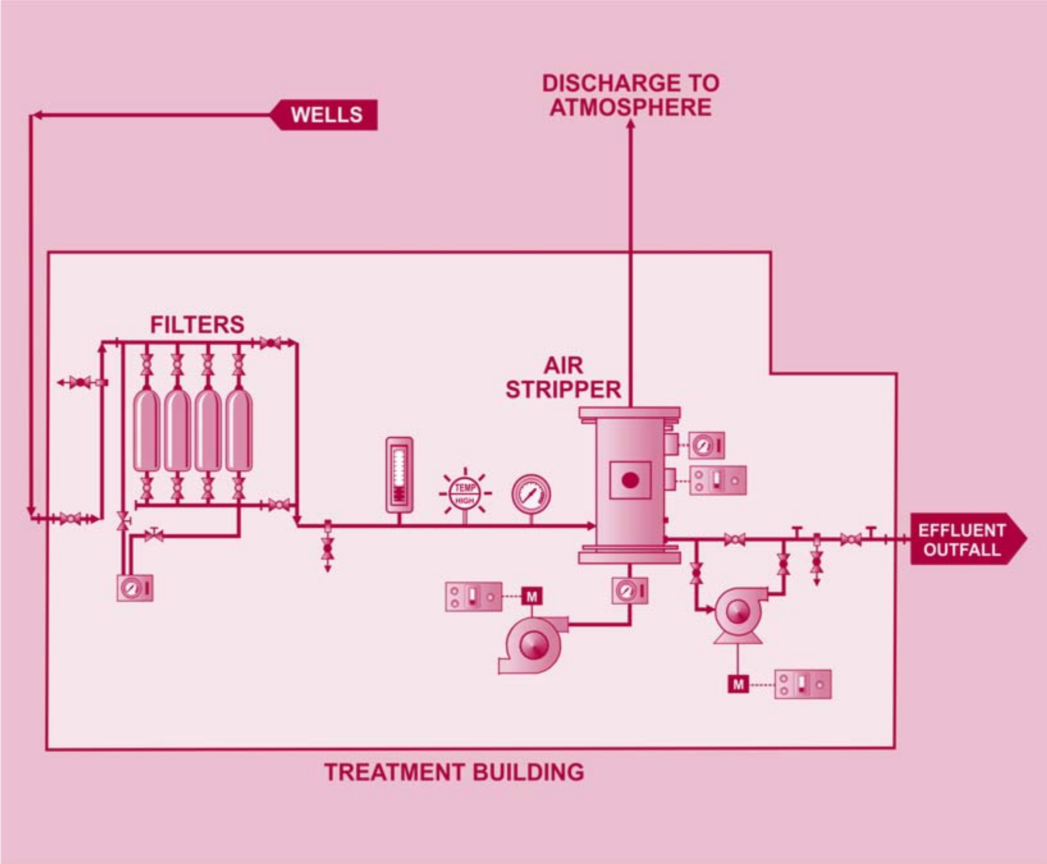
UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Cost-Effective Design of Pump and Treat Systems



One of a Series on Optimization

Office of Solid Waste
and Emergency Response
(5102G)

OSWER 9283.1-20FS
EPA 542-R-05-008
April 2005
www.cluin.org
www.epa.gov/superfund

Cost-Effective Design of Pump and Treat Systems

DISCLAIMER

This document provides references to models and processes in use by outside parties and other Federal Agencies. Mention of these models and processes does not imply endorsement for specific purposes.

This fact sheet is not intended to be a detailed instruction manual. In addition, this fact sheet is not a regulation; therefore, it does not impose legally binding requirements on EPA, States, or the regulated community, and may not apply to a particular situation based upon the circumstances. The document offers technical recommendations to EPA, States and others who manage or regulate ground water pump and treat systems as part of the Superfund program or other cleanup programs. EPA and State personnel may use other approaches, activities and considerations, either on their own or at the suggestion of interested parties. Interested parties are free to raise questions and objections regarding this document and the appropriateness of using these recommendations in a particular situation, and EPA will consider whether or not the recommendations are appropriate in that situation. This fact sheet may be revised periodically without public notice. EPA welcomes public comments on this document at any time and will consider those comments in any future revision of this document.

