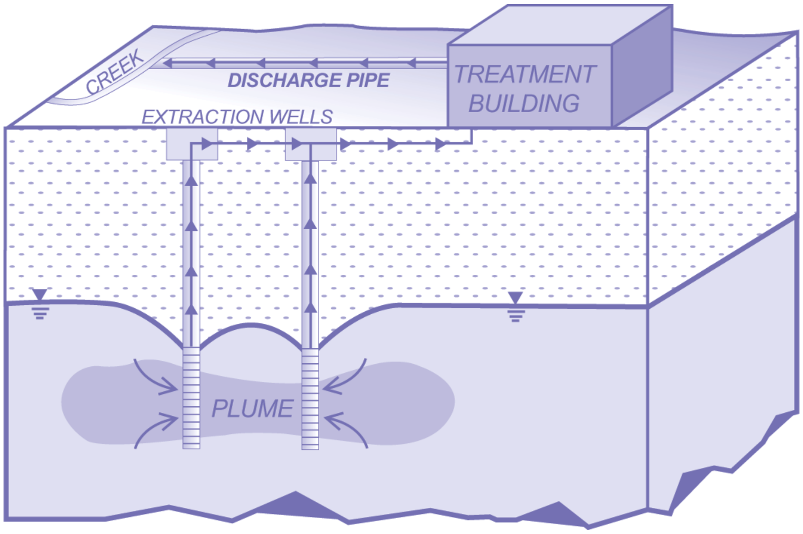
Elements for Effective Management of Operating Pump and Treat Systems



Elements for Effective Management of Operating Pump and Treat Systems

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This fact sheet summarizes key aspects of effective management for operating pump and treat (P&T) systems based on lessons learned from conducting optimization evaluations at 20 Superfund-financed P&T systems. The lessons learned, however, are relevant to almost any P&T system. Therefore, the document may serve as a resource for managers, contractors, or regulators of any P&T system, whether or not that system is within the Superfund Program. This fact sheet is meant to provide a framework for effective site management, but is not intended to be a detailed instructional manual.

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A. INTRODUCTION

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The basic components of a P&T system include ground water extraction, above-ground treatment, disposal of the treated water, ground water monitoring in the subsurface, and process monitoring in the treatment plant. P&T system management includes the following primary activities:

Setting system goals[1] and exit strategy - Are the system goals clearly stated with estimated time frames for achievement? Are the goals and time frames still appropriate? Are there measurable performance standards (i.e., metrics) for evaluating system performance? Is it clear what is required for some or all of the P&T system to be discontinued?

Evaluating performance/effectiveness - Do data indicate that the P&T system is achieving the stated short-term goals (e.g., preventing plume migration) and that it will likely achieve the stated long-term goals (e.g., cleanup to specified levels or continued containment of the plume)?

Evaluating cost-effectiveness - Can the life-cycle cost of the P&T system be reduced (while maintaining effectiveness) by lowering the annual costs of operations and maintenance (O&M) and/or shortening the system duration?

Continuous improvement can occur if the above items are routinely addressed and if modifications to improve the system are subsequently implemented.

Skill sets from many disciplines are required for effective P&T system management:

- policy and regulations
- hydrogeology
- engineering
- risk assessment
- contracting

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[1] Throughout this document, the word "goal" refers to a target or aim including the following:

- a broad, long-term purpose or intent specified in a decision document (e.g., cleanup to a specified concentration)
- a performance-based metric or milestone intermediate in duration (e.g., a 20% decrease in monthly influent concentrations within 24 months of operation)
- a specific and short-term objective (e.g., demonstration of plume containment)

Goals, as stated in this document, are not to be confused with Preliminary Remediation Goals (PRGs) specified in a Superfund Feasibility Study.

Site managers may not have expertise in all of these disciplines, but this fact sheet can be used as a quick reference guide and checklist for site managers, to make sure that the key aspects of P&T system management have been adequately addressed.

B. SYSTEM GOALS AND EXIT STRATEGY

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Goals for P&T systems typically involve cleanup and/or containment of impacted ground water as a means of protecting human health and the environment. It is essential that goals, both short-term or long-term,

- are clearly stated and prioritized and include a time frame;
- are appropriate relative to the site-specific conceptual model;
- include metrics for evaluating system performance;
- clearly indicate when some or all of the P&T system can be discontinued; and
- are revised over time as appropriate.

Each of these items is discussed below.

Goals Must Be Clearly Stated and Prioritized and Include a Time Frame

The system goals should be unambiguous, and each goal should include the expected time frame for achievement, even if that time frame is subject to uncertainty. When multiple goals are stated, they should be prioritized. For instance, ground water cleanup may be a long-term goal, but plume containment may be a short-term goal that is critical for immediate protection of human health and the environment. In such a case, containment should be given the higher priority.

Goals Must Be Appropriate Relative to the "Site-Specific Conceptual Model"

A site-specific conceptual model is a combination of text and figures that describe the hydrogeologic system, the cause of the ground water impacts, and the fate and transport of the ground water contaminants. *It is not a numerical model!* The conceptual model should attempt to explain the items listed in Exhibit 1.

Exhibit 1

A Site-Specific Conceptual Model Should Identify/Explain the Following Items

- historical and continuing sources of ground water contamination, both above ground and below the surface
- historical growth and/or retreat of the ground water plume
- ground water flow velocity (horizontal and vertical) and other parameters controlling contaminant fate and transport
- potential human and ecological receptors
- anticipated results of remedial actions

If the conceptual model does not adequately identify or explain all of these items, the data gaps should be addressed with a focused investigation. This does not imply a return to the "remedial investigation" phase. The conceptual model should evolve over time, including during active remediation, as more information about the site becomes available.

The goals of the P&T system must be appropriate relative to the site-specific conceptual model; otherwise, they may not be achieved. For example, a P&T system will not likely restore ground water to cleanup levels in a reasonable time frame if there are continuing sources of contamination, such as non-aqeuous phase liquid (NAPL) or soil contamination. Example 1, on the following page, provides an excerpt from a conceptual model to demonstrate the type of data and interpretation that should be included. The example also highlights potential data gaps in the conceptual model and related considerations for the site-wide exit strategy.

Goals Must Include Metrics For Evaluating System Performance

To help determine whether or not the system goals are achieved, each goal must include metrics (i.e., performance standards that can be measured). For example, a goal of "ground water containment" is vague unless stated in conjunction with specific metrics such as gradients, drawdowns, or ground water elevations ("water levels") that must be achieved at specific locations. Similarly, metrics for "ground water cleanup" might include specific milestones for mass removal, peak concentration

Example 1

Excerpt from a Conceptual Model

.... PCE concentrations in excess of 2,500 ug/L have persisted in shallow well MW-12S since the remedial investigation, despite pumping from the underlying but adjacent deep extraction well EW-2. This persistence may indicate the possible presence of a continuing PCE source (NAPL or soil contamination) near MW-12S. Furthermore, little drawdown is noted at MW-12S, despite pumping from EW-2. The lack of draw down at MW-12S due to pumping at EW-2 calls into question the ability of EW-2 to capture the PCE in the shallow zone in the vicinity of MW-12S and may indicate that EW-2 is in a low conductivity zone or that a low conductivity layer separates EW-2 and MW-12S....

