CHAPTER 7

CONSTRUCTION, START-UP & GENERAL OPERATIONS AND MAINTENANCE

7-1. Introduction.

a. This chapter provides guidance on: 1) collecting baseline data for future evaluation of MPE performance; 2) testing the equipment (i.e., shakedown); 3) operating the MPE system during start-up; 4) monitoring MPE (the equipment and the subsurface conditions) during start-up and over the long-term; and 5) operating and maintaining the MPE system over the long-term.

b. Some of the guidance on operations and maintenance (O&M) is taken from EM 1110-1-4001, SVE and Bioventing. Additional O&M activities that are required for MPE but not SVE/BV include:

- Preventing leaks in system piping that is subjected to much higher vacuums.
- Adjusting the system to optimize free-phase product removal.
- Operating oil/water or DNAPL/water separators.
- Treating contaminated groundwater that is extracted.
- Adjusting the placement of drop tubes or submersible pumps to desired depths (e.g., in some cases, sequential lowering of the water table may be beneficial in that SVE can be performed in certain strata without dewatering potentially higher permeability soil layers and thereby promoting preferential airflow).

7-2. Construction Oversight. The construction of an MPE system consists of well installation, piping and wiring installation, and placement of pumps, blowers, or vacuum pumps and accessories. The construction of an MPE system is comparable to the installation of soil vapor and groundwater extraction systems. EP 415-1-261, Volume 5, Chapters 2 and 6, contain specific information on construction of groundwater and soil vapor extraction systems, respectively, that can be applied directly to oversight of installation of the various components of MPE systems. In particular, the guidance contained in those chapters is applicable to the installation of extraction wells, piping, and aboveground equipment.

7-3. Collection of Baseline Data.

a. General.

(1) Information on subsurface conditions must be updated just prior to implementation of MPE to provide a baseline against which the future effects of MPE can be compared and evaluated. Although much of the necessary characterization data may have already been developed during earlier site investigations, it should be confirmed that all necessary information has been collected and that baseline information is current. Collection of baseline

data is very important because once MPE has begun, baseline conditions cannot be determined accurately.

(2) An efficient way to ensure that the necessary baseline data are collected is to produce a checklist of parameters to be measured, including measurement locations and methodology. Table 7-1 lists the parameters that typically should be considered for measurement, and the following paragraphs explain some of the rationale behind their inclusion. Table 3-10 provides additional information about many of these parameters). The specific measurement locations (see 7-3(e)(3)) for each parameter must be selected so variations in subsurface conditions can be determined.

TABLE 7-1

Checklist of Baseline Data to Consider Collecting
(This assumes site characterization has been completed.)

Soil characteristics	
	Variation in contaminant concentrations (laterally and with depth)
Soil gas pressures in:	
	Vadose zone monitoring points
	Groundwater monitoring wells
Barometric pressure	
Groundwater elevations in:	
	Phreatic zone (shallow) wells
	Deep wells (for determination of vertical hydraulic gradients)
Soil gas concentrations measured in:	
	MPE wells
	Vadose zone monitoring points
	Groundwater monitoring wells
Biological activity parameters (if biodegradation is a remedial component)	
	Respiratory parameters (e.g., O_2, CO_2, CH_4,)
	Nutrient concentrations (e.g., nitrogen, phosphorus)
	Plate counts of total heterotrophs and/or specific types of degraders (e.g., hydrocarbon degraders)
Groundwater quality (e.g., oxidation/reduction potential, pH, conductivity, temperature, concentrations of: contaminants, dissolved oxygen, dissolved hydrogen, iron, manganese, nitrate, sulfate, chloride, hardness, alkalinity, anions and cations) in:	
	MPE wells
	Groundwater monitoring wells
NAPL (if present)	
	Viscosity, density, composition and type (e.g., of petroleum product); tendency to form emulsions
	Area of plume and thicknesses across site
	Depth of smear zone
Estimate of total mass of contaminants and distribution among all phases and zones	

b. Soil Vacuum/Pressure Head Distribution. At most sites, especially those with shallow water tables, the static soil gas pressure in the soils to be remediated should be equal to or very similar to atmospheric pressure, or the differences should be small compared to the vacuum to be applied. Still, this should be confirmed by measuring baseline vadose zone pressures. Also, changes in atmospheric pressure when weather fronts pass through the area can cause small pressure differences between the subsurface and the atmosphere. Therefore, soil gas pressure should be monitored in several wells over at least a few hours to establish the baseline variations that can be expected. This will become important when evaluating whether pressure changes observed during remedial operations are due to weather conditions or the application of a vacuum.

c. Soil Characteristics. Chapter 3 discusses the rationale and methodology for collecting data relative to the following soil characteristics:

- Stratigraphy.
- Permeability of different soil layers (this can be estimated from data collected during pumping tests in the saturated zone or SVE pilot tests in the vadose zone, and/or by laboratory triaxial cell permeability measurements of soil samples).
- Porosity (air- and water-filled) in different soil layers.
- Soil moisture content in different layers (can be measured or calculated from the above porosity data).
- Fraction organic content (foc) in different soil layers (for estimating the amount of adsorbed contamination).
- Spatial variation in the above soil properties site-wide.

d. Piezometric Head Distribution, NAPL Thickness.

(1) Application of a vacuum to SVE or MPE wells will cause upwelling within the extraction well if liquid is not removed. Even with liquid removal, upwelling may occur in the area around the extraction well where pressures are sub-atmospheric. Therefore baseline static groundwater levels must be measured in the MPE system area. It is also very important to accurately measure baseline LNAPL thicknesses in the extraction well(s) and in surrounding monitoring wells containing LNAPL. The true LNAPL thickness (see paragraph 3-5a(2)) should be estimated from the apparent LNAPL thickness. True DNAPL thicknesses should also be estimated, if possible.

(2) If deeper or nested groundwater monitoring wells exist, the piezometric heads should be measured in order to calculate vertical hydraulic gradients.

e. Chemical Data Requirements. If recent data are not sufficient, then additional baseline chemical data should be collected prior to start-up. For most chemical parameters, data should not be more than a month or two old. Concentrations of contaminants in the groundwater, soil, and soil gas, and free product composition will change during remediation as the more volatile components are removed and more biodegradable compounds are consumed. Therefore, it is important to have a good understanding of pre-remediation (baseline) concentrations against which to compare future concentrations. These changes will also affect efficiencies, costs, and sometimes methods of treatment. A Sampling and Analysis Plan (SAP) should be prepared that specifies how, what and where to sample, and how samples will be analyzed. The SAP should also include protocols for sample transportation and chain of custody procedures. The quality objectives and other quality assurance and control procedures that are appropriate or required for the site must also be included in the SAP. For these requirements, the designer should follow EM-200-1-3, Environmental Quality - Requirements for the Preparation of Sampling and Analysis Plans. This document provides guidelines for implementing any SAP in a way that will produce data of the necessary quality, accuracy, representativeness, etc. The following sections discuss some of the key aspects of SAPs.

(1) Contaminants to be Measured.

(a) The contaminants to be measured in the extracted groundwater and soil gas should have been identified during previous investigation phases. The parameter list should be reviewed for completeness and should include:

- Contaminants that exceed a clean-up standard and must be remediated.

- Other compounds that can affect treatment or whose change in concentrations will help the evaluation of the remediation progress. For example, observing different rates of decrease in concentrations of various volatile contaminants (including compounds that do not require remediation) can help evaluate the rate of progress of MPE. Similarly, changes in concentrations of compounds of differing biodegradabilities, and the production of biodegradation breakdown products, can assist the evaluation of the degree of biodegradation that is occurring. Other constituents may be oxidized or adsorbed along with the target compounds.

- Specific contaminants to be measured in each medium will depend on the contaminant characteristics. For example, only VOCs need to be measured in the soil gas and only soluble components of the NAPL need be measured in the groundwater. Soil samples should generally be analyzed for VOCs, SVOCs and petroleum hydrocarbons. For NAPL, quantifying the major constituents is usually sufficient (and it is usually difficult to quantify lesser constituents because of interferences from the major constituents).

(b) In addition to the need to determine mass balances and removal rates, additional parameters need to be measured to enable evaluation of other aspects of MPE remediation. Physical, biological and chemical parameters that may affect treatment or may be important for evaluating bioventing and natural attenuation are included in Table 7-1.

