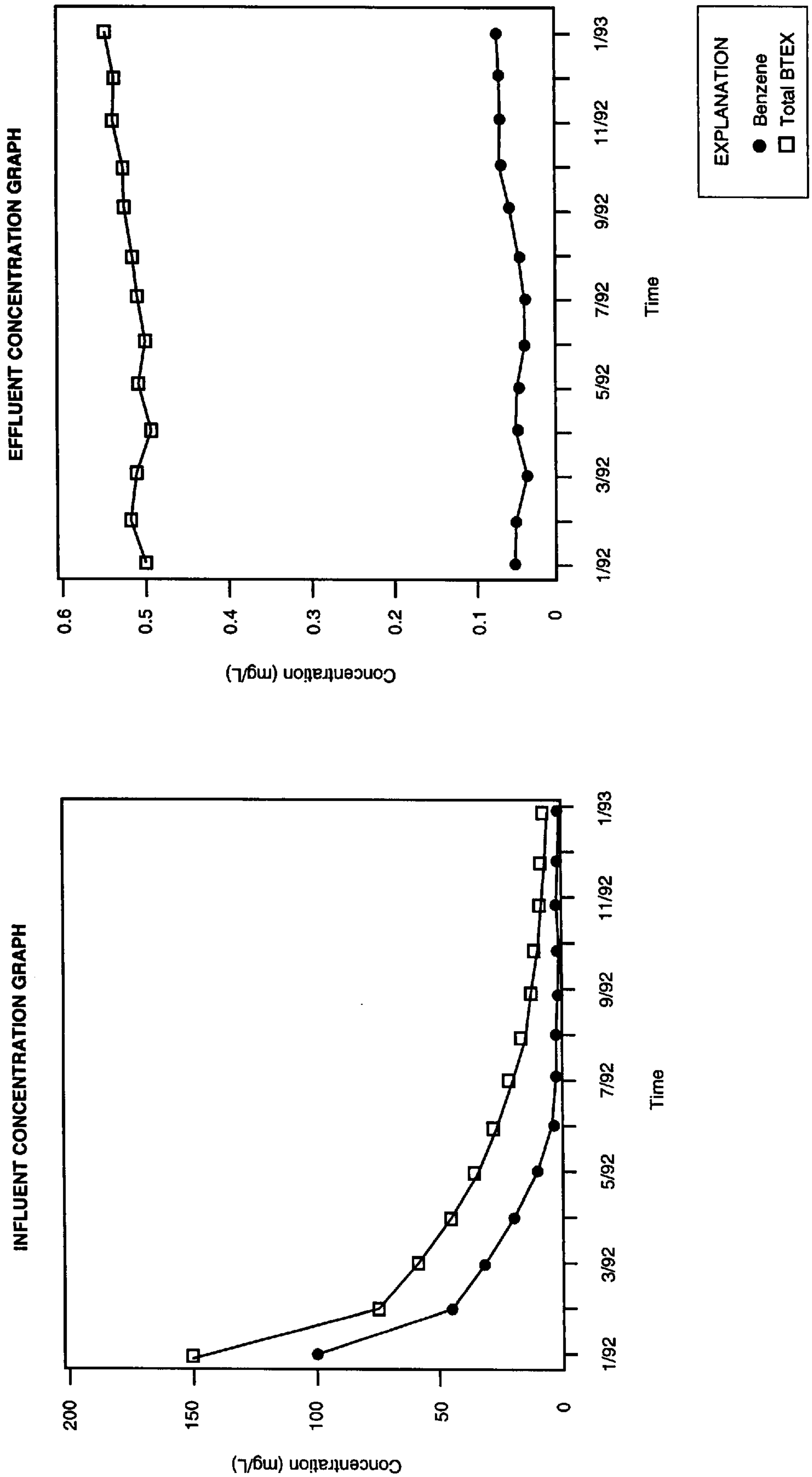

Figure 3—Groundwater Influent/Effluent Concentration Graphs

3.3 Inorganic Scaling

Inorganic scaling or fouling of recovery wells, equipment, and/or treatment systems can lead to plugging and reduced efficiency. Scaling occurs when chemical changes cause certain inorganics to precipitate and build up on recovery/treatment system surfaces. Primary sources of inorganic fouling include iron, manganese, and hardness (particularly, calcium and magnesium).

Under reducing conditions, caused by the depletion of dissolved oxygen due to the natural degradation of hydrocarbons, inorganics such as iron and manganese will remain in solution. During pumping and/or aboveground treatment, these inorganics are exposed to oxygen, which can cause precipitation and scaling problems. Hardness is usually precipitated due to a shift in pH towards alkaline conditions. The most common reason for this type of pH shift is the stripping of carbon dioxide due to air stripping or hydraulic turbulence.