Data Gaps:
- presence of a continuing PCE source
- degree of capture near MW-12S

Considerations for the Site-Wide Exit Strategy:
- contain shallow ground water near MW-12S by pumping (short term)
- characterize and then remove or contain the continuing PCE source

reduction, and/or plume area reduction that must be achieved within specified time periods or at specified locations.

Goals Must Clearly Indicate When Some or All of the P&T System Can Be Discontinued

To provide a viable exit strategy for the P&T system or some of its components, the following details or metrics should be specified as part of the system goals:

- contaminants of concern (COCs) being addressed by the P&T system, which may be a subset of the COCs for the entire site
- cleanup levels that must be achieved for each specific COC addressed by the P&T system
- specific criteria for shutting down individual extraction wells, including the number of consecutive monitoring events where cleanup levels must be achieved for attainment at a particular well and consideration of potential contaminant rebound
- process monitoring levels or other milestones that will indicate when individual components of the above-ground treatment process can be removed

Goals Must Be Revised Over Time As Appropriate

There are many reasons to consider revising goals of the P&T system over time, some of which are highlighted in Exhibit 2.

Because the site-specific conceptual model evolves, periodic review of system goals should occur on a regular basis, perhaps at a minimum of once every 5 years. For Superfund sites, this review of system goals could be done with the Five Year Review process. In some federal and state programs, a change in the site decision document may be needed prior to changing the goals.

Exhibit 2

Some Reasons To Modify Goals of the P&T System

- revised regulatory framework
- new treatment technologies or strategies
- operating experience suggests existing goals are unrealistic and will not be met
- costs are greater than originally anticipated
- changes in plume extent
- discovery of additional and/or continuing sources of contamination, such as soil contamination or NAPL
- changes in land use or ground water production near the system

C. EVALUATING PERFORMANCE AND EFFECTIVENESS OF THE P&T SYSTEM

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Evaluation of P&T system performance should include evaluation of the subsurface performance, offered by the extraction system, and evaluation of the above-ground performance, offered by the treatment system. The following five steps are crucial for thorough P&T system evaluation:

- evaluating plume capture
- performing and interpreting treatment process monitoring

- performing and interpreting ground water monitoring

- evaluating extraction well performance

- if applicable, evaluating injection well performance

Evaluate Plume Capture

For ground water remedies, protection of human health and the environment often requires hydraulic containment ("capture") of a contaminant plume. Evaluation of containment includes defining an appropriate target capture zone, interpreting actual capture, and then demonstrating that the actual capture zone is consistent with the target capture zone. Care must be taken to ensure this consistency is present through various temporal changes, such as seasonal variations in recharge and/or nearby pumping.

Although the complex hydrogeology at fractured bedrock or highly heterogeneous sites may prohibit conclusive results, capture zone analyses should be attempted at these sites for the following reasons: (1) the analysis may actually be conclusive, and (2) valuable insights to site-specific ground water flow and contaminant transport may be gained.

<u>Define the "Target Capture Zone"</u>

A three-dimensional target capture zone should be indicated on maps and/or on cross-sections of the site. It should be based on clearly stated criteria (such as a specific concentration contour or a site boundary). In some cases capture of the entire plume may be required, but in other cases capture of a portion of the plume may be acceptable (e.g., if natural attenuation of the remaining portion is viable and can be demonstrated). If the target capture zone is based on a specific concentration contour, it may need to be updated over time as plume boundaries change. If a variety of contaminants of concern are present, the target capture zone should consider each of those contaminants. If a target capture zone is not defined, then it will be uncertain if actual capture is sufficient.

<u>Interpret Actual Capture Zone Achieved</u>

An actual capture zone is defined as the three-dimensional zone in which all ground water flow paths converge to one or more extraction points. The extent of the capture zone depends on many factors:

- pumping rate
- hydraulic gradient (magnitude and direction)
- hydraulic conductivity
- vertical flow to other aquifers
- spacing of extraction wells
- transient influences (recharge, other pumping)

Accurate interpretation of actual capture is difficult and is best evaluated with converging lines of evidence. Some potential lines of evidence are listed in Exhibit 3 and described below. Generally, capture is actually achieved if multiple lines of evidence suggest it; however, capture may not be achieved if only one or two of the multiple lines of evidence suggest it. Figure 1, on page 6, illustrates the role of multiple lines of evidence in a capture zone analysis.

Flow Budget and Analytical Modeling. For idealized conditions (i.e., one well, no recharge, uniform saturated thickness, and a homogeneous, isotropic aquifer), the width of the capture zone some distance upgradient of the extraction system can be estimated for specific flow rates with a straightforward analytical equation (see Exhibit 4). Using the same equation, the pumping rate (*Q*) required for a desired width of capture (*W*) can be estimated. The pumping rate required for a given capture width must generally be higher than estimated by this equation to account for recharge and uncertainties in the other parameters. Similarly, actual capture width for a specified

Exhibit 3

Potential Lines of Evidence for Ground Water Capture

- calculations of capture zone width based on flow budget and/or analytical models

- interpretation of ground water flow lines from potentiometric surface maps that are based on measured ground water elevations from the various subsurface stratigraphic units

- inward flow relative to a compliance boundary, based on measured ground water elevations at two or more locations oriented perpendicular to the boundary

- concentration trends over time at sentinel wells located downgradient of the capture zone

- particle tracking in conjunction with a numerical ground water flow model calibrated/verified by actual ground water elevations under pumping conditions

- implementation and analysis of data from tracer tests pumping rate will typically be less than estimated by this equation for the same reasons.

This approach for idealized situations can and should be used as a rudimentary analysis of ground water flow at a site. However, the simplifying assumptions and resulting limitations must be understood and specified. The limitations of this approach strongly indicate a need for considering additional lines of evidence for evaluating capture.

Potentiometric Surface Maps. Ground water elevation measurements can be used to create potentiometric surface maps, from which ground water flowlines and the capture zone can be interpreted. Unfortunately, the number of ground water elevation measurements typically available is not sufficient to unambiguously interpret capture. It is important to exclude ground water elevation data from active pumping wells when constructing potentiometric surface maps because they are influenced by well losses and are not representative of aquifer conditions. Note that when potentiometric surface maps indicate capture with respect to horizontal flow, capture may not be adequate with respect to vertical flow. Thus, information from other lines of evidence may be required.

Ground Water Elevation Pairs. In some cases, pairs of ground water elevation measurements on either side of a boundary can be used to demonstrate inward flow relative to that boundary. An example might be ground water elevation measurements on either side of property boundary or on either side of a slurry wall. Another example would be stage measured in a creek relative to the ground water elevation in the aquifer immediately adjacent to the creek. A higher creek stage indicates no discharge from the aquifer to the creek. Because flow between the creek and aquifer can change magnitude and even direction with changes in precipitation and recharge, frequent measurements from these locations may be required. Ground water elevation pairs from different levels of the aquifer can also be used to verify vertical gradients that are indicative of capture. It is important to exclude ground water elevations from active pumping wells and to consider recent recharge events.