(2) Health and Safety considerations. Health and Safety issues are to be addressed in a Site Safety and Health Plan (SSHP). Many of the specific issues that relate to MPE sites are related to volatile and flammable gasoline and other petroleum compounds. Therefore, combustible gas indicators should be employed to ensure that explosive mixtures do not collect in enclosed areas. Other volatile or hazardous compounds (such as toxic chlorinated compounds) may be present, representing a potential exposure hazard to workers. The SSHP should therefore specify the use of appropriate field instruments (e.g., PIDs or FIDs in the case of volatile compounds) to evaluate concentrations of these compounds.

(3) Quantity of Samples. The number of baseline samples must be sufficient to characterize variations across the site and provide representative data. EM 200-1-3 and Breckenridge (1991) provide guidance for selecting the number of samples to collect. Geostatistical methods can effectively be used to estimate average concentrations in various areas (blocks) and can provide measures of the uncertainties in those estimates. Refer to other USACE guidance on geostatistics. However, such a rigorous effort is not usually necessary for remediation design purposes since very high and very low concentrations will be averaged out in the gas and liquid waste streams. What is important to gather from the sampling results is some certainty that the chosen design basis concentration(s) are not much different than the average concentrations in the area to be remediated. If the design concentration turns out to have been overestimated, the remediation system may be oversized and therefore more expensive than necessary. If the design concentration turns out to have been underestimated, the treatment system will not be able to handle the flow or mass loading.

(a) Sufficient data should also be gathered such that the initial contaminant mass in the various phases (free phase, adsorbed, dissolved) can be estimated so that mass removed during MPE can be compared to that originally present.

(4) Field Sampling and Analytical Measurement Methods.

(a) The field sampling methodology (including sampling equipment, sample containers, preservatives, holding times, equipment decontamination procedures, etc.) should be detailed in the Field Sampling Plan (FSP) section of the SAP. EM 200-1-3 should be used for guidance. Examples of appropriate analytical methods are listed in Tables 3-7 and 3-8 of this EM.

(b) Similarly, screening and analytical methods to be used (in-situ, on-site or laboratory) should be specified in the SAP. Specific field instruments (i.e., dissolved oxygen meters, field test kits, portable VOC detectors, etc.), calibration procedures, and proper use should also be described.

(5) Quality Assurance/Quality Control procedures will be chosen with the help of Appendix H of EM-200-1-3 and will be contained in the Quality Assurance Project Plan (QAPP) section of the SAP.

(a) Since the FSP and QAPP of a SAP will likely also be appropriate for the start-up phase as well as long-term monitoring and closure, it may be advantageous to prepare a single SAP to guide monitoring for the entire remediation program. The locations and numbers of samples will vary with the different phases of work. Also, the degree of required QA/QC will vary depending on the phase of remediation (i.e., specifications for O&M monitoring may be less rigorous than those for baseline or closure monitoring).

7-4. Equipment Shakedown/Testing.

a. Before actually beginning the remediation effort, all aboveground equipment and piping should be inspected and tested. An extensive shakedown checklist is included as Table 7-2. Manufacturers' specifications should be included on this checklist so that performance can be easily checked. Out-of-compliance conditions should be corrected prior to start-up of the entire system.

TABLE 7-2

Example Pre-Commissioning/Shakedown Checklist

Checklist Item		Approved by	Date
Subsurface			
	Wells installed and developed as specified		
	Well head covers in good repair and clearly marked		
	Determine/record specific capacity of wells		
	Drop tube (s) and well heads assembled correctly		
	Vadose zone monitoring points installed, developed and pressure tested		
	Trenches, seals and horizontal wells installed per specifications		
	Trenches for subsurface piping installed per specifications		
Piping installation			
	Piping complete (aboveground and subsurface)		
	Piping flushed and pressure/vacuum tested		
	Silencers, strainers and filters installed in correct direction		
	Control and check valves installed and operation verified		
	Valves accessible (easy to reach/manipulate)		
	Piping leak tested (insulation/heat tape, if required, will be installed later after system has been started up)		
	Piping clearly labeled and valves tagged		
Pumps and blowers			
	Foundation, trailer, or shed complete according to specifications and inspected by building inspector (if required)		
	Vibration dampers installed, heavy equipment bolted in place		
	Motor and blower coupling alignments are level and true		
	Pipe supports installed/tested		
	Pumps and seals intact (no leaks)		
	Centrifugal pumps primed as needed or plumbed to self-prime		
	Belts properly tensioned, guards in place		
Electrical/controls/instrumentation			
	Grounding installed/checked		
	Lighting/HVAC and thermostats functional		
	Lockouts/covers/panels in place		
	Pressure/vacuum transducers functioning and calibrated		
	Temperature and pressure gauges installed or portable gauge connections provided		
	Blower and pump rotation verified		
	High and low fluid level sensors operating		
	Disconnects in sight of unit being controlled		
	PLC, controls/alarms, remote monitoring system and interlocks functional and calibrated		
	Power connected to on-line monitoring instruments		
	Final approval received from electrical inspector		

TABLE 7-2

Example Pre-Commissioning/Shakedown Checklist (Continued)

Checklist Item		Approved by	Date
Other			
	Operators have been trained (with respect to Health & Safety and equipment operation)		
	Groundwater treatment system operating (hydraulically) and groundwater discharge (sewer, NPDES, re-injection) arranged		
	Flame arrestor on vapor oxidizer installed correctly		
	Vapor treatment system functional		
	Liquid ring fluid make-up system functional		
	Oil/seals/recirculation system (for oil-cooled blowers) functional, and lubricating oil filled		
	Treatment enclosure ventilation functional		
	Control panel purge system (if required) functional		

b. After the operator has confirmed that all engineered systems meet specifications, the operator will recommend to the project manager that operation begin. The site Health & Safety officer must also be in agreement that all safety devices are operable and that site personnel have, and are trained to use, the appropriate personal protective equipment as required by the SSHP.

7-5. System Start-Up. System start-up refers to the actual initial period of extracting, separating, and treating fluids and measuring the response at surface and subsurface measuring points. This period may last hours, days, or weeks, depending on the complexity of the system, the conditions encountered, and the time to reach steady-state operating conditions.

a. Operations.

(1) This section presents an overall strategy for the start-up of an MPE remediation system, including monitoring the initial response in the subsurface and making the necessary adjustments to begin meeting the operational and remedial objectives. As with all paragraphs in this chapter, the designer preparing the O&M manual must decide which of the suggestions included here (or not included here but relevant to the site-specific remediation system) are appropriate given site-specific conditions, remedial objectives, and remedial equipment. The designer must also decide what constitutes the start-up phase since there is likely to be a specific contract in place to bring the system from installation to normal, long-term operations. The intent should be made clear in the start-up contract. The best way to specify what is expected from the contractor in the start-up phase is to list the performance criteria that must be met before the start-up phase contract is considered complete. Examples of performance criteria are: 48 (or more) hours of continuous operation of all equipment, reaching steady-state flow or pressure conditions; completion of a specified number of cycles of pumping based on water level switches; or completion of all start-up data collection. There may be unexpected problems during the start-up phase, especially if the start-up contractor was not the installation contractor. The contract should thus also specify the conditions or situations that are understood to be out of scope,

and which aspects of a second or third start-up are within scope and which are out of scope.

(2) The designer must state the specific intent and objectives of the start-up phase of system operation. In general, the intent of the start-up phase is to bring all systems, above and below ground, into normal operation (although concentrations and flows may continue to change). The objective of the start-up phase of MPE (and of SVE as well) entails more than simply the mechanical start-up of aboveground equipment. It is also a very important phase in the remediation, because often the highest rates of contaminant removal occur during this initial operating period. Start-up monitoring data can be tabulated and displayed graphically to determine trends in the subsurface response to the MPE system.

(3) The principal objective of many MPE projects is to maximize NAPL removal. However, in cases where MPE is used to augment SVE, the principal objective could be to depress the water table surface and remove enough water to facilitate vapor extraction within the enlarged vadose zone. In this case, greater groundwater extraction rates may be desired to consistently reduce the water table over the entire remedial area. Another example for which greater groundwater extraction rates may be desirable is vacuum-enhanced groundwater extraction systems. Depending on the amount of NAPL at a site and how recoverable the NAPL is, the relative amount of contaminant mass removed during a MPE remediation via either soil gas or groundwater may be less or greater than via NAPL. Initially, if recoverable NAPL is present at the site, most contaminant mass removal is usually in the form of NAPL. But as NAPL recovery rates decline, relatively more may be removed via soil gas and groundwater. The amount of contaminant mass removed per time via soil gas is usually greater than via groundwater, at least initially when soil gas concentrations are high. If soil gas concentrations decrease but groundwater concentrations decrease more slowly, contaminant mass removal via groundwater may eventually become predominant.