Troubleshooting inorganic scaling requires routine monitoring and evaluation of system efficiencies, equipment condition, and routine water-quality checks for suspect inorganics. Concentration ranges with corresponding levels of effort for O&M are presented in Table 4.

Table 4—Operational Consideration for Inorganic Scaling

Iron (Fe), Magnesium (Mn)	Maintenance Requirements
Concentration	
0–5 ppm	Maintenance as required
5–10 ppm	Routine maintenance
10–20 ppm	Constant maintenance
>20 ppm	Pretreatment can be considered depending on the flow rate
Maintenance:	
Diffused Air Strippers	Changing of filters
Packed Tower Air Strippers	Acid washing of packing or replacement of packing. Required system shutdown
Hardness	
Concentration	
0–150 ppm	Maintenance as required
150–300 ppm	Routine/constant maintenance
>300 ppm	pH control

Maintenance: Required system shutdown and removal of scaling with muriatic acid.
pH Control: Requires continuous addition of hydrochloric acid (HCl) to maintain the pH of the influent in 4.0–5.0 range.

Common solutions to inorganic scaling include filter changes (diffused air strippers), chemical treatment (wells and treatment systems), well redevelopment, and pH control.

3.4 Iron Bacteria/Biofouling

Iron bacteria and other biofouling can be one of the most difficult O&M problems associated with hydrocarbon remediation systems. Natural microorganisms are prevalent in the subsurface and can also be introduced into the wells during drilling operations. If these microorganisms adapt to and begin to utilize hydrocarbons as a food source, they can multiply very rapidly. The collective biomass of these microorganisms will attach to well materials, pumps, and treatment components and can cause severe plugging problems. The biomass will also accumulate within the gravel pack of wells and in the adjacent formation, reducing well yields. The cumulative results are a loss of well and treatment system efficiency and equipment deterioration.

Biofouling is usually first recognized by the presence of slime on pumps, probes, and other downhole equipment during routine maintenance. Left unchecked, the problem quickly escalates to cause severe plugging. If not treated early, biofouling can ultimately lead to well and equipment replacement.

There are no easy solutions to O&M problems caused by biofouling. The best approach is to perform routine maintenance at the first sign of growth on downhole equipment. At sites where biofouling is suspected, a test probe can be suspended downhole and checked routinely for the presence of slime. Once the biomass is detected, the well can be treated with an acceptable biocide. Chlorine solutions or acids (e.g., hydrochloric acid) can treat this problem; however, these solutions may have undesirable reactions with the hydrocarbons present. Nontoxic biocides that may be more appropriate for this problem are available. After treatment is applied, the well may require redevelopment. Similar maintenance can be performed on treatment systems with this problem. Some form of continuous treatment may be required to control more serious biofouling problems.

3.5 Cold Weather

Cold weather can present many O&M problems. Primary impacts due to cold weather include the following:

a. Freezing of groundwater in pipes, sumps, and reactors.
b. Freezing of moisture in air lines.
c. Reduction in treatment system efficiency.

A number of measures can be taken to prevent these cold weather problems. These measures should consider worst-case ambient conditions:

a. If water will be in place (standing) for a period of time in which it can freeze, that portion of the system should be located in a heated enclosure; this is a general rule for prevention of cold-weather problems.
b. The water pipes and air lines should be heat taped and/or insulated.
c. The water pipes should be slightly sloped to enable the water to properly drain in case of a system shutdown.
d. In some situations, the treatment unit can be heated with immersion heaters or heat tape.

SECTION 4—SYSTEM O&M COMPARISONS

The most appropriate time to consider implications of long-term O&M costs is during system design. Past experience with various remediation systems is valuable in designing a cost-effective system for a given site.

Numerous systems and combinations of systems are being utilized for hydrocarbon remediation. A comparison of common O&M requirements for various recovery and treatment systems is presented in Tables 5 and 6, respectively.

No one system is appropriate for every site. Several technical and economic factors, including O&M requirements, need to be evaluated during design to select the most effective system. In addition, site-specific conditions might dictate the use of a more O&M intensive system. O&M requirements should not be the only design factor evaluated.