Exhibit 4

Width of Capture Zone and Flow Budget For Very Simple Hydrogeologic Systems

Assumptions:

- one well
- single layer of constant thickness
- homogeneous, isotropic aquifer
- no recharge from above or below

$$W = \frac{Q}{C \times B \times K \times i}$$

or

$$Q = W \times C \times B \times K \times i$$

Q = extraction rate (gpm)
C = conversion factor (0.00518 gal/ft^3 min/day)
W = total width of capture zone upgradient of the extraction system (ft)
B = saturated thickness (ft)
K = hydraulic conductivity (ft/day)
i = hydraulic gradient (ft/foot)

Sentinel Wells. If capture is adequate, monitoring wells downgradient of the extraction system (i.e., sentinel wells) can be monitored over time as follows:

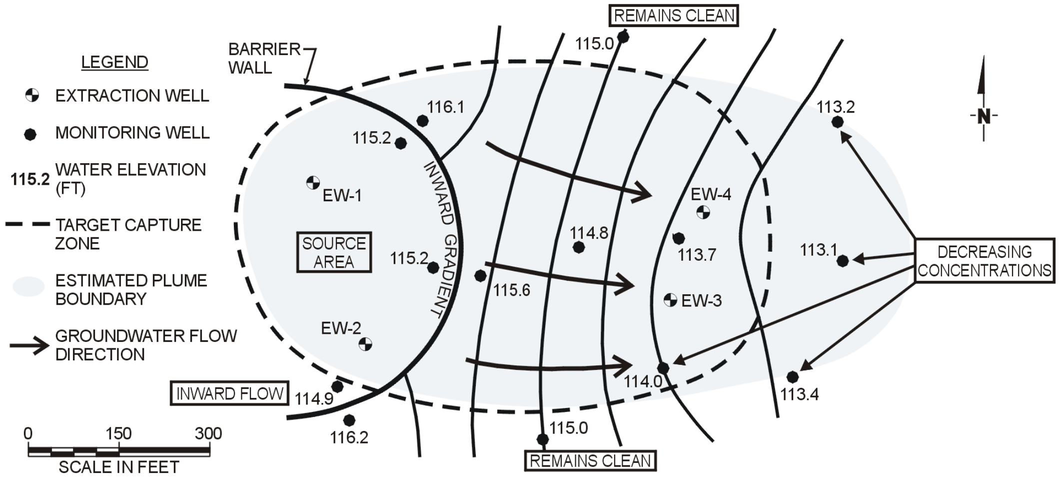
- Sentinel wells that are not currently impacted by contaminants should remain without impacts over time.
- Sentinel wells that are currently impacted by contaminants should reach background levels over time. If concentrations decrease in these wells but remain over regulatory standards, capture provided by the extraction system is likely inadequate.

Because ground water flow is slow, impacts at sentinel wells may take years to appear, and concentration measurements over time at sentinel wells can become very costly. Interpretation may be ambiguous if the sentinel wells are actually located within the zone of capture or if they are not in the correct locations to detect uncaptured portions of a plume. Also, if the plume is not well delineated, portions of the plume may have previously migrated beyond the capture zone and the sentinel wells. These limitations of sentinel wells emphasize the importance of using multiple lines of evidence. For sites with fractured bedrock and/or highly heterogeneous conditions a greater density of sentinel monitoring points may be merited due to the increased potential for preferential pathways of contaminant migration. In addition, for sites with multiple layers or stratigraphic units with potential impacts, sentinel wells would likely be required in each unit of concern.

Particle Tracking in Conjunction with Ground Water Modeling. Particle tracking in conjunction with a

Figure 1

Converging Lines of Evidence for Evaluating Horizontal Capture
(evaluating vertical capture requires additional analysis)



Data:

Hydraulic conductivity
- K = 10 ft/day
- relatively homogeneous

Pumping
- EW-1& 2 = 3 gpm each
- EW-3 & 4 = 4 gpm each
- fully penetrating wells

Aquifer thickness
- B = 20 ft
- unconfined aquifer

Target capture zone width (north to south)
- W = 600 ft

Hydraulic gradient
- i = 0.006 ft/foot

Background:
- barrier wall, plus wells EW-1 and EW-2, act to contain the contaminant source
- EW-3 and EW-4 address the downgradient plume
- target capture zone is a specified concentration contour based on risk assessment, natural attenuation addresses plume fringe
- plume delineated by monitoring to the north and south

Potential Evidence for Capture:
- ground water flow budget (Exhibit 4) consistent with target capture zone
  < (Q>4 gpm required based on simple calculation, actual Q=8 gpm)
- water levels demonstrate "inward flow" across barrier wall
- potentiometric surface indicates flow in the direction of EW-3 & 4, but resolution is insufficient to confirm capture
- sentinel wells downgradient to the east show decreasing concentrations, provides increased confidence that capture is occurring

Next Steps:
- delineate on a map the interpreted capture zone and compare it to target capture zone
- consider seasonal variation in ground water flow and plume
- consider additional piezometers in vicinity of EW-3 and EW-4
- consider use of ground water flow model and particle tracking
- continue to monitor sentinel wells (concentrations should decrease to clean up levels)
- ensure vertical capture

ground water flow model can indicate if all model cells within a target capture zone are captured by a simulated extraction system. A three-dimensional model can be particularly helpful in evaluating capture at sites where vertical heterogeneity and/or migration greatly affect contaminant fate and transport. However, the reliability of this line of evidence for interpreting actual capture depends on the reliability of the model. Predictions from models are subject to uncertainty based on the presence of heterogeneity in natural systems that can be difficult to characterize and represent in the model. Ideally, the numerical model can be "verified" by reproducing measured drawdown responses to various pumping scenarios, increasing confidence in the model's ability to accurately predict capture.

Tracer Tests. Demonstrating capture of a tracer injected into the contaminant plume can increase the confidence that capture of the plume has been achieved. Valuable data can be obtained from monitoring tracer concentrations in sentinel wells and tracer mass recovery in extraction wells over time. The presence of the tracer in sentinel wells indicates a lack of capture, and a high mass recovery rate in extraction wells indicates a high degree of capture. The following are some advantages of tracer tests:

- In fractured bedrock environments, tracers may indicate flow along bedding planes and the connectivity of fractures between monitoring points.
- A known mass of a tracer can be injected at a specified location and time, allowing mass removal efficiency to be quantified.
- Data from tracer tests can be used to calibrate ground water flow and contaminant transport models.
- Depending on the tracer, sampling and analysis can be relatively straightforward and low in cost if the proper sensors are available.

However, tracer tests have the following disadvantages:

- Because the tracer is likely injected only at select locations, demonstrating capture of the tracer does not confirm capture of the entire contaminant plume.
- Injecting tracers may require obtaining an Underground Injection Control permit.
- Due to the relatively slow movement of most ground water, tracer tests may take months or years to yield useful information.

Perform/Interpret Process Monitoring

Process monitoring refers to measurements of concentrations in treatment plant influent and effluent, and in some cases at intermediate points in the treatment process.

Verify that Discharge Standards are Being Achieved

Treated water from a P&T system must meet appropriate standards prior to discharge. Fortunately, most implemented treatment technologies have been proven reliable through years of use in a variety of conditions, and treatment plants regularly meet the discharge criteria. Nevertheless, sampling of plant effluent is required, and the resulting data should be scrutinized by both the site manager and the site contractor. For facilitated review, the effluent sampling results should be presented alongside the discharge criteria. Exceedances should be highlighted and technical explanations for the causes of the exceedances and the planned corrective action should be provided.