(4) A periodic or preventative maintenance plan is typically not included in the start-up plan because the start-up period is typically too short to require scheduled maintenance. Regular or scheduled maintenance items are covered in paragraph 7-6. However, some components may require adjustment during start-up, so manufacturers' specifications and a troubleshooting guide should be included in the start-up plan. For very complicated equipment such as a catalytic or thermal oxidizer, it may be very beneficial to have the equipment supplier or representative on-site during initial start-up activities.

(5) The start-up plan should be prepared and implemented sequentially, to allow comparison of the observations and measurements with the design criteria. This will ensure that the plan is implemented systematically and safely. This sequence is especially important because flammable liquids and explosive vapors may be present.

(6) Table 7-3 is a sequential list of operations that is likely to be followed during an MPE system start-up. In addition to developing such an operations list to follow during start-up, a checklist of the expected ranges in flows, pressures, etc. should be prepared to accompany the monitoring schedule discussed in paragraph 7-5b. If measured conditions vary significantly from the expected range, the reason(s) must be investigated, and explained or corrected. If the reason for the variance cannot be determined or remedied, the system may need to be shut down until corrections can be made.

TABLE 7-3

Suggested Sequence of Operations During Start-up

Check that all planned baseline measurements have been collected (see Table 7-1)	
Calibrate all dedicated and portable instruments	
Pressure test vadose zone monitoring points (they should slowly lose an applied pressure – no loss indicates clogging, fast loss indicates leak)	
Set fluid extraction drop tubes or submersible pumps to selected depths	
Ensure that liquid/air seals are tight at top of MPE wells	
Start groundwater pumping if separate groundwater pump is used (record flow rate and water levels)	
Confirm operation of level control sensors for pump operation	
Turn on vapor treatment system	
Open bleed/dilution valves and all valves controlling flow through vapor extraction/treatment system (extraction wells vapor valves closed)	
Turn on power for liquid transfer pump	
Start vacuum blower	
Open valves from extraction wells completely	
Slowly decrease flow through dilution air valve(s)	
Monitor and record:	
	Extraction well vacuum and vacuum at vacuum pump
	Gas and dilution air flow rates
	Groundwater drawdown
	Groundwater flow rates
	NAPL accumulation rate in tanks, NAPL/water separator
	Blower and pump cycles (programmable logic control should record on and off times)
	Fluid levels in extraction wells (not necessary if levels are controlled by drop tubes or level controls)
	Fluid levels in holding tanks
	Catalytic oxidizer catalyst temperature (if applicable)
Measure gas influent and effluent concentrations with PID or FID	
Monitor pressure changes in nearby vadose zone monitoring wells	
Check for emulsion formation in NAPL/water separator	
Adjust drop tube depths (TPE) or pump intake depths (DPE) to maximize free-phase product removal	
Adjust vacuum at the blower and valves on the extraction wells to optimize operation in accordance with operating strategy	
Leak test lines again at design vacuum	
Check instrument calibration at end of each day (or more frequently if required by SAP)	
Collect vapor samples for laboratory analysis if specified in SAP	
Collect influent and effluent compliance samples as required by permits/regulations	
Insulate/heat trace piping, after startup	

b. MPE Monitoring During Start-Up: Parameters, Methods and Frequency. During MPE start-up, measurements of both the aboveground equipment parameters and below-ground conditions must be performed. Some of these measurements must be real-time or almost real-time since adjustments in the operating conditions will frequently be required.

(1) During the design phase, one cannot precisely predict the required applied vacuum to extract groundwater, NAPL or soil gas from the soil. Therefore, the applied vacuum is typically increased gradually while monitoring

the resulting fluid flows and the resulting pressure effects in the soil formation surrounding the extraction wells or trenches. With a regenerative blower, this is usually done by beginning start-up with a dilution valve open that allows ambient air as well as soil gas to be taken in by the vacuum blower, thereby reducing the vacuum applied to the soil. (The blower exhaust could be recycled instead of bleeding in ambient air, but the potential of excessive temperature increases must first be evaluated before trying this.) The dilution valve is then gradually closed to generate increasing vacuum in the subsurface. The vacuum applied to the extraction well can also be varied through the use of a constricting valve on the inlet side of the vacuum blower. While this is an efficient control method for centrifugal blowers, it is energy inefficient to employ regenerative blowers in this way. Other methods of varying the applied vacuum include using variable speed motors or changing the pulleys and sheaves between the motor and the blower.

(2) A comprehensive monitoring plan is required in order to effectively evaluate subsurface response to MPE. The following sections discuss the types of measurements to be made and the rationale for each so that the O&M Plan author can develop an appropriate monitoring plan. Most of the same parameters must be measured during both the start-up and long-term operating phases of a MPE remediation. Therefore, it will usually be efficient to prepare an overall monitoring plan and simply specify the slightly different parameters and different monitoring frequencies during start-up and long-term monitoring. To help guide the preparation of a monitoring plan (for both phases), Table 7-4 notes monitoring parameters, including those that are not critical to measure during start-up. Long-term monitoring is discussed in paragraph 7-6c. The sampling and analyses aspects of the monitoring plan will follow the procedures specified for the SAP discussed in paragraph 7-3e. The following paragraphs discuss the rationale behind the more important monitoring issues.

TABLE 7-4

Suggested Checklist for Monitoring an MPE System

Physical and Mechanical Parameters (in approximate descending order of importance)
Vacuum in extraction wells and monitoring wells and ambient barometric pressure
Vacuum blower inlet vacuum
Vacuum at each flow measurement point
Vacuum blower outlet pressure
Groundwater drawdown in extraction wells
Volume of groundwater removed
Individual well head fluid velocities
Blower inlet flow rate
Treated effluent flow rate
Bleed/dilution air flow rate
Temperature at blower discharge
Temperature at each flow measurement point
Temperature of treated effluent
NAPL thickness in extraction wells and monitoring wells
NAPL accumulation rates
Appearance of flow regime in transparent portions of piping
Volume of condensate
Blower amperage meter readings
Run time of blowers or pumps
Soil moisture content changes (not critical during start-up)
Groundwater elevations near extraction wells
Degree of upwelling observed

TABLE 7-4

Suggested Checklist for Monitoring an MPE System (Continued)

Relative humidity of gas to be treated if by activated carbon (not critical during start-up)
Ambient temperature (not critical during start-up) Atmospheric pressure (not critical during start-up) Gas temperature at extraction wellhead (not critical during start-up) Noise level (as required)
<u>Chemical Parameters</u> Vapor contaminant concentrations at blower inlet and/or outlet Contaminant concentrations in treated effluent (gas and/or water) Contaminant concentrations at treatment midpoint (if using activated carbon vessels in series) Contaminant concentrations in extracted groundwater (not so critical during start-up) Gas contaminant concentrations in individual MPE extraction wells Gas contaminant concentrations in vadose zone monitoring points (not so critical during start-up) Compositional changes in NAPL (not critical during start-up)
<u>Biological Parameters (if biodegradation is an important remedial process)</u> Dissolved and gas phase oxygen concentrations (not critical during start-up) Gas phase carbon dioxide concentrations(not critical during start-up) Nutrient concentrations, e.g., nitrogen and phosphorus (not critical during start-up) pH (not critical during start-up) Oxidation/reduction potential (not critical during start-up) Microbial plate counts (not critical during start-up)

(a) Vacuum/pressure. Vacuum or pressure should be monitored in gauges installed throughout the MPE system whenever significant changes are expected (e.g., across the blower, the fluid separator, particulate filter). The vacuum at the well(s) is the most important factor to monitor and relate to evidence of the beginning of flow of fluids (air, groundwater, free-phase product). Increases in the resulting flow and changes in soil vacuum at soil gas monitoring points [installed around the extraction well(s)] over time are also important as they indicate when steady-state conditions are being approached. As reported by Johnson et al. (1990) and Peargin and Mohr (1994), the time to reach steady state can range from several hours to several days or much more, depending on soil permeability. The frequency of vacuum/pressure measurements can then be reduced over time as the magnitude of changes in measured values decline and steady-state conditions are approached. If many points need to be monitored and if initial changes are expected to be significant, it may be worthwhile to use electronic data loggers. If data loggers are used, the monitoring plan should include the calibration and operating procedures for the equipment. An accuracy of 0.2 mm Hg (0.1 inches water) column is usually sufficient, especially for the higher applied vacuums associated with MPE. Different strategies and monitoring may be appropriate for horizontal MPE systems where the vacuum is applied through horizontal piping and screens installed in trenches and the overlying soil must be of low permeability. In horizontal (trench) MPE systems, the applied vacuum should be checked at different locations along the horizontal screen, because the vacuum is not likely to be uniform throughout. Important measurements include vacuum in vadose zone monitoring points in order to evaluate the zones of influence and to confirm that the upper trench seals meet the design criteria.