Table 5—Free Product Recovery and Control Systems and Equipment (USEPA 1993)

Systems	Relative Capital Costs	Relative Operating Costs	Relative Maintenance Costs	Potential for Product Removal	Advantages	Disadvantages
Skimming Systems					No water pumped, skims very thin layers, moves up and down with GW	Limited radius of influence. Clogging of screen, Generally limited to shallow (< 25 ft) applications
Floating:						
large saucer type	L	L	M	L-M		
small float type	L	L	M	L-M		
Floating inlet:					No water pumped, skims very thin layers, low cost	Limited radius of influence, manually adjusted, clogging.
bailer/passive	L	L	L	L		
pneumatic pump	L	L	L	L		
Absorbent:						
absorbent bailer	L	L	L	L		
belt skimmer	L	L	L	L		
Single Pump Systems					Low cost, low maintenance surface mounted pumps, easy to maintain low flows	Pumps water and product, requires o/w separator, shallow (< 20 ft)
Diaphram pump	L	M	L-M	L-M		
Centrifugal pump	L-M	M	M	L-M	Low cost and maintenance	Level sensor and o/w separator, required (< 25 ft), emulsification
Submersible pump	M	M-H	M	L-M	No depth limitation, ease of installation, removes water and product	Flow < 1-5 GPM, o/w separator water treatment, emulsification
Pneumatic					Can operate over wide range of low rates, can pump from deep, low K aquifers	Requires air compressor system and water treatment
top filling	M	M	M	M-H		
product only	M	M	M	M-H		
Dual pump Systems					Cone of depression induces migration of product to well, high potential product removal rates, pump GW and Product, potential large radius of influence	High initial cost, high maintenance, recovery well often becomes clogged and inefficient, works best in clean sands and gravels, cycling the GWP on and off with level sensor not recommended approach
GWP and PP with separate levels and product sensors	M-H	M-H	M-H	H		
GWP running steady with PP and product sensor	M-H	M-H	M	H		
GWP running steady with floating producr skimming pump	M-H	M-H	M	H		
Direct Removal					Good initial remedial action using vacuum track, absorbent pads etc.	Not practical for removing product away from excavation area
Open excavations or trenches	–	L	–	L-M		
Routine skimming or bailing wells	–	L	–	L	Inexpensive, works on small localized product layers	Very limited radius of influence and removal rate
Vacuum Enhanced Pumping					Works well with low to medium permeability soils, large radius of influence. Increases water and product flow by 3 to 10 times. Can significantly reduce site remediation time.	Requires high vacuum pump or blower, usually requires thermal air treatment system and water treatment
Drop tube lift	M	H	L	L-H		
In well pump augmented by vacuum on well	H	H	L	L-H		

Notes: GW = Groundwater.
GWP = Groundwater Pump.
PP = Product Pump.
K = Hydraulic Conductivity.
GPM = Gallons Per Minute.
L = Low.
M = Medium.
H = High.
o/w = Oil/water.

Approximate cost ranges based on a unit single well system including water handling and treatment.

Capital Costs:	Operating Costs:	Maintenance Costs:
L = $3,000–10,00	L = $500–1,000/mo	L = < 10% of Capital Cost/yr
M = $10,000–25,000	M = $1,000–3,000/mo	M = 10 to 25% of Capital Cost/yr
H = > $25,000	H = > $3,000/mo	H = > 25% of Capital Cost/yr

Table 6—Comparison of Treatment Alternatives for Removal of Dissolved Petroleum Hydrocarbons in Groundwater

Activated Carbon Adsorption	Air Stripping	Combined Air-Stripping and Carbon Adsorption	Spray Irrigation	Biological Treatment
		CAPABILITIES		
Proven technology for removing aromatic compounds	Proven technology for removing aromatic compounds	Proven technology for removing aromatic compounds	Volatilization, biodegradation, and adsorption are used to remove dissolved contaminants	Proven technology for removing a wide range of organics
Flexible method that can be used with a variety of technologies	Low capital, operating, and maintenance costs	Cost-effective because carbon is consumed only for for removing less volatile organics	Enhancement of in-situ biodegradation	Potential problems with air emissions are minimized
Readily available technology	Simple technology that is easy to operate	Readily available technology	Treated waters can be polished	Compounds not removable by other methods (t-butyl, alcohol, for example) may be removed
Tolerant of some fluctuations in concentrations and flow	Readily available techn-ology			
Potential problems with air emissions are minimized				
		LIMITATIONS		
Carbon costs can be high	Dissolved constituents in groundwater, such as iron, may result in fouling of packing material	Higher capital costs because two-unit operations are required	A large area will be required for treatment	Higher capital, operating, and maintenance costs
Spent carbon must be re-generated or disposed	Air emissions standards may require treatmen of vapors	More complicated because two units must be operated and maintained	Available land must be suitable to handle anticipated hydraulic loading	Greater potential for malfunctions
Pretreatment for oil and grease removal where concentrations are greater than 10 ppm is required	Low temperature will result in poor remova efficiency		Regulatory constraints	System requires more monitoring
Intolerant of high suspend-ed solids levels	Sensitive to fluctuations in hydraulic loading		Potential air emissions issues	
	Requires oil/water separ-ation			

Note: ppm = Parts per million
t- = Tertiary

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