Compare Design Parameters and Actual Parameters for Treatment System

Because site conditions change over time and these changes can have implications on the cost and effectiveness of a remedy, P&T managers and their contractors should routinely compare design values versus actual values for the following treatment process parameters:

- influent flow rate to the treatment plant
- influent concentrations for each contaminant of concern
- contaminant mass loading to the treatment system (see Exhibit 5)
- removal rates for the treatment system (influent mass minus effluent mass, or effluent concentration divided by influent concentration)
- air to water ratio for an air stripper
- pressure drop across granular activated carbon (GAC) units or filtration media

Addressing discrepancies between design and actual parameters can lead to changes that improve effectiveness and/or reduce O&M costs. Some examples are provided in a later section of this fact sheet (“Modify Inefficient System Components”). Discrepancies between design and actual parameters should be discussed with site contractors and potentially with other technical assistance resources.

Evaluate Treatment System Components

The performance of the treatment system and its components can be evaluated by determining the mass loading and removal rates. Especially during start up, determining the mass loading and removal rates for the individual treatment components may be merited. After system startup, however, these components should be operating reliably and evaluation of the treatment system as a whole (i.e., influent and effluent monitoring) should suffice.

Perform/Interpret Ground Water Monitoring

Long-term ground water monitoring programs typically involve quarterly, semi-annual, or annual monitoring of ground water quality and elevations. The data from this monitoring should be managed electronically to facilitate analysis, reduce time, and reduce the possibility of entry errors. The data should be used to monitor the effectiveness of the subsurface remedy and update or calibrate site ground water flow and contaminant transport models, if they exist. New data should be interpreted and compared to historical data on a regular basis. Though not always necessary, statistical analysis may be helpful in interpreting the data. Based on trends from these data, site managers should periodically consider the following options (perhaps every 2-3 years as part of a comprehensive performance evaluation such as the Five Year Review for Superfund sites):

- continue with the current P&T system
- increase capacity of the current P&T system and/or modify extraction well locations
- investigate and characterize potential additional contaminant sources
- apply an aggressive source removal technology
- switch to another remedial technology or implement an additional technology
- consider alternate goals
- focus extraction on specific areas
- reduce the extent and frequency of monitoring as a clear pattern develops

Exhibit 5

Calculating Contaminant Mass Loading and Removal Rates

Contaminant mass loading and removal rates can be calculated with the same basic equation. However, the units and conversion factors are different for air than they are for water.

For Water:

$$M_{H_2O} = Q_{H_2O} \times C_{H_2O} \times \frac{3.785\ \text{L}}{\text{gallon}} \times \frac{1440\ \text{min.}}{\text{day}} \times \frac{2.2\ \text{lbs.}}{10^9\ \text{ug}}$$

M_{H_2O} = mass loading, removal rate in water (lbs / day)
Q_{H_2O} = flow rate in water (gpm)
C_{H_2O} = contaminant concentration (ug / L, ppb)

For Air:

$$M_{air} = Q_{air} \times C_{air} \times \frac{0.0283\ \text{m}^3}{\text{ft}^3} \times \frac{1440\ \text{min.}}{\text{day}} \times \frac{2.2\ \text{lbs.}}{10^6\ \text{mg}}$$

M_{air} = mass loading, removal rate in air (lbs / day)
Q_{air} = flow rate in air (cfm)
C_{air} = contaminant concentration (mg / m^3)

For air calculations, C_{air} in mg/m^3 (with molecular weight, MW_X, in grams per mole) can be obtained at 70°F and a pressure of 1 atmosphere from parts per million by volume (ppmv) by the following steps:

$$C_{air}(mg/m^3) = \frac{Conc(ppmv)}{10^6} \times \frac{1\ \text{mole air}}{24.1\ \text{L}} \times \frac{1000\ \text{L}}{\text{m}^3} \times \frac{1000\ \text{mg}}{\text{g}} \times \text{MW}_\text{X}$$

Note: The conversion factor (1 mole air)/(24.1 L) varies with both temperature and pressure. At a pressure of 1 atmosphere and a temperature of 32°F (0°C), the conversion is (1 mole air)/(22.4 L).

Approximate Molecular Weights (MW) in grams/mole of Common Volatile Organic Compounds (VOCs)

Benzene: 78
Carbon tetrachloride: 154
Chlorobenzene: 113
DCA: 99
DCE: 97
Ethylbenzene: 106
PCE: 166
TCA: 133
TCE: 131
Toluene: 92
Vinyl chloride: 62.5
Xylene: 106

Collect and Report Accurate and Reliable Data

Accurate data is crucial for making well-informed decisions about site operations and strategy. It can also represent a significant portion of O&M cost. As a result, a number of considerations should be applied to collection and management of ground water elevations (Exhibit 6) and water quality data (Exhibit 7, on the following page).

Update Plume Maps, Potentiometric Surfaces, and Trend Analyses

Plume maps, potentiometric surfaces, interpreted flow directions and magnitudes, and data trend plots are fundamental to data interpretation and are useful for site decision making, tracking the progress of remediation, determining target capture zones, and interpreting success or failure of actual capture (see previous Section "Evaluate Plume Capture").

Processing data and generating and reviewing these plots for each monitoring event ensures data quality because errors, inconsistencies, or data gaps can be addressed before subsequent events. Electronic data management, spreadsheets, and plotting software allow these plots to be updated with minimal level of effort and low cost. Thus, if practical, the plots should be generated after each monitoring event. Consistent contouring methods or software should be used for developing the plots for a given site, and the method or software used should be noted.

Exhibit 6

Considerations for Collecting and Recording Ground Water Elevation Measurements

- Measure depths to ground water in each well or piezometer two or three times to avoid false readings, and measure depths to water at all locations on the same day, if possible. Include water levels from surface water bodies that may influence ground water elevations.
- Have on hand historical data when measuring depths to ground water to confirm that current measurements are consistent with the historical ones. If there is a significant discrepancy, determine if a similar discrepancy exists for each sampling location. If the discrepancy appears to be an anomaly (exists at only one or two wells), note the discrepancy in the field log book and in the O&M reports.
- Note piezometer and monitoring well integrity and condition. Routine redevelopment or cleaning may be necessary.
- Always measure depths to ground water from a clearly visible surveyor's elevation mark on the well.
- The location of each piezometer and well should be accurately surveyed to within 0.1 feet horizontally, and the reference mark should be accurately surveyed to within 0.01 feet vertically.
- Re-survey wells and piezometers if changes in casing elevation are suspected due to settling, frost heaves, or other damage to wells.
- Maintain surveyor's mark to prevent fading.
- In reports, clearly distinguish the difference between the depth to ground water and the ground water elevation (i.e., "water level"). Specify the reference points and units for each measurement (i.e., "feet below ground surface" for depth to ground water and "feet above mean sea level" for ground water elevation).
- Report new ground water elevations alongside previously recorded ground water elevations in tables so that trends can be easily noticed by the reader.
- Interpret each round of ground water elevation measurements with respect to the site conceptual model and site goals.
- Reconsider the frequency of measurement events if the amount of data and interpretation are either insufficient or excessive with respect to the system goals. The monitoring frequency for water levels and water quality need not be the same.
- Obtain ground water elevations from clusters of wells or piezometers with various elevations if vertical flow is an important aspect of the site conceptual model.