This page is intentionally left blank.

PREFACE

This fact sheet summarizes key aspects to consider for designing cost-effective pump and treat (P&T) systems. It is part of a series of fact sheets that the EPA Office of Superfund Remediation and Technology Innovation (OSRTI) is preparing as guidance for the ground water remediation community on effectively and efficiently designing and operating long-term ground water remedies. This series is available at www.cluin.org/optimization and consists of the following fact sheets, plus others that will be available in the future.

- *Elements for Effective Management of Operating Pump and Treat Systems*
  OSWER 9355.4-27FS-A, EPA 542-R-02-009, December 2002

- *Cost-Effective Design of Pump and Treat Systems*
  OSWER 9283.1-20FS, EPA 542-R-05-008, April 2005

- *Effective Contracting Approaches for Operating Pump and Treat Systems*
  OSWER 9283.1-21FS, EPA 542-R-05-009, April 2005

- *O&M Report Template for Ground Water Remedies (with Emphasis on Pump and Treat Systems)*
  OSWER 9283.1-22FS, EPA 542-R-05-010, April 2005

Access to a wider range of EPA documents is available at www.cluin.org.

The recommendations contained in this series of fact sheets are based on professional experience in designing and operating long-term ground water remedies and on lessons learned from conducting Remediation System Evaluations (RSEs) at Superfund-financed P&T systems. The results of the first 20 RSEs conducted at Superfund-financed P&T systems are summarized in *Pilot Project to Optimize Superfund-Financed Pump and Treat Systems: Summary Report and Lessons Learned* (EPA 542-R-02-008a), and the site-specific recommendations from the evaluations are available in the individual RSE reports (EPA 542-R-02-008b through 542-R-02-008u). The content of these fact sheets is relevant to almost any P&T system. Therefore, these documents may serve as resources for managers, contractors, or regulators of any P&T system, regardless of the regulatory program. Examples provided in this document have costs that are reasonable based on 2003 dollars but do not reflect rigorous pricing through vendors.

A. INTRODUCTION

....

Remediation System Evaluations (RSEs) conducted at 20 Superfund-financed pump and treat (P&T) systems have identified potential opportunities for reducing annual operating costs without compromising protectiveness at 17 of the 20 systems. On average, the opportunities for each system translate to a potential reduction of more than 30% in the annual operating costs. The results of these RSEs are summarized in *Pilot Project to Optimize Superfund-Financed Pump and Treat Systems: Summary Report and Lessons Learned* (EPA 542-R-02-008a). Cost reduction recommendations included reducing labor costs, simplifying the treatment plant, replacing treatment components with more efficient units, and reducing process monitoring. Many of these cost savings opportunities arose because the parameters used to design the P&T systems differed from the actual parameters during system operation. This finding suggests that EPA project managers and other environmental professionals would benefit from guidance on designing cost-effective P&T systems.

An appropriately designed P&T system should achieve the ground water remedy goals in a cost-effective manner for the operating life of the system. Therefore, the design of the P&T system should account for the capital costs associated with system installation as well as the annual costs for operation and maintenance (O&M). In this instance and the remainder of the document, the term "O&M" refers to activities associated with operating and maintaining a P&T system, and does not refer to any specific period of time or regulatory status associated with the remedy. For example, the Superfund program generally refers to the first 10 years of a Fund-lead P&T system as Long-term Response Action (LTRA), and the subsequent period as "O&M". However, in this document both of those time periods are considered to be types of O&M.

System design generally occurs after site characterization has been completed and usually consists of the following steps:

- considering remedy goals and associated performance monitoring requirements
- establishing design parameters (e.g., system flow rate and influent concentrations)
- selecting appropriate ground water collection/extraction methods
- selecting appropriate technologies for treatment of each class of constituents
- determining an appropriate option for discharge of treated water
- incorporating appropriate system controls and automation

Each of the above steps is discussed in this document and design scenarios are provided in appendices for two hypothetical sites as illustrative examples of cost-effective P&T system design.