(b) Fluid head distribution. Applying a vacuum to the well will cause the zone of saturation to upwell (rise) in the recovery well upon application of vacuum. However, in MPE, there is typically a drop tube or separate pump to remove groundwater and/or free phase product. Hence, this upwelling does not present the same problems encountered with SVE/BV systems of raising the top of the zone of saturation. Measuring the actual changes in the top of the saturated zone in the formation and/or in the extraction well may be desirable, but can only be accomplished if appropriate pressure transducers have been installed (see paragraph 4-2e(5)(c). It would also be possible to install sensors to detect the thickness of NAPL in a MPE well during extraction but it is rarely done. Water and NAPL levels in nearby monitoring wells might also change due to the applied vacuum. If significant soil vacuums are noted during monitoring, the elevation of the top of the saturated zone should also be measured in the vadose zone monitoring points (if they intercept the water table), in such a way as to prevent air from leaking into the monitoring points. In a DPE trench system, water levels in the trench must be monitored to confirm that LNAPL or groundwater is indeed above the level of the horizontal pipe so that extraction can take place.

(c) Fluid flow. To measure the efficacy of the MPE system, the flows of extracted gas, water, and NAPL must be measured. Paragraphs 5-7a(3) and 5-7a(4) discuss the various flow measurement devices available and note that fluid flows must be measured after the fluids have been separated. While these issues will have been considered during the design of the instrumentation and control system, they are also discussed here as a very important aspect of proper O&M.

- Gas velocities are typically measured with pitot tubes, rotameters or hot wire anemometers. The flow through a vacuum blower can also be estimated based on the inlet vacuum, outlet pressure and the manufacturer’s blower curve. In DPE, the extracted gas flow from each well is typically measured using a pitot tube or hot-wire anemometer placed in the riser or in the conduit from the well to the manifold. With TPE (e.g., bioslurping), if flow from multiple wells are manifolded together before phase separation, it will not be possible to measure the soil gas flow from each well when both liquids and soil gas are being extracted. Only the total airflow to or from the vacuum blower will be measurable in this case.

- It is also very important to measure the flow of any dilution air so that the airflow from the subsurface can be calculated as the difference between the entire airflow being treated and the dilution airflow.

- Sufficient pipe length must be provided to reduce turbulence upstream and downstream of the measurement location. Attaining less turbulent flow conditions may also be aided by installing stabilizing fins, but this is usually not necessary (there is usually sufficient room in a MPE system to provide the required straight length of pipe). Airflow should be measured frequently during start-up, perhaps every 10 to 15 minutes during the first several hours and then hourly for the first several days to monitor the natural variation in flows. Measurement of the airflow from individual wells allows one to adjust the flow or vacuum to meet a particular operating strategy (e.g., equal flows, equal applied vacuum, equal mass removals).

- Gas flow rates should be reported in both scmm (flow at standard temperature and pressure) and acmm (flow at the actual temperature and pressure), and the temperature and pressure should also be recorded. (Scmm data are useful for comparing flows in standard units, while acmm data are required for calculating mass removal rates.) Corrections to standard temperature and pressure can be significant during high vacuum MPE. For example, the algorithm used by most hot wire anemometers (which actually measure fluid mass flow) report the velocity as if the air is at standard temperature and pressure. When calculating velocities from pitot tube data, both the differential pressure and absolute pressure must be known and used to calculate the velocity and flow (in accordance with manufacturers' instructions). Even the flow readings from rotameters must be adjusted depending on the absolute pressure and whether the rotameter is calibrated for a certain pressure (usually atmospheric) at the inlet or the outlet. Temperature corrections to flow measurements are generally small and are often ignored since the overall accuracy of flow measurement is ordinarily only about plus or minus 5 percent.

- When designing the instrumentation system, the designer and operator must choose the correct pipe diameter for the velocity measurement device to be used. For example, an operator who later wants to use a pitot tube instead of the hot-wire anemometer (or vice versa) may discover that the pipe diameter is not appropriate.

- Groundwater recovery rates may be measured with the use of flow rate meters or totalizing flow meters or by measuring accumulation in a holding tank over time, after separation from NAPL. Initial flow rates will be very important for evaluating conditions in the recovery well(s) and should also be monitored frequently, perhaps hourly on the first day. After separation, NAPL flow can generally be measured in a manner similar to that for groundwater. However, flow meters for NAPL measurement must be calibrated to the specific gravity of the NAPL.

(d) VOC concentrations in extracted gas.

- In almost all cases, the mass of contaminant being removed in the gas phase will need to be measured during start-up (when significant changes often occur). The removal efficiency of the gas treatment system must also usually be monitored. Thus, influent and effluent VOC concentrations should be measured frequently enough to observe changes. The precision, accuracy and quantification requirements are specified in the SAP and will depend, in part, on the chosen sampling and analytical methods. Sampling and analysis may employ: FIDs, PIDs, on-site GCs, combustible gas indicators, detector tubes (i.e., Draeger®), gas (Tedlar®) bags followed by laboratory GC or GC/MS analysis, activated carbon adsorption tubes followed by laboratory GC or GC/MS analysis, or summa canisters followed by laboratory GC or GC/MS analysis. Paragraph 3-5d provides guidance on selecting the most appropriate methodology.

- The specific analytical methods, holding times, QA/QC requirements, etc., for VOC monitoring in gas should be included in the SAP described in paragraph 7-3e, but they may be different than those chosen for other purposes such as determining of the extent of contamination or demonstrating that remedial goals have been achieved. Effluent air sampling frequency is often specified in discharge permits.

- Methods for evaluating the VOC mass removal data are discussed in paragraph 7-5c(2).

(e) Groundwater quality.

- During the relatively short start-up period, groundwater contaminant concentrations in monitoring wells are not likely to change sufficiently to warrant any sampling or analysis.

- The quality of the extracted groundwater may change over time and therefore monitoring of contaminant concentrations is necessary for calculating mass removal of dissolved contaminants. If a groundwater treatment system is part of the MPE system, the SAP will address details of monitoring contaminant concentrations in the influent and effluent. Often, a discharge permit will specify monitoring frequencies and maximum discharge flow rates and concentrations.

(f) Other measurements. Performing the following supplemental measurements should also be considered for additional information that will help in evaluating MPE system operations:

- A volt meter (at a minimum) or an amperage meter (recommended) can be used to determine whether a motor is overheating or is functioning properly.

- Ambient atmospheric pressure should be monitored if it is important to distinguish small changes in vadose zone pressure from changes in ambient atmospheric pressure.

- If vapors are to be treated by vapor-phase carbon, the temperature and humidity may need to be controlled for optimum adsorption efficiency and to minimize costs (i.e., significantly lower adsorption capacity occurs when the relative humidity (RH) is greater than 50 percent). Therefore, the RH in the exhaust of the vacuum blower system should be measured. Alternatively, the RH in the exhaust can be estimated by assuming that the incoming air is at 100% RH at the temperature of the subsurface and then calculating the RH at the higher temperature in the blower exhaust.

- The temperature rise through the blower should be compared to the manufacturer’s specifications for an indication of whether the blower is operating properly.

- Differential temperature through a catalyst (where applicable) can indicate the approximate level of VOC contamination in the gas extracted from the subsurface.

- Monitoring the level detectors in liquid/gas separators, water/NAPL separators, and holding tanks is important for the proper operation of, and troubleshooting of, the MPE system.