***Note: Inaccurate or insufficient data can lead to poor management decisions, and excessive data is not cost-effective*.**

Exhibit 7

Considerations for Ground Water Quality Sampling and Analysis

- Select sampling locations, sampling techniques, analytical methods, and sampled constituents based on the goals of the system (e.g., sampling from the body of the plume may not be required if plume containment is the only system goal).

- Note piezometer and monitoring well integrity and condition. Routine redevelopment or cleaning may be necessary.

- Use consistent sampling techniques and analytical methods; report any inconsistencies if they do occur.

- Select sampling techniques that are appropriate for the site:
  - Consider dedicated sampling equipment when cost-effective and appropriate.
  - Utilize low-flow sampling when appropriate (e.g., reduced sampling time, more accurate measure of dissolved metals concentrations, less purge water, etc.).
  - Consider traditional purge and sample techniques if parameters, such as turbidity, do not stabilize in a reasonable time frame during low-flow sampling.

- Data validation is a methodical process of checking precision, accuracy, and completeness of laboratory data quality and utility. Such validation is merited during initial investigations and at other decision points of the remedy but should be avoided for most routine sampling events during O&M.

- Interpret ground water samples from each event with respect to the site conceptual model and site goals.

- Sample for appropriate natural attenuation parameters if natural attenuation is or will be considered as a site remedy.

- Reconsider sampling frequency and locations if current amount of data and interpretation is either insufficient or excessive with respect to the system goals and site conceptual model. The monitoring frequency for water levels and water quality need not be the same.

Note: Inaccurate or insufficient data can lead to poor management decisions, and excessive data is not cost-effective.

New plume maps, potentiometric surfaces, and data trend plots do not always require immediate submission in individual reports. In some cases, it may be more appropriate to collect data and generate plots for several events prior to interpreting the combined results in a single O&M report (e.g., generating an annual report that discusses four quarters of ground water monitoring).

The frequencies of monitoring events, data analysis, and reporting should each be commensurate with the time frame for site decision making and consistent with appropriate regulations. Relatively new systems, where the system and the site conditions are in a state of flux, may require more frequent monitoring, data processing, and reporting than relatively mature, stable systems. A review of historical trends in the data may help a site team determine if a change in monitoring frequency is merited.

Evaluate Concentration Trends At Monitor Wells

The trends in concentrations at each monitoring well and groups of monitoring wells should also be studied. Increased or constant concentrations, or even decreased concentrations that remain above the site standards, in downgradient or sentinel wells may indicate inadequate capture by the extraction system. In such cases, the capture zone should be analyzed, and the extraction system may require augmentation.

Increases or constant, but elevated, concentrations in a well may indicate the presence of a continuing source of contamination from the vadose zone or from NAPL. If such sources are not addressed, the P&T system will likely operate indefinitely.

Decreases in contaminant concentrations at wells may indicate success of the remedy, but they may also indicate dispersion or contaminant transport to downgradient areas. Reviewing water quality data at other locations or ground water flow patterns may help confirm which of the above is occurring. Contaminant levels may also decrease and then plateau above cleanup levels or may rebound after pumping has stopped.

Evaluate Extraction Well Performance

Extraction wells should be monitored to determine if they are in the most effective location, given potential changes in the contaminant plume, and also to determine if they are performing as expected.

Evaluate Concentration Trends at Extraction Wells

As contaminant mass is extracted from the subsurface, the contaminant concentrations in extraction wells should decrease unless a continuing source of contaminant exists or contaminant levels have reached a plateau. If the contaminant concentration in an extraction well, or nearby monitoring wells, has decreased to low levels, then it may be more effective to shut down that extraction well, relocate it, or reallocate ground water extraction to other wells. However, shutting down a well may not be possible if that well is required for capture of the contaminant plume. If a well is shut down, monitoring should continue for some period of time to ensure that concentrations do not "rebound" due to desorption of contaminants from soil to ground water, diffusion of contaminants from tighter portions of the formation, or additional dissolved contamination from continuing sources. Monitoring ground water concentrations in individual extraction wells on an annual or semi-annual basis is likely sufficient for the above analyses.

Pumping Rates and/or Specific Capacity Versus Time

Bacterial growth and chemical deposits can lead to fouling of extraction wells. If addressed properly through a well-maintenance or well-rehabilitation program, fouling can usually be mitigated. If well fouling is left unattended, however, it may reach a point where well rehabilitation is infeasible and the well will need to be reinstalled.

In general, fouling blocks the well screen and provides resistance to water entering the well. As a result, the water level in the well decreases until there is a sufficient hydraulic gradient directing water into the well to balance that being extracted by the pump or until the water level in the well drops below the pump. Fouling may therefore occur with no noticeable change in the extraction rate until the pump shuts down.

The best indicator of well fouling is the specific capacity of the well, which is the extraction rate divided by the drawdown (note that the ground water elevation under both static and pumping conditions is required to calculate drawdown). A baseline level of specific capacity should be recorded when the well first becomes operational. Specific capacity should then be measured regularly and a trend line plotted. The average extraction rate should also be compared to the design extraction rate. If a decrease in specific capacity or the extraction rate of more than 10% is noted, well-rehabilitation is likely required. In some cases, a well-maintenance program may need to be implemented. Note that for a well operating at a constant rate, drawdown trends provide the same information as specific capacity trends. For wells where ground water elevations cannot be measured due to restrictions in access, measurement of the extraction rates will have to suffice (i.e., decreasing rate over time may indicate fouling).

Regional changes in the ground water elevations due to drought, recharge, or off-site pumping should be considered by reviewing ground water elevation trends in nearby monitoring wells. Regional increases in ground water elevations could mask a decrease in specific capacity, and regional decreases in ground water elevations could falsely suggest a decrease in specific capacity.

A general guide to well maintenance developed by the U.S. Army Corps of Engineers (USACE) can be found in USACE Engineering Pamphlet EP 1110-1-27.

If Applicable, Evaluate Injection Well or Infiltration Gallery Performance

If a system discharges treated water to the subsurface through injection wells or an infiltration gallery, the performance of these points should be monitored to ensure fouling does not limit the discharge capacity, and therefore the capacity of the entire P&T system.

Many of the same procedures for monitoring extraction wells can be used to monitoring injection points. The discharge rate and the increase in ground water elevation within the wells or galleries are measured rather than the extraction rate and the drawdown.

Increases in the water levels within the reinjection points, given a constant discharge, indicate either regional increases in ground water elevation or fouling of the injection wells. Regional increases in the ground water elevation can be confirmed or rejected by reviewing ground water elevation trends in nearby monitoring wells. If increases are not due to regional influences a rehabilitation program may need to be implemented, and the treatment system should be reviewed for options to minimize solids in the effluent.