Because capital costs for installation and annual costs for O&M are significantly higher than the costs of designing a system, it is often appropriate to request a design review from a third party. Once a system is installed and operating reliably, the system performance should be routinely evaluated to determine if the performance and site conditions are as expected. Changes to the system over time are generally expected, due to evolving site conditions and emergence of innovative technologies. The system should be evaluated/optimized on a regular basis by the site team each year and evaluated by an independent party perhaps every five years.

TABLE OF CONTENTS

B. REMEDY GOALS AND PERFORMANCE MONITORING

....

P&T systems are generally constructed and operated to accomplish one or both of the following:

- *Containment* - prevent migration of a constituent above a selected concentration to a receptor or potential receptor
- *Aquifer restoration* - remove contaminant mass, including non-aqueous phase liquid (NAPL) if present, from an aquifer to achieve selected cleanup criteria

In addition, a P&T system can be designed to meet requirements for the discharged water, and possibly discharged air, depending on the system.

The design of a cost-effective P&T system considers these goals and requirements for the following reasons:

- The performance of each system generally includes monitoring and evaluation with respect to its goals, and a system can be designed to make this performance monitoring easier and less costly.
- As a remedy progresses and site conditions improve, intermediate goals and milestones may be achieved. A cost-effective P&T system is one where operation of unnecessary system components is discontinued.

Consideration of these two points during design is facilitated by the concurrent development of an exit (or closure) strategy and/or a performance-based monitoring plan. An exit strategy generally is a compilation of measurable milestones that indicates progress toward remediation goals, specific conditions that clearly indicate achievement of these milestones, and a set of actions to occur (e.g., discontinuing a component of the remedy) when these milestones are achieved. If milestones are not achieved as expected, this might be an indication that the remedial approach and/or the goals need to be revisited. A performance-based monitoring plan typically focuses on collecting information that is necessary to document achievement or progress toward goals.

The following three subsections describe how a system design and elements of an exit strategy and/or a monitoring plan can work together to result in a cost-effective P&T system that addresses the remedy goals. Containment, aquifer restoration, and meeting discharge requirements are discussed separately.

Containment

Containment generally refers to hydraulic capture of contaminants in a three-dimensional zone of the subsurface and may pertain to a dissolved contaminant plume and/or a NAPL plume.

Some containment remedies may be designed to operate indefinitely, and may not be conducive to an exit strategy. However, some of the contaminants at a site may degrade over time or otherwise fall below standards and not need further treatment. In such cases, monitoring can be reduced, and components of a treatment system may be discontinued if discontinuing them does not compromise other treatment components that are still in use. Therefore, although an exit strategy may not be applicable for a containment remedy as a whole, exit strategies for some individual components (particularly those with significant annual costs) are generally applicable.

Consideration of a performance-based monitoring plan during design could lead to reduced annual costs and a more cost-effective remedy. A performance-based monitoring program for a containment remedy will likely need to demonstrate plume capture through interpretation of water level measurements and water quality samples. In some cases, extracting more water at a site may make evaluating capture easier and less costly without substantially adding to treatment costs. At those sites, it may be more cost-effective to increase the extraction rate. Therefore, the scope of monitoring needed to evaluate capture should be considered for a variety of pumping scenarios. For each scenario, the associated costs of this monitoring and evaluation should be compared to the costs of pumping and treating water.

> ***"... it may be more cost-effective to increase the extraction rate."***

Aquifer Restoration

For aquifer restoration, an effective P&T system design might have two components to the extraction system: extraction wells dedicated to source control (e.g., hydraulic capture of a NAPL source zone) and extraction wells dedicated to restoration throughout the rest of the plume. If feasible, this is a particularly effective strategy because controlling the source area allows the remainder of the P&T system to remediate the downgradient portion of the plume. An exit strategy associated with such a P&T system may include discontinuing the downgradient portion of the extraction system when certain conditions are met but continuing the operation of the source area extraction system to maintain source control. With the majority of the plume restored, source control and associated monitoring can continue at a presumably lower cost. This contrasts with an approach that aims to restore an entire plume with little consideration to controlling the source area. In such a case, the source area, which may consist of elevated concentrations and/or NAPL, can increase in size, and the entire system, rather than just the source area component, will continue to operate indefinitely.