(g) Steady-State Conditions. Once steady-state operating conditions appear to have been reached, at least three sets of measurements of groundwater elevations, vadose zone vacuums, and gas and liquid flow rates should be collected at least one day apart (or more in the case of low permeability soils) to confirm the achievement of steady-state conditions. The start-up phase can then be considered technically complete. Long-term operational and monitoring guidance from this point forward is described in paragraph 7-6. For contractual purposes, there should be more specific criteria for the start-up contractor to fulfill before this phase is considered complete and payment is approved. These criteria should be reasonable but give an incentive to the contractor to complete the start-up efficiently and expediently, For example, it could be required that the entire system operate for a specified number of hours or days and at some minimum flowrate without attendance for start-up to be considered complete.

c. Start-up Report.

(1) A start-up report should be prepared to report the data and observations developed during baseline monitoring, equipment shake-down and start-up. This information will be very important in evaluating the likelihood of success of the remediation, the expected time to reach remedial goals, long-term O&M costs, and potential quantities of contamination to be removed via gas and liquid phases. Many of the procedures to be specified in the long-term O&M plan described in paragraph 7-6 will be based on the start-up results.

(2) A suggested format for the report would be to present the data by activity (baseline monitoring, equipment shakedown, instrument calibration, and startup) and chronologically within data categories (vacuum levels, flow rates, NAPL volumes, vapor concentrations, groundwater elevations, etc.). The following topics should be included at a minimum:

- Statement of objectives of the start-up phase of the remediation.

- Baseline information collected (as listed in Table 7-1 as well as data collected during earlier investigation phases that may be relevant for describing initial conditions), including field measurements and laboratory data.

- Results of equipment performance checks (as listed in Table 7-2 and Table 7-5).

TABLE 7-5

Suggested Operational Performance Checklist

	Checklist Item	Checked by	Date
Subsurface hydrogeology/soil conditions			
	Water level upwelling within expected ranges		
	Monitoring point chemical data within expected ranges		

TABLE 7-5

Suggested Operational Performance Checklist (Continued)

	Checklist Item	Checked by	Date
	Monitoring point pressures within expected ranges for zone of influence		
	Well specific capacity within expected ranges		
Piping, valves, and instrumentation			
	No leaks in piping or extraction well connections/fittings		
	All valves operate freely and correctly		
	Flow meters in good working order and properly calibrated		
	Expansion joints sufficient to take up movements due to temperature changes		
	Pressure relief valves operate at set pressures		
Pumps and blowers			
	Start and stop of all control mechanisms functioning		
	Operating conditions match pump curve specifications		
	Current draw and voltage balance match specifications for all phases		
	Support systems (sufficient make-up water for liquid ring systems, fuel for catalytic combustion systems) operate within specifications		
	No excessive temperature rises		
	No excessive vibration/noise		
Treatment systems			
	Air and water treatment system performance meets discharge requirements (i.e., maximum concentration, minimum percent removal)		
	Pressure/vacuum transducers maintain calibration		
	NAPL not escaping NAPL separator		
	Mass removal rates follow expected trends		

- Calibration records for instrumentation used on-site.
- Start-up operating procedures that were used.
- Times that pumps and blowers were started.
- Total elapsed time that pumps and blowers were operated.
- Times that various valves were opened and closed.
- Dates and times that the system was shut down (either purposefully or inadvertently).
- Pressure and vacuum measurements taken at blowers and other aboveground equipment.

- Lessons learned, i.e., a documentation of issues and difficulties encountered during the project.

- Pressure and vacuum measurements in recovery wells (before and after balancing flows if multiple wells are present) and in vadose zone monitoring points.

- Flow rates and total cumulative volumes of extracted gas, water and NAPL.

- Dilution air flow rates.

- Flow rates from individual wells should be tabulated if possible. In TPE (e.g., bioslurping) systems, it may not be possible to monitor individual well liquid and gas flow rates. Since NAPL is usually collected separately for disposal, its volume is usually known. At a minimum, the appearance of the flow regime within transparent portions of piping should be recorded.

- Samples collected and analytical results obtained for influent and effluent groundwater and gas.

- Calculations of contaminant mass recovered in water and gas streams, both total and on a well-by-well basis, if possible. EM 1110-1-4001, Chapter 7 ("air emission calculation"), describes in detail how to perform such calculations. Basically, the extraction rate (mass/time) = Q (volume/time) x C (mass/volume). However, concentrations in soil gas are most typically reported on a ppmv (volume/volume) basis. Conversion to a mass/volume (usually grams/m^3) value is based on the molecular weight of the contaminant and the air temperature. For weathered gasoline sites, USEPA (1989) suggests using a molecular weight of 177. More accurate determinations are possible if gas concentrations of individual contaminants are known.

- Corrective actions or changes in design required due to construction conditions, design error or omission, or field observations during construction and start-up.

- Recommendations for adjustments to accommodate seasonal variations.

- Variation in actual versus anticipated operating conditions.

7-6. Operations, Maintenance and Monitoring. Every remediation system should have a site-specific, equipment-specific, comprehensive Operations and Maintenance manual. EM 1110-1-4001, Chapter 8, discusses O&M manuals and presents a typical manual outline. An O&M manual for a MPE system would have similar contents. The paragraphs that follow present guidance on specifying the appropriate long-term (e.g., after the start-up period) O&M procedures as well as monitoring required for fine-tuning operation and evaluating remediation progress. Some of the monitoring activities are the same or similar to those performed during start-up discussed in paragraph 7-5.

a. Operation Strategy. Based on the chosen remediation strategy and objectives, a site- and equipment-specific O&M plan can be prepared. It is very important that the design basis and remedial strategy be considered in preparing this plan and that the system designers be involved in plan preparation.

(1) Subsurface Operations.

(a) The primary parameters that the operator can control to manipulate the subsurface during MPE, and strategies to consider, are discussed in the following paragraphs:

- The vacuum applied to the MPE well affects liquid and/or gas extraction rates, the extent to which vacuum dewatering and NAPL removal occurs in the formation, and to what distance it occurs from the extraction well.

- The position of the drop tube (for TPE systems) affects the amount of upwelling experienced adjacent to the MPE well and the liquid and gas extraction rates from the MPE well. Initially, the drop tube may be placed just at the liquid surface to remove mostly soil gas, thereby helping to dewater the soil. The drop tube can be lowered and raised to determine the optimal position for recovering LNAPL. With deep groundwater (>~25 feet), it is the flow of gas into the drop tube that entrains the liquid and carries it upwards. If the vadose zone soils have such low permeability that there is insufficient gas velocity to entrain liquids, it can be helpful to “prime” the system, e.g., have a separate tube deliver air to the liquid surface to convey the entrained liquids out of the well.

- For horizontal (trench) MPE systems, since the horizontal pipe cannot be lowered or raised, changes in the depth at which gas or liquid extraction is performed must be made by: choosing a different level pipe (if multiple level horizontal pipes with individual risers have been installed in the trench), or by varying the level of the drop tube or submersible pump in the trench sump (if multiple level horizontal pipes all discharge into sumps at the ends of the trenches).

- For recovery of shallow DNAPL (less than about 8 meters below surface) a drop tube placed into the water column to where the DNAPL has accumulated can be used. If the DNAPL is deeper, a submersible pump may be required. Experience has shown that centrifugal submersible pumps will often produce emulsions of water and NAPL. Therefore, unless a pilot test has shown that it is unlikely that emulsions will be created, positive displacement pumps (usually pneumatic) should be used instead. As the depth of DNAPL varies, the depth of the pump intake will need to be raised or lowered.

- Water pump intake depth and pumping rate (for DPE systems) affect the depth of the water table that is maintained in the vicinity of the MPE well. They also affect the extent of "dewatered" or unsaturated soil available for air flow to the MPE well.

- The depth interval over which vacuum is applied (in the case of nested or multi-level MPE wells) enables the operator to minimize the effects of soil heterogeneity and thus preferential flow pathways.

(b) The following secondary operational activities and their possible effects are discussed in more detail in EM 1110-1-4001, Chapter 8:

- Transition from high flow extraction to low flow bioventing after significant contaminant mass is no longer being removed.

- Pulsed extraction from the wells.

- Cycling the applied vacuum among different extraction wells.

- Injecting air into some of the wells to enhance pressure gradients driving fluids toward extraction wells.