D. EVALUATING COST-EFFECTIVENESS OF THE P&T SYSTEM

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An evaluation of system cost-effectiveness should consider life-cycle costs because life-cycle costs account for up-front capital expenditures, annual costs, the time frame for system O&M, and costs for replacing or updating the system. For example, by considering life-cycle costs, a site manager can better evaluate if up-front expenditures for more efficient equipment or for making modifications will result in overall savings to the project. Because it may be difficult to calculate life-cycle costs due to the uncertainty of a remedy time frame, best estimates should be used. Depending on the organization funding the remedy, life-cycle costs may need to be expressed in net present value, which considers the effects of inflation and the rate of investment returns on future expenditures. Most commonly used spreadsheet software applications can calculate net present value when provided with a remedy time frame, adjustment or discount rate, and system costs.

Identify Significant Cost Items

For an operating system, the first step in evaluating the cost-effectiveness of a P&T system is to identify the significant cost items. A table of average annual costs, similar to the one presented in Example 2, should be developed for the site based on previous invoices and/or contracts. Using annual rather than monthly costs will account for costs that vary monthly or that are incurred on a quarterly, annual, or irregular basis. The areas of highest costs will likely be the areas where the greatest savings can be realized.

Site managers should keep in mind that reducing annual costs may require capital expenditures and that cost-effective modifications are those that result in overall savings to the project. Typically, a site manager should expect the savings in annual costs expressed in net present value to pay for the capital expenditures in less than 5 years, though the acceptable time frame for payoff is highly dependent on the expected duration of the remedy.

Maintain and Clean Equipment as Appropriate

Proper maintenance of system components can help maximize the efficiency of the treatment plant. All system components should be maintained and cleaned as needed, especially if biological or chemical fouling is a concern. Even relatively passive treatment components, such as clarifiers in metals removal systems, may require cleaning to effectively reduce solids in the process water. However, a cost-benefit analysis should be conducted and discharge requirements should be considered to determine the appropriate frequency for maintenance and cleaning for a P&T system.

Example 2

Hypothetical Annual Costs for P&T O&M

Category	Annual Cost	% of Total Annual Cost
Labor		39%
• PM & reporting	$30,000	
• O&M operator	$49,200	
• sampling labor	$28,800	
Utilities		23.5%
• electricity	$54,000	
• gas	$9,600	
• public water	N/A	
• phones	$2,400	
Materials		16%
• GAC	$12,000	
• chemicals	$30,000	
• filters	$2,400	
Chemical analysis	$36,000	13%
Disposal costs	$24,000	8.5%
Total	$278,400	100%

Modify Inefficient System Components

Modifying inefficient system components can yield significant savings, especially in the use of utilities and materials. Four common examples of inefficient system components are described below.

Oversized Motors

Pumps, blowers, air compressors, and other equipment have motors that have different power requirements, measured in horsepower (hp), depending on the amount of air or water they must move and against what head they must move it. In many cases, oversized motors are being used and the valves are throttled back to reduce the flow. However, this approach does not reduce power usage and may also decrease the motor’s life span.

The following steps should be taken on a regular basis to reduce the use of oversized motors:

- inventory all pumps, blowers, and air compressors
- note their power requirements (in horsepower)
- use their manuals and O&M data to compare their specifications to the actual task
- conduct a cost-benefit analysis of replacing oversized equipment with new equipment or installing a variable speed drive that will allow an operator to control its power usage
- replace equipment that demonstrate significant cost savings (i.e., can pay off cost of replacement in a few years)

In general, assuming 75% motor efficiency and $0.10/kilowatt-hour (kWh),

$$1 \text{ horsepower} = \$70 / \text{month}$$

The cost savings of replacing a large blower for a smaller, more efficient one is shown in Example 3.

Example 3

Savings from Replacing a 50-hp Blower with a 15-hp Blower

50 hp × $70/month/hp	$3,500/month
15 hp × $70/month/hp	– $1,050/month
Savings	$2,450/month

Payoff time: Less than one year assuming a capital cost of $25,000 to replace the blower.

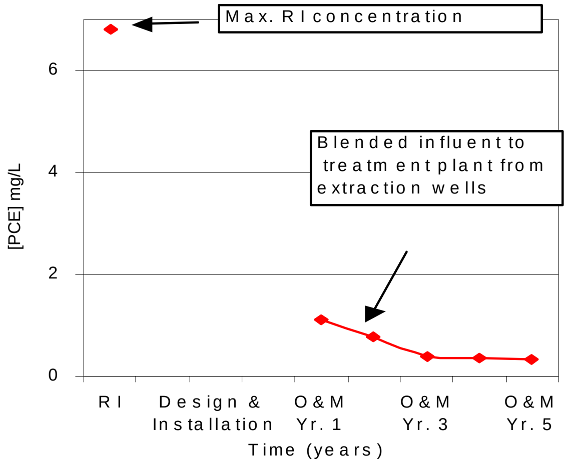
<u>Over-designed Treatment Components</u>

Individual components of the treatment system may be over-designed with respect to the operational parameters of the system, such as pumping rate or influent concentration. Figure 2 illustrates why some systems may be over-designed.

Comparing design parameters and actual parameters for a treatment system and its components will help determine if components are oversized. As shown in Example 4, conducting a cost-benefit analyses will help determine if it is cost-effective to eliminate or replace oversized components.

Figure 2

Maximum RI Concentrations Overestimate Actual Concentrations During P&T



The concentration of PCE is measured during the remedial investigation and then during O&M. Due to pumping and the blending of water from different extraction wells and overall mass reduction in ground water, the influent concentration to the treatment plant during O&M is often much lower than the maximum RI concentration observed in the aquifer.

Example 4

Evaluating Over-design of Treatment for Air Stripper Offgas

Operational Parameters
- 36 lbs of VOCs per day in plant influent
- 0 lbs of VOCs per day in plant effluent
- 36 lbs of VOCs per day in air stripper offgas

Offgas Treatment (Thermal Oxidizer) Parameters
- designed for 160 lbs of VOCs per <u>hour</u>
- requires $22,000/month for natural gas
- requires $3,000/month for electricity

Solution: Replace thermal oxidizer with an onsite carbon regeneration system.
- designed for over 50 lbs of VOCs per day
- capital costs for implementation: $370,000
- utility costs of $2,000 per month
- estimated annual cost savings: $276,000 per year

Ineffective Filtration Media

Filters are often included in treatment trains to remove solids and metal precipitates. Filters help the treatment plant meet discharge criteria for solids and metals. They also protect the other treatment components, such as GAC units, that might otherwise become fouled. For instance, if filters are ineffective, the GAC units may require more frequent replacement due to fouling than would otherwise be required due to chemical loading alone. Because costs of GAC replacement substantially exceed the cost of properly maintaining a filtration unit, ineffective filtration may result in increased O&M costs.

Premature fouling of carbon or decreased reduction in total suspended solids are indications of ineffective filtration units.

Inefficient Air Strippers

Removal of volatile organic compounds (VOCs) is often most effectively achieved with air stripping. Packed towers and tray aerators are two types of systems that, when properly designed, effectively strip VOCs.

In some cases, typically in systems that at one point utilized biotreatment, air stripping is achieved by diffused air strippers (i.e., large storage tanks that use large blowers to diffuse air through process water). Such an approach typically uses a 20- horsepower blower and results in 80% removal of VOCs whereas a well-designed tray aerator may use a 5-horseblower blower and achieve 99% removal of VOCs. Thus, switching to a well-designed air stripper from a diffused air stripper might reduce power costs substantially and allow for removal of a GAC polishing step due to improved removal efficiency.