"Control the source area to allow the remainder of the P&T system to remediate the rest of the plume in a timely manner."

The specific conditions for shutting down any part of the system or the whole system should be considered during system design and clearly defined before operation begins. If other remedial technologies that can help meet these conditions are available at the time of design or become available during O&M, a cost-benefit analysis could be conducted to evaluate continued P&T versus implementation of these other technologies.

Given the above scenario, an appropriate performance-based monitoring program would likely include limited ground water quality sampling in the source area. Because the source area would be controlled and not necessarily restored, substantial water quality sampling in the source area may not provide valuable information regarding the performance of the remedy.

Meeting Discharge Requirements

Monitoring of the process water, and in some cases, treatment system off-gas, is often conducted to evaluate performance and document that discharge standards are met. Because process monitoring can be a significant portion of annual O&M costs, system design should consider how system performance can be cost-effectively demonstrated by process monitoring.

Monthly or quarterly sampling is typically specified by discharge permits to demonstrate that effluent is meeting standards, but additional process monitoring is generally determined by what is needed to operate the plant. Because frequent sampling and laboratory analysis can become expensive, treatment plants, when possible, should be designed to operate based on readings from sensors and less frequent sampling with laboratory analysis. Turbidity, oxidation-reduction potential, and pH (in conjunction with influent and effluent samples) often provide sufficient information to operate a metals precipitation system. The pressure differential across filters is often used to indicate fouling. Air flow rates and pressure are generally sufficient to indicate an air stripper's performance. The use of sensors is generally more cost-effective than frequent sampling with laboratory analysis, and the sensor data are provided in real time.

System designers should incorporate various sampling ports throughout the treatment plant. Ports should be located for samples to be collected from the influent and effluent of each major treatment component so that the efficiency of each unit can be determined. This is especially helpful during system startup, when more frequent sampling is appropriate, and is also helpful for less frequent sampling throughout the duration of the remedy.

Because site conditions change, the influent concentrations of some constituents may fall below discharge standards over time, and/or some extraction wells may be taken offline. System designers should anticipate the conditions that would allow discontinuing the use of treatment components (or a treatment system) so that these components are not operated unnecessarily. The conditions that would merit restarting or reincorporating those components could also be determined, if changing site conditions lead to an unexpected increase in influent concentrations.

An onsite laboratory for frequent chemical analysis is costly to install and operate and is rarely appropriate once system operation is stable. Designers should thoroughly consider the use of sensors before including an onsite laboratory in the design. During system startup, more frequent sampling may be appropriate, but a short-term solution, such as sending samples offsite or using a temporary mobile laboratory, is generally more appropriate and cost-effective in the long term than installing and operating a permanent laboratory.

"An onsite laboratory is costly and is rarely appropriate..."

C. SYSTEM DESIGN PARAMETERS

………

Proper evaluation and selection of treatment equipment during design requires reliable estimates of the extraction system flow rate and influent characteristics. System designers, however, should note that changes in the values of these parameters will likely occur during system operation, particularly in the first five years. These changes in parameter values might result from a change in site conditions related to the operating remedy, such as modifications to the extraction system or source control/removal. Ideally, a system is designed to minimize equipment that becomes unnecessary soon after operation begins. Regardless, system components that are initially needed may later become unnecessary. In such circumstances, the system should be sufficiently flexible to allow these components to be bypassed so that unnecessary materials and labor costs do not continue. In some cases, it may be appropriate to lease a particular treatment component if the designer believes that the component will only be needed for a short time. In other cases, it may be appropriate to install equipment that is appropriate for the reduced mass loading that is expected over the long term. In such cases, the system would operate with increased cost and/or modified extraction in the short term to accommodate the initially elevated mass loading and meet discharge standards.

Selecting appropriate design parameters reduces the likelihood that installed treatment equipment will be unnecessary. Common design parameters are discussed below. Terms in **bold** are summarized in Exhibit 1.