(2) Aboveground Operations. The O&M plan for aboveground treatment components must meet the goal of effectively extracting and treating fluids before discharge for the least cost of power, labor, and materials. To do this, consideration should be given to the following:

- Developing a training program for operators and adhering to a policy of using only these trained operators.

- Not running groundwater through the NAPL/water separator after NAPL flow has ceased. Additional groundwater may actually become more contaminated by being placed in contact with residual NAPL in the separator.

- Switching from thermal or catalytic oxidation to activated carbon adsorption when vapor concentrations decrease to a level where the cost for supplemental fuel for the oxidizer exceeds costs for carbon replacement and disposal or regeneration.

- Proper storage, removal and disposal of collected NAPL.

- Periodic re-evaluation of whether 1) systems to prevent or sense the release of explosive vapors are adequate, 2) grounding and bonding to prevent static electricity discharge is sound, and 3) automatic shutdown systems are still functioning and appropriate.

- Deciding if and when to utilize an automatic or remote interface control (higher capital cost and lower O&M costs) versus manual control (lower initial costs and higher labor O&M costs).

- For vacuum truck MPE systems (Ueland et al. 1998), the schedule for pump-out times must be set based on criteria (e.g., length of time for LNAPL to drain toward extraction wells) that can be monitored and revised as appropriate. A vacuum truck MPE system is an alternative where capital and initial costs are minimized by not providing a fixed aboveground extraction system. Rather, a vacuum truck periodically visits the site and extracts liquids from the extraction wells/trenches for subsequent off-site disposal.

b. Troubleshooting. Two types of troubleshooting will be necessary for successful implementation of the O&M plan: 1) troubleshooting the mechanical and control systems, and 2) troubleshooting the subsurface extraction processes.

(1) Mechanical and Control Systems. Table 7-6 lists specific problems, what to consider in diagnosing the problem and suggested solutions. In addition to the items listed in Table 7-6:

TABLE 7-6

Field Troubleshooting Guide

Problems/Symptoms	Possible Reasons/Considerations	Potential Solutions
High pressure drop in air stripper, activated carbon canisters, or piping	Excessive bacterial growth and/or iron precipitation clogging surfaces Hardness deposition, or large material lodged in piping, valves, etc.	Physically clean top layer of carbon in openable drum, and clean piping Acid-clean air stripper packing Add water treatment chemicals to hold minerals in solution
Excessive noise from motors/blowers	Operating out-of-range Needs lubrication	Lubricate. Check if vacuums/pressure is too great
Freezing of water lines and/or the moisture in gas lines, especially at low spots, are reducing or preventing flow	Typical in cold climates. Low points in the gas lines may collect moisture that is never carried further into the moisture separator	Heat taping and/or insulating may be necessary Add traps with drain valves at low points to regularly remove condensate
Lower groundwater flow rates at same head	Well screen filter pack becoming clogged	Develop or redevelop well Clean or treat well
High vacuum or low vacuum alarms sound	Vent lines blocked, vent lines leaking	Measure vacuums in the lines to locate blockages or leaks; repair
Motor shutdown on thermal overload	Loss of power in one leg, undersized wire, blower pump working too hard	Check recent vacuum/pressure values Have electrician check systems
High water alarm, but no liquid in moisture separator	Float stuck, float/transducer malfunctioning	Release float if possible Remove and test transducers
Water and/or NAPL level detectors become covered with bacterial growth, preventing their proper operation.	This occurs frequently and usually cannot be stopped if the contaminants are biodegradable	Periodic detector performance evaluation and preventive maintenance program

TABLE 7-6

Field Troubleshooting Guide (Continued)

Problems/Symptoms	Possible Reasons/Considerations	Potential Solutions
Excessively high vacuum blower exhaust temperatures	Flow constrictions Blower malfunction	Check for piping blockage, open dilution valves, open SVE valves Verify that blower is operating within design specifications, if so a heat exchanger or other design modification may be necessary
Motors shut down, will not reset or restart	Fuse or circuit breaker blown	Shut off main circuit breakers, check individual fuses
Chattering in water level- controlled pumps	Time between high and low levels is too short; control logic is faulty	Increase delay; change control logic
Pump motor operating but not pumping water	Loss of prime with centrifugal pumps Air in suction line (i.e., vapor lock) Intake or intake strainer clogged Pneumatic pump not receiving air	Redesign system to guarantee flooded suction Compressor down or unable to keep up with compressed air demand Clean pump intake Install air relief valve
NAPL in water only tanks	Piping leaks, baffles improperly installed Too much NAPL in NAPL/water separator	Repair leaks, reinstall baffles, select properly sized separator
Water bubbles in air flow meter (rotameter)	Liquid/air separator not working properly Liquid not being pumped out of separator fast enough	Re-evaluate liquid/air separator design, increase liquid pumping rate Purge meter, or wait for water to evaporate before using again
Air pockets in water flow meter	Liquid/air separator not working properly Leaks in vacuum piping or fittings	Install an air bleed-off valve at a high point in the system before the water flowmeter Re-evaluate liquid/air separator design; Purge meter
Cover influent concentrations and/or higher flow rates than expected	Short-circuiting, leaks in vacuum piping or fittings	Check for leaks in surface cover and piping/fittings

- Check valves between the vacuum pump and extraction wells are important for preventing backflow, but they can become stuck in the open position after a period of time.

- Vacuum pump bearings or seals may wear out. Comparing the operational data with manufacturers' specifications after some months of operation may indicate such problems before they turn into more expensive repairs (see paragraph 7-6d).

- If liquid ring vacuum pumps are used, there are additional components that can wear out. These must be considered in formulating a preventive maintenance program and schedule.

- The control system will be made of many transducers, switches, interlocks, motor starters, etc., each of which could cause the entire control system to malfunction. It is important to insist that a complete as-built wiring and instrumentation diagram be provided by the equipment vendor so that electronic troubleshooting can be done readily by anyone capable of reading the wiring diagrams.

(2) Subsurface System Troubleshooting.

(a) Since MPE is an in-situ technology that manipulates conditions within the subsurface (which cannot be observed directly), problems often arise that make the remediation objective difficult to attain. Table 7-7 is a troubleshooting guide addressing some of the problems commonly encountered with the subsurface components of MPE systems.

TABLE 7-7

Operational Strategy Guide

Example Problems	Considerations	Potential Solutions
The zone of influence of the vacuum extraction system is not as predicted and may be insufficient for remediation	The soil may be less permeable than believed There may be preferential flow pathways	Apply greater vacuum Install additional wells Check wells for silt clogging Check for preferential pathways, including borehole short-circuiting Install less permeable surface cover
Vacuum levels are spatially very variable	There may be preferential flow pathways	Same as above
VOC concentrations in gas have been reduced in some but not all wells	Treatment may be completed in some, but not all, areas of the site due to heterogeneities	Reduce flows or take some wells offline Check for ongoing sources of contamination
Free-phase product now absent but groundwater VOC concentrations remain high	Large amounts of sorbed contaminant is present beneath the water table	More aggressive MPE to dewater the saturated soil, if feasible, or removal of mass by SVE and/or air sparging

TABLE 7-7

Operational Strategy Guide (Continued)

Example Problems	Considerations	Potential Solutions
No more free product, low concentrations of VOCs extracted during operation, but high concentrations reappear when system is shut off	Diffusion limitations, preferential flow, soils too moist, fluid flow rates higher than necessary	Pulse SVE/bioventing Thermal enhancement Excavation of "hot spots" and ex-situ soil treatment Reduce flow rates
Continued high levels of less volatile components in the soil	This is likely to occur with a contaminant mixture with a large range of volatility	Concentrate on bioventing if remaining target contaminants are biodegradable
Decreasing air flow rates, increasing vacuum levels	Soil has become too moist Wells are clogged	Surface cover to limit infiltration Increase dewatering Clean/treat wells
A decline in vapor concentrations has made thermal/catalytic oxidation uneconomic	Tailing off of the concentrations with time is a common occurrence	Evaluate whether treatment is still necessary. Change to activated carbon or biofilters. Possibly reduce airflow rates
Groundwater concentrations very low in some wells	Area is remediated	Consider closure for this area and/or well abandonment
Freezing of water lines and/or the moisture in vapor lines, especially at low spots, reduces or prevents flow	Typical in cold climates. Low points in the vapor extraction line may collect moisture that is never carried further into the moisture separator	Heat taping and/or insulating may be necessary. Traps with drain valves should be added at low points to regularly remove condensate
Poor catalytic oxidizer efficiency	Lack of sufficient oxygen for combustion in the soil gas Unexpected chemicals in the subsurface that poison the catalyst	Bleed air in with dilution valve or allow ambient air to enter MPE well through a priming tube Replace catalyst
In bioslurping, fluids not extracted with soil gas	Soil is too tight or too moist to permit enough soil gas to be extracted at a rate than can entrain fluids Drop tube is positioned too high or too low	Install a priming tube that delivers air to the well screen initially; airflow will then need to be reduced as soil dewaters and more soil gas flows Lower drop tube; raise drop tube, or reduce diameter of drop tube
Filters prior to vacuum blower become clogged, leading to excess pressure head losses. Material breaks through, potentially damaging blower	Filter needs to be changed Filter type was not properly chosen or sized	Change filter Try a different filter type, institute a preventive program of changing filter regularly