Remove Redundant or Unnecessary Components

Eliminating unnecessary components that stem from over-design or changing site conditions may result in substantial savings. Three common examples of redundant or unnecessary components are provided.

Metals Removal Systems

Metals removal is a common treatment component that may be unnecessary shortly after a system becomes operational and functional, at some other point before site closure, or with proper filtering. Because elevated metals concentrations in extracted water may be due to suspended solids, proper filtering of process water can often eliminate the need for a metals removal system. Metals concentrations in extracted water may also decrease over time because the mobility of metals is sensitive to their oxidation states. Metals such as iron, manganese, and arsenic become relatively immobile when oxidized and relatively mobile when reduced. Ground water with elevated levels of organic contaminants may initially have highly reducing conditions, making these metals more mobile. Once pumping begins, however, the reducing conditions may diminish due to mixing and/or contaminant removal. Therefore, as remediation progresses, the extracted water may have significantly lower metals concentrations than anticipated from remedial investigation data. In some cases, metals concentrations may fall below the discharge criteria, rendering metals treatment unnecessary.

Metals treatment via precipitation involves chemicals for pH adjustment, significant labor (i.e., one or more operators full time), and generation and disposal of filter cake. As a result, metals removal systems are extremely costly and should be eliminated, shutdown, or bypassed if they are unnecessary. At some sites where metals, such as iron and manganese, are not COCs but frequently cause fouling of other system components, it may be cost-effective to frequently clean the P&T system than it is to operate a metals removal system.

GAC Polishing Steps

Although not always the case, air strippers can often reduce VOC concentrations in extracted ground water without a GAC polishing step. If a GAC polishing step is planned for or is part of a P&T system, efforts should be made to optimize the air stripper because the polishing step may not be required. Often, strippers can be made more effective by increasing the air/water ratio, changing the packing material (for packed towers), or adding another tray (for tray aerators). A second air stripper can also be considered as a polishing step. A cost benefit analysis should be conducted to determine which approach is most appropriate for a specific site.

Parallel Systems or Components

Providing redundancy (e.g., a spare component, perhaps installed in parallel to the operational component) for filters or mechanical equipment such as pumps and blowers is often warranted. However, splitting the flow of process water into parallel treatment trains or providing an additional treatment train as backup is not usually warranted for removal of VOCs or metals. The components of these treatment trains require minimal downtime, and because ground water moves slowly, maintaining and operating parallel systems to prevent a few days of downtime per year is not cost-effective. If one train of an operational parallel system can treat the extracted water, managers should consider bypassing or eliminating the other train if savings from labor and maintenance are expected to exceed the capital cost of the modification.

Consider Alternate Discharge/Disposal Options

The following discharge options are typically available for treated water:

- publicly owned treatment works (POTWs)
- storm sewer and surface water (both regulated under National or State Pollutant Discharge Elimination System, NPDES or SPDES, programs)
- reinjection to the subsurface (regulated by Underground Injection Control Program)

Each of these options have positives and negatives associated with them, and these are summarized in Exhibit 8. Site managers should regularly evaluate discharge options to determine which is most cost effective and should consider capital, negotiation, and sampling costs of the options in this evaluation.

Disposal of filter cake from biotreatment or metals precipitation can generally be disposed of as non-hazardous waste if it passes Toxicity Characteristic Leaching Procedure (TCLP) testing. This costs less than disposal at a hazardous waste facility. If these materials are considered "listed" waste because of past site use, but the wastes pass TCLP testing, then "de-listing" should be pursued. Savings of up to $200 per ton could result from a change in disposal practices. For some sites, this could translate to savings of up to $4,000 per month in costs associated with transportation and disposal of such wastes.

Identify Opportunities for System Automation

Common treatment components such as air strippers and GAC units, when properly designed and installed, have been proven reliable through years of testing in the field. As a result, when these systems are installed with alarms, auto shut-offs for high levels, and auto-

Exhibit 8

Discharge Alternatives for Water from a P&T System

Discharge alternative	Positives	Negatives
Publicly-owned treatment works (POTWs)	• require relatively flexible discharge standards compared to other alternatives (typically 2.13 mg/L total toxic organics) • accept and treat some hard to treat contaminants (ketones and ammonia)	• may refuse to accept treated or untreated ground water due to dilution or lack of capacity • require payment (approximately $0.002 to $0.03 per gallon) • often require pretreatment
Storm sewer and surface water	• typically do not require payment • often readily accessible from treatment plant • minimal capital costs	• for resource conservation, some areas do not allow discharge of ground water to surface water • discharge criteria is generally stringent (e.g., MCLs for naturally occurring inorganics) • lengthy permitting process • frequent sampling requirements
Reinjection to subsurface (reinjection wells or infiltration galleries)	• may help with hydraulic control of plume • relatively easier permitting process • biotoxicity testing not required	• may hinder hydraulic control of plume • may require substantial capital cost • potential issues with fouling of wells • requires space for wells or galleries

dialers to remotely contact an "on-call" operator, they can often run unattended with only weekly or biweekly checks and maintenance. Metals removal systems may require more attention than these units, but the chemicals required for operation may be automatically dosed and batched thereby reducing operator labor to 40 hours per week. System operators should be local, (i.e., located within an hour from the system, if possible) to quickly address potential alarms and to minimize or eliminate per diem or travel costs. In some cases, remote access to system data and controls by modem can further reduce operator labor. Opportunities for increased system automation and decreased operator labor can result in significant cost savings. The table in Exhibit 9 provides general guidelines, based on information gathered during reviews of 20 Fund-lead P&T systems, as to the amount of labor typically required for various types of treatment plants.

Exhibit 9

General Guidelines for Labor Typically Required for Various Types of Treatment Plants

Treatment Plant	Estimated Labor
• air stripping • vapor phase GAC for offgas treatment	• weekly checks by local operator (8-12 hours/week) • quarterly checks by engineer
• GAC treatment	• weekly checks by local operator (8-12 hours/week) • quarterly checks by engineer
• metals removal • filtration	• one or two operators full time (1 or 2 × 40 hours/week)
• metals removal • filtration • air stripping • GAC	• two operators full time (2 × 40 hours/week)

A number of factors can affect these guidelines. For example, additional labor may be required if substantial maintenance is required for recurring issues, such as well or system fouling due to iron bacteria. Very few systems should require more than 2 full time operators, and with proper automation, sites should not require a 24-hour presence.

Eliminate Excess Process Monitoring

Process monitoring is required to demonstrate the effectiveness of the treatment plant but can be costly if laboratory analysis is required. Therefore, excess process monitoring should be eliminated, and when possible sensors should be used to determine the performance of the treatment components. Many commonly used treatment technologies, such as air strippers and granular activated carbon, have been used successfully and reliably for years and minimal monitoring is necessary to demonstrate their effectiveness once the system is operating. In many cases, a metals removal system can be effectively operated based on sensor readings of total suspended solids and oxidation-reduction potential, and its performance can be cost-effectively evaluated by analyzing samples from the plant effluent for metals.