System Flow Rate

Design Extraction Rate

Based on the remedy goals for plume capture and source control discussed above, a system design flow rate and extraction well locations can be developed. The **design flow rate** should be the actual flow expected based on well yield data, pumping tests, and, if appropriate, modeling using site-specific conditions. Modeling can also help determine the optimal locations for extraction wells. The design flow rate is used for estimating initial contaminant mass loading, and, depending on the system, items such as granular

Exhibit 1

Summary of Design Terms Used for Purpose of this Guidance

Design flow rate: expected flow rate of P&T system calculated from estimated extraction rates necessary to achieve remedy goals (e.g., plume capture).

This value should be used to select treatment components and to calculate the design mass removal rate.

Hydraulic capacity: maximum expected flow rate of P&T system, generally calculated by multiplying the design flow rate by a factor of safety greater than 1.0.

This value should be used to size pumps, piping, and tanks but should NOT be used to calculate the design mass removal rate.

Design influent concentration (for each constituent or class of constituents in system influent): expected blended influent concentration from all extraction wells based on concentrations obtained from sustained pumping conditions (e.g., after more than 24 hours of pumping) and not from routine monitoring data.

This value should be used to calculate the design mass removal rate.

Maximum influent concentration (for each constituent or class of constituents in system influent): maximum expected blended influent concentration from combined extraction, typically calculated by multiplying the design influent concentration by a factor of safety between 1.0 and 2.0.

The treatment system should be able to handle this concentration. Therefore, this value should be used to help select a treatment process but should NOT be used to calculate the design mass removal rate.

Design mass loading rate (for each constituent or class of constituents in system influent): estimated mass loading rate (pounds per day) to the treatment plant of contaminants in extracted ground water, calculated by multiplying the design flow rate by the design influent concentration (Exhibit 2).

This value should be used for estimating materials/utilities usage when analyzing costs of various treatment options.

activated carbon (GAC) usage, sludge production, and chemical usage. It can also be used to screen potential discharge options. For example, as the flow rate increases, discharging to a publicly owned treatment works (POTW) becomes more expensive, whereas the costs for other discharge options, such as surface water or reinjection, often remain the same.

Hydraulic Capacity

A maximum system flow rate (**hydraulic capacity**) should be calculated using the design flow rate multiplied by a factor of safety. The factor of safety is site-specific and is determined by professional engineering judgment, based on the importance of hydraulic capacity for system cost and effectiveness and on the reliability of the design flow rate calculation (e.g., the calculation will be more reliable if the yields of the extraction wells have been estimated with pump tests on either extraction wells or nearby monitoring wells). For example, if the design flow rate for a system is 2 gpm, a factor of safety of 5 (for a hydraulic capacity of 10 gpm) is usually reasonable, primarily because the same size treatment components would likely be used for any flow rate at or below 10 gpm. However, for systems with multiple wells and flow rates over 50 gpm, the factor of safety should generally be 2 or less, according to the design engineer's judgment.

The hydraulic capacity is used to size treatment equipment, pumps, and piping to allow appropriate throughput. Pump and piping design should consider flow velocities and head loss. If any system components are fed by pumps that cycle on and off, the flow rate while the pump is operating should be considered, not the average flow rate over a cycle. For example, the average flow through an air stripper may be 50 gpm, but if the treatment system is designed to operate in batch mode (i.e., intermittently) at a flow rate of 100 gpm, the air stripper should be designed with a flow capacity of 100 gpm. To avoid over-design, the hydraulic capacity should not be used to determine GAC usage, sludge production, disposables, or the selection of a treatment process. These items are best determined with the design flow rate, which is the best estimate of the expected flow rate.