TABLE 7-7

Operational Strategy Guide (Continued)

Example Problems	Considerations	Potential Solutions
NAPL and water do not separate in NAPL/water separator	Emulsion has formed	For single pump systems, change pump type (e.g., centrifugal to bladder) Change to a dual-pump system that pumps free phase separately
Stable emulsion persists in the NAPL/water separator	Not unusual	Break emulsion chemically or physically in batches Dispose of as emulsion
Large vacuum losses between pump and well	Compare to design friction pressure losses	Increase pipe diameters, check for clogging Check for pipe leaks Check for water in pipes
Groundwater extraction rates decrease but site is not adequately dewatered	Extraction wells could be clogged	Redevelop extraction wells
Much less NAPL recovered than was expected	NAPL is not very recoverable; much less NAPL may be present than initially estimated; snap-off	Increase or reduce vacuum Change over to bioventing and/or air sparging
Unexpectedly high vapor concentrations at or near explosive levels	VOC component in NAPL is high; methane may be present that was not detectable with PID	Dilute intake air, use internal combustion engine system Alter system to be explosion-proof

(b) Evaluating unexpected monitoring results, solving system problems and making the necessary operational changes will likely change one's understanding of the subsurface, thereby requiring the original conceptual model of site conditions to be updated. Therefore, the O&M plan must be flexible and allow for creative solutions. Continual coordination between those responsible for O&M and system designers is essential.

c. Monitoring.

(1) Monitoring Strategy.

(a) Like the monitoring plan developed as part of the start-up procedures, the long-term O&M plan should specify parameters, locations, methods and frequencies for monitoring. The strategy should be to collect data frequently enough to ensure that trends are detectable, with decreasing monitoring frequency as conditions appear to reach steady-state (to minimize costs).

(b) Table 7-8 lists the MPE equipment maintenance activities to consider including in the long-term O&M plan. Table 7-9 is a checklist of monitoring topics to consider in the future after operating and monitoring data have been collected for a period of time. EM 1110-1-4001, Chapter 8, presents an overview of the parameters to monitor. Another reference is the Air Force's

Long Term Monitoring Optimization Guide, August 1997 (available off the internet at www.afcee.af.mil). Principal monitoring parameters are discussed below.

TABLE 7-8

Routine MPE Equipment Maintenance Activities

Periodically drain the water that has accumulated at low spots in the header lines
Check for leaks in water and NAPL lines
Perform pressure tests of pneumatic lines
Check operation of remote monitoring system and all transducers and level detectors
Check volume of seal water in liquid ring vacuum pumps.
Calibrate gas concentration monitoring instruments by collecting gas samples for GC analysis.
Recycle or dispose of collected NAPL according to plan and regulations
Approximately every 500 hours, regrease blower assembly per manufacturer's instructions
Based on operating hours and manufacturer's instructions, regrease bearings and change any oil
Periodically check and clean particulate filters on intake points or change when pressure drop becomes too great

TABLE 7-9

Checklist of Items to Consider for Long-Term Monitoring

Field Sampling
• Are sampling pumps, bailers, and other non-disposable sampling equipment properly maintained? • Are field sampling crews adequately trained in proper sampling procedures (what are their qualifications)? What costs are incurred for disposal of purged groundwater? • Would there be a cost/time benefit to using low-flow sampling techniques? • Can cost savings be achieved through the increased use of dedicated equipment?
Sampling Program Strategy
• Is there a comprehensive Sampling and Analysis Plan (SAP) for long-term environmental monitoring at the site? What are the objectives of the environmental monitoring program (in addition to monitoring the operation of the MPE remediation system)? • Monitor the extent of the plume? • Monitoring for plume migration to exposure points or sensitive receptors? • Evaluate plume remediation? • Does the SAP agree with the Record of Decision (ROD) or comparable document in its prescription for a sampling program? • Has the data quality objective (DQO) approach prescribed by USEPA (EPA 540-R-93-071) and/or EM 200-1-2 been used to develop the SAP? Based on discussions with the owner and operator, is it appropriate to evaluate/reconsider the DQOs?

TABLE 7-9

Checklist of Items to Consider for Long-Term Monitoring (Continued)

- Does the Record of Decision (ROD) or comparable document prescribe a sampling program?
- Are there "decision rules" in the ROD or comparable document that allow one to determine when to stop the monitoring program or to eliminate a well from the program? If not, can changes to the environmental monitoring program be considered in consultation with stakeholders?

Analytical Program Strategy

- Evaluate every well included in the current monitoring program relative to plume location, hydrogeological units, monitoring objectives, concentration history (plots of concentration versus time), mass removal versus time, and well construction (is it properly constructed to provide reliable data? Can it act as a contaminant pathway between hydrogeological units/aquifers?)
- Can the well be eliminated from the program because it is redundant, unreliable, or outside the area of current interest? (Note that any well determined to be unnecessary must be properly decommissioned in accordance with state regulations. The costs for this must be considered in any economic evaluation of potential program changes.)
- Are additional wells needed to properly meet monitoring objectives? (Note that in some cases there may be existing wells, not currently part of the current program, that may serve the purpose.)
- Evaluate the sampling frequency for each well and analyte in the program.
  - Can the monitoring frequency be reduced?
  - Do wells require more frequent monitoring to be protective of receptors?
- Evaluate the sampling frequency in light of the estimated rate of plume migration, proximity to receptors, past contaminant concentrations changes, and the frequency of operational changes in the remediation. (Refer to section 3.1.4 of the Long-Term Monitoring Optimization Guide [AFCEE 1997]).
- Evaluate the analytical program for each well and analyte in the monitoring program. Can laboratory analysis be replaced with less expensive field methods (in conjunction with confirmatory laboratory analyses)?
- Can the current analytical methods be replaced with less expensive analyses and still meet the data quality objectives?
  - Can the analyte list be shortened to focus on the known contaminants of concern? For example, can a Target Analyte List be replaced with a list of indicator compounds?
  - Can off-site analysis be replaced with less expensive on-site analysis?
  - Can a less expensive (but still USACE validated) laboratory be found to do the analysis?
  - Is the level of quality control/quality assurance (QC/QA) appropriate?
  - Are the data appropriately validated?
  - Were there any major failures in data acquisition and reporting?
  - Were proper corrective actions prescribed for such events?
  - Were corrective actions implemented to correct data failures?
  - Are additional corrective actions needed?

TABLE 7-9

Checklist of Items to Consider for Long-Term Monitoring (Continued)

- Evaluate data management practices.
  - Are sampling results entered into an electronic data retrieval system (e.g., GIS, IRPIMS, etc.)?
  - Are monitoring data available in a form that enhances usability (provides for graphical presentation of time histories, contour maps, reports in format expected by regulators, etc.)?
  - Are data archived in a reliable manner?
- Cost Evaluation - a chemist and a cost engineer should evaluate the potential cost savings (or additional costs if the current monitoring program is not adequate) of the potential changes and document this in the evaluation report.

(2) Subsurface Vacuum/Pressure/Head Distribution. One of the most important conditions to understand is the zone of influence around an extraction point or trench. If the entire target zone is not influenced, more extraction points may need to be installed. Gas pressure/vacuum should be monitored at different depths and distances from the extraction wells. EM 1110-1-4001, Chapter 8, presents guidance on how to choose appropriate long-term pressure/vacuum/head monitoring equipment, as well as the frequency and locations (horizontal and vertical placement) for measurement.