Process monitoring samples that are collected are generally most cost-effectively analyzed in off-site laboratories. Although the use of inexpensive field kits are often beneficial and cost-effective as screening level data, the use of staffed on-site laboratories or sophisticated on-site analytical equipment, such as gas chromatographs, are often not cost effective over time. Such laboratories or equipment may have been included during the design or early in O&M, when frequent sampling was necessary for system "shakedown". However, the need for this frequent sampling is eliminated when the system reaches steady-state or continuous operation. Except in rare cases, a reduced number of samples can be analyzed in an independent off-site laboratory with a one-week or even 24-hour turnaround time for a lower cost than the labor and materials required to maintain and staff an on-site laboratory or calibrate and operate sophisticated equipment.

If frequent sampling is required for a treatment plant during "shakedown", a temporary period of on-site monitoring could be arranged if cost-effective compared to sending samples off site. This approach is generally more cost effective than arranging and staffing a permanent laboratory.

E. CONTRACTING CONSIDERATIONS

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An O&M contract for a P&T system should clearly outline the responsibilities of the O&M contractor. However, because of changing site conditions, progress toward site closure, and optimization opportunities, the contract should also allow for reductions in the scope of work.

Clearly Establish Responsibility For Key Items

Standard Operating Procedures and Site Records

Contracts should clearly task the contractor with development and updates to an O&M manual that provides fundamental information about the system and standard operating procedures. The contracts should also task the O&M contractors with maintaining site records and providing transition training for future O&M contractors.

Evaluation of P&T System Performance

O&M of a P&T system requires regular evaluation of the remedy's effectiveness. These evaluations need to consider performance of both the above-ground treatment processes and responses in the subsurface. Because many parties (site owner, state and federal regulators, contractors, and possibly subcontractors) are involved in the O&M of a P&T system, the responsibility for evaluations should be clearly defined and tasked to the O&M contractor in the O&M contract.

Evaluations can be divided into three components:

- data collection
- data analysis and interpretation
- reporting

O&M contracts typically task the responsibility for data collection and reporting but may assume data analysis and interpretation is the responsibility of the site owners or regulators. In such cases, sufficient data analysis may not occur to monitor system effectiveness. To avoid such situations, a contract should clearly task, to the contractor, all data evaluation and analysis. Further analysis could then be conducted by the site manager, if necessary.

Key items that should be included in a typical O&M report are listed in Exhibit 10.

Compare Lump Sum versus Cost Reimbursable

Contracts should clearly delineate financial responsibility. Example 5, on the following page, provides summaries of two contracting options for operation of the same P&T system. It illustrates that lump sum is most effective for items that are highly predictable while cost reimbursable is more effective for items that are more uncertain. Examples of items that should be cost reimbursable are materials, utilities, and unexpected or emergency repairs or modifications.

Plan For Reductions in Scope

Due to changing site conditions and progress toward cleanup, reductions in the scope of work may be warranted during a contract. Therefore, well-written contracts will provide for potential reductions in scope. The following are examples of areas where scopes may be reduced during a long-term contract.

Process monitoring: Substantial process monitoring may be required, especially during "shakedown". However, when stable operation is achieved, process monitoring can be reduced.

Ground water sampling: During the first few years of operation, quarterly ground water monitoring may be

Exhibit 10

Key Items to be Included in an O&M Report

Subsurface performance
- ground water quality data and updated plume map(s)
- ground water elevations and updated potentiometric surface(s)
- extraction well rates and specific capacities
- concentrations at extraction wells
- updated trend analyses
- capture zone analysis

Treatment plant performance
- plant influent concentrations presented along side design influent concentrations
- plant effluent concentrations presented along side discharge criteria
- plant flow rate and operational parameters (e.g., head differentials across filters, air stripper air to water ratio, etc.)
- system efficiency along side design efficiency
- materials and utility use
- maintenance items
- identification and description of exceedances
- system downtime

Interpretation
- are short-term goals being met?
- are long-term goals expected to be met?
- evidence of progress toward goals (trends in concentrations, etc.)
- revised site conceptual model

Other Significant O&M Activities
- system modifications
- non-routine maintenance and costs (e.g., well-rehabilitation)
- communication with neighbors or local/State authorities
- Other significant site activities

merited at many sites. However, once the plume is found to be relatively stable, sampling semi-annually, annually, or at some other frequency may be merited, and the number of sampling locations and/or parameters may also be reduced. Provisions in the contract should exist to reduce the sampling scope of work accordingly.

Reductions in materials and labor: If a metals removal system or another treatment component is no longer necessary because influent concentrations meet discharge requirements, that system should be removed and the associated labor eliminated.

Example 5

Lump sum versus cost reimbursable

Hypothetical P&T System
- system addresses polyaromatic hydrocarbons (PAHs) from a former wood treating facility.
- extracted water is pumped through an oil/water separator and then through large GAC units.
- replacement of GAC units occurs twice every year and costs $20,000 per replacement.
- electricity rates have varied from $0.05 to $0.10 per kWh over the past 5 years. On average 20,000 kWh are used per month (240,000 kWh per year).

Contracting option 1: lump sum
Contractor bids $750,000 lump sum for 3 years of O&M assuming six potential GAC replacements ($120,000), a possible electrical rate of $0.12 per kWh ($28,800 per year) to account for uncertainty, and $50,000 for non-routine maintenance

Contracting option 2: combined lump sum/cost reimbursable
Contractor receives $495,000 lump sum for labor, reporting, sampling and analysis for 3 years of O&M. To remove uncertainty from the lump sum bid, the site owner pays for GAC replacements, electrical usage, and non-routine maintenance as required (cost reimbursable).

Scenario:
During 3 years of O&M, improved filtration and decreasing concentrations reduce frequency of GAC replacement to once per year (3 total), electrical rates are approximately $0.06 per kWh, and $25,000 of non-routine maintenance is required.

Costs for contract 1:	**$750,000**
Costs for contract 2:	**$623,200**
Difference:	**$126,800**

Lesson: Lump sum is more effective for items that are highly predictable, and cost reimbursable is more effective for items that are uncertain.

F. OPTIMIZATION AND CONTINUOUS IMPROVEMENT

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Continuous improvement can occur by periodically evaluating goals, performance, and cost-effectiveness and then implementing changes from these evaluations.

Periodic third-party (or independent) reviews of a P&T system that include a review of site documents and discussions with the site stakeholders are recommended. These reviews, when performed by a team of experts, can provide the following benefits:

- an unbiased, external review of system operation and costs
- expertise in hydrogeology and engineering
- specific knowledge and experience with new or alternative technologies
- experience gained from designing, operating, or reviewing other systems
- a fresh perspective on the problems at hand and the current remedy

System improvement, however, will only occur if recommendations are implemented.

G. CITED RESOURCES

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U.S. Army Corps of Engineers, Operation and Maintenance of Extraction and Injection Wells at HTRW Sites, Engineer Pamphlet 1110-1-27, January, 27, 2000.Available at http://www.usace.army.mil

This document may be downloaded from EPA's Clean Up Information (CLUIN) System at http://www.clu-in.org. Hard copy versions are available free of charge from the National Service Center for Environmental Publications (NSCEP) at the following address:

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