(3) Water, Gas and NAPL Flow.

(a) The volumes of the extracted fluids must be measured. The most appropriate methods (discussed in more detail earlier) are a totalizing flow meter for groundwater; pitot tube, hot wire anemometer or rotameter for gas; and thickness (or volume) of NAPL in the NAPL/water separator or holding tank.

(b) Pumps, blowers, oxidizers or other electrically operated devices should be equipped with hour meters so that on and off periods can be tracked. Total volumes can then be calculated from the average flows and on-time.

(4) Sampling and Analysis Plan.

(a) The number and location of samples collected as part of the long-term monitoring plan will be specified in the FSP portion of the SAP. Analyses of contaminants in the vadose zone, extracted soil vapor, extracted groundwater and the groundwater plume will be specified in the QAPP section of the SAP. The procedures will probably be the same as those developed under the guidelines of paragraph 7-5 for the start-up plan. In most cases, the earlier prepared SAP can be updated and revised based on the data collected during start-up. The frequency of sampling will depend on permit requirements, the magnitude or rate of change of influent concentrations and the progress of remediation. The SAP must address not only in-situ remedial progress, but also the removal efficiency of any water or gas treatment processes. These data will enable the contaminant mass removed via water and gas to be calculated (see paragraph 7-5c(2) of this EM and Chapter 7 of EM 1110-1-4001 for guidance on calculations).

(b) To minimize analytical costs, consideration should be given to analyzing only a few carefully selected indicator compounds instead of all contaminants, if feasible. Analysis of recovered NAPL should be performed at least quarterly, or possibly more often depending on the rate of change of its composition.

(c) Additional monitoring parameters may include:

- Changes in soil moisture content within the depth that the vacuum is being applied. This may be accomplished through the use of neutron probes (for the saturated zone and capillary fringe), time domain reflectometry, or electrical resistivity tomography. For more information about these tools, see the In-situ Air Sparging EM (1110-1-4005), Chapter 4.

- Biological factors (vadose zone methane, oxygen and carbon dioxide, and nutrient concentrations, and/or bacterial enumeration).

- Confirmatory soil sampling should be performed (see paragraph 8.2) after other monitoring data indicate that cleanup goals have been met, or that mass removal via MPE has decreased to the point that continued operation of the MPE system is no longer justified.

d. Maintenance.

(1) Aboveground System Maintenance. Table 7-8 lists some of the routine and non-routine maintenance tasks that may need to be performed on the aboveground equipment. A similar list with a schedule must be prepared based on the specific equipment in use at the site.

(2) Extraction Wells. Over time, extraction wells may become clogged or leak, diminishing the ability to extract fluids. Consult with the project chemist, hydrogeologist and/or microbiologist for guidance on how to evaluate and solve such problems. Very serious problems may require installation of new extraction wells. Additional information can be found in other USACE guidance on well maintenance.

e. System Operating Schedule. An operating schedule must be developed that is specific to the particular MPE system and subsurface conditions, as well as the rate of mass removal at the time. Items that may require periodic attention include:

- Continuous or pulsed (intermittent) extraction for optimizing contaminant removal rates versus cost of operation.

- Flow rate adjustments for optimizing contaminant removal rates.

- Adjusting the depth of the drop tube or liquid pump intake for extracting maximum NAPL and minimal groundwater (unless enhanced pump-and-treat is the objective).

- Adjusting the depth of liquid level indicators as needed for groundwater versus NAPL extraction.

- Carbon (vapor phase and/or aqueous phase) regeneration or replacement to meet emission permit requirements.

- Disposal of collected NAPL at a frequency that complies with hazardous waste storage requirements.

f. System Modifications. After several months of operation and monitoring data have been collected and evaluated, it may become clear that the installed MPE system needs significant modification to optimally remediate the site. Modifications may include:

- Additional extraction wells.

- Installation of a less permeable surface cover.

- Cessation of liquid removal if NAPL is absent and groundwater quality is not significantly contaminated.

- Reduced vacuum to support bioventing instead of MPE. Related issues are also discussed in Table 7-7.

Any changes made to the system should be clearly documented (see following section).

g. Recordkeeping. A data management system is crucial for evaluating the operation and remedial progress of a MPE system. Data on groundwater elevations, water and gas concentrations, flows, NAPL thicknesses, applied vacuums, NAPL recovery volumes, gas pressures, operating times, etc. that are collected (manually or electronically via a telemonitoring system) must be organized, evaluated and archived. Sampling and analytical data will have Chains of Custody as specified in the SAP. For a small project, simple worksheets (e.g., Excel, Lotus) may suffice, while for a larger project, a more versatile database (e.g., Access, dBase) may be desirable. Maintenance logbooks must be kept on site that note the time and date of site visits and contain a summary of any important observations that were made and tasks that were performed. Ideally, a section of the computer database would be used to record these maintenance activities. There would then be a backup to the site logbook and a convenient means of accessing the site activities log without needing to check the dedicated site logbook. When properly managed, the aggregate data collected during site remediation can be used not only for site-specific purposes but also for overall technology assessment purposes. In 1995, all agencies of the Federal Remediation Technologies Roundtable endorsed standardized collection and reporting of remediation performance and costs (USEPA 1995).

h. Operating and Maintenance Contracting Approaches.

(1) Operation, maintenance and monitoring costs are typically a major component of the overall remediation project cost. Developing a sound contracting strategy for this phase of the MPE remediation project is critical to controlling the total project budget. Capital costs frequently comprise only a small portion of the overall project cost, while the majority of the costs are generally expended during the operating phase of the project. Costs are typically incurred for: electricity and/or natural gas, operator labor,

groundwater sampling labor, laboratory analyses, remediation waste disposal, reporting, and project management. Contracting officers should consider viewing MPE projects as service contracts rather than construction contracts in cases where this phase of the project is expected to comprise the majority of the total project cost.

(2) Contracts should be written flexibly enough so that the remediation contractor has the option to use portable (trailer/skid mounted) or modular remediation equipment. In this way, if MPE is expected to take place for a relatively period of short time, the contractor can reuse the equipment elsewhere, thereby reducing costs. An example of this approach would be to use a rented thermal or catalytic oxidizer for off-gas treatment. The capital cost of an oxidizer will frequently exceed that of the remainder of the MPE system hardware; however, influent vapor concentrations may only justify the use of this component for the initial period of operation (e.g., several months). In this case, a rental or lease-purchase arrangement for the oxidizer will likely reduce overall project costs.

(3) Designers writing O&M specification requirements should also carefully consider the best strategy for service contract payment. The objective is create a contract that motivates the system operator to operate the system at maximum efficiency as well as determine modifications that can improve efficiencies and reduce O&M costs. Several possible O&M contracting and payment strategies are listed below:

- Simple time and materials.
- Cost plus fixed fee.
- Operation time (system up-time, but with the contractor estimating and including repair time labor).
- Contaminant mass removal or other performance criteria.
- Lump sum.
- Use of an independent consultant to manage the operator and the operation, providing the consultant incentives (e.g., a bonus equal to a percentage of any O&M savings that the consultant can generate by operating the system more efficiently).

(4) There are advantages and disadvantages to each of these payment strategies. Time and materials has been the traditional method of payment for remediation system O&M. Payment for up-time provides the contractor with added incentive to minimize MPE system downtime; however, the contracting officer and project manager must ensure that efficiency (i.e., mass removal rate) is also maximized to the extent practicable such that payment is for effective operation of the MPE system. The contractor should factor repair costs into the amount bid for up-time operating hours. Payment based on contaminant mass removal may pose some risks in that disputes may arise over issues such as: methods of calculating the actual amount of contaminant mass removed, underestimation of the mass initially in the subsurface resulting in unexpected operating costs, and items such as equipment repair and/or replacement, which may not be easy to correlate with contaminant mass removal. Is it also likely that no contractor will be willing to be paid on a mass removal basis if they

were not involved in the design. In a lump sum contract, the contractor assumes the risk to complete the O&M for a fixed sum; this option may be attractive to both a contractor who is willing to assume the risk in return for potentially higher profit and a contracting officer seeking to cap project costs at a specific limit. Selection of the most appropriate payment strategy by the contracting officer and project manager should be based on site-specific circumstances and input from technical staff (e.g., hydrogeologists and process engineers) and construction representatives.