Design Concentration

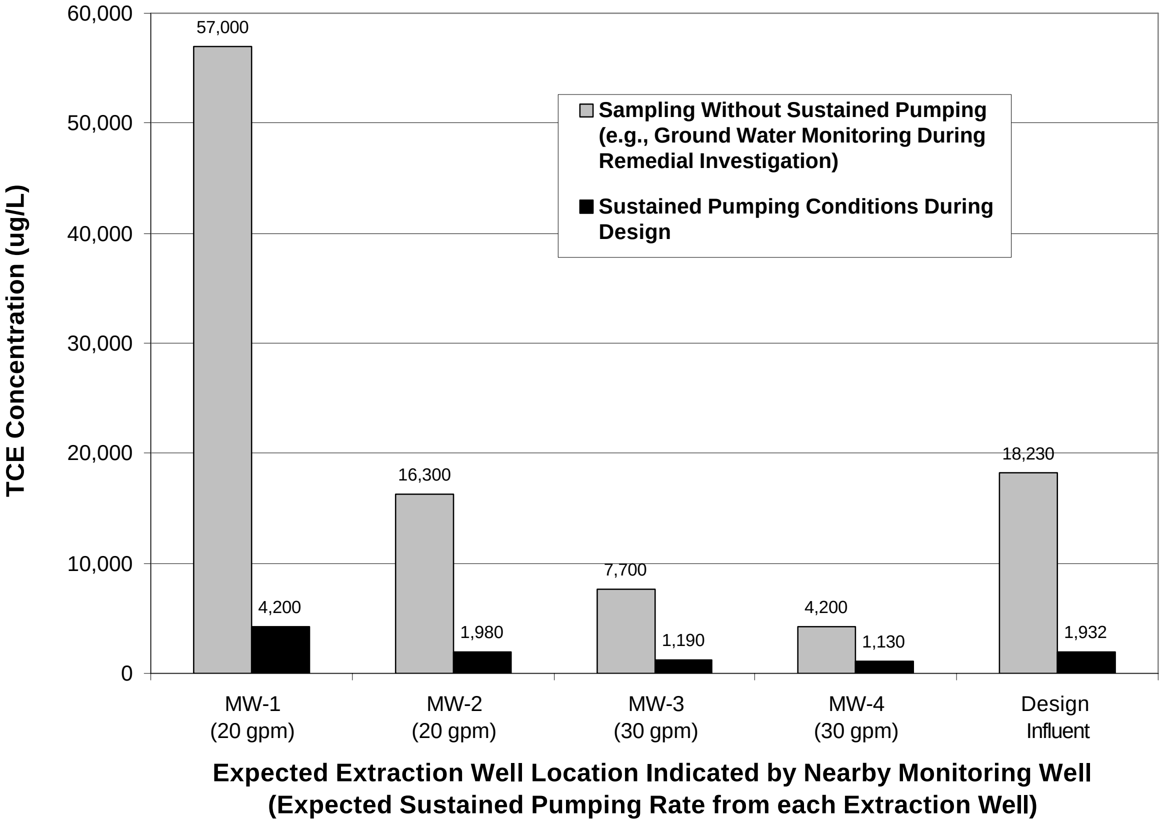
In addition to the system flow rate, concentrations of constituents expected in the system influent should be determined. Site contaminants of concern, as well as naturally occurring inorganics, such as iron, manganese and hardness, should be considered. Extracting ground water changes ground water flow patterns, blends contaminated and relatively clean water, and often changes the oxidation-reduction potential of the subsurface. Concentrations of both organics and inorganics under sustained pumping conditions are sometimes orders of magnitude lower than under non-pumping conditions. As a result, concentration data used for determining the design concentration of a P&T system should be collected for each potential constituent during sustained pumping conditions from operating extraction wells or from pump tests at monitoring wells in the vicinity of the proposed extraction wells. For inorganics, both unfiltered and filtered samples should be analyzed to determine the potential need for treatment and the potential for physical filtration to be an effective primary treatment. The longer pumping can be sustained and the closer that rate is to the expected extraction rate, the more accurate the estimate of the influent concentrations will be. In general, allowing 24 to 48 hours of pumping prior to sampling is a reasonable compromise between the cost for the test and the value of obtaining data under pumping conditions. However, test pumping for longer periods of time may be beneficial for wells with a lower yield (e.g., less than 5 gpm).

Typically mobile large-volume tanks are used to store water from pumping tests. Treatment of the generated water depends on the volume, influent characteristics, and discharge standards. If discharge to a POTW is feasible, treatment may not be needed and the relatively low volume of water from pumping tests make discharge to the POTW cost-effective. In some cases, approval can be obtained for short-term discharge to a nearby surface water body or to a storm sewer. If a discharge point is unavailable or testing/treatment standards are extremely stringent, off-site treatment at an appropriately permitted facility may be warranted, with costs at these facilities typically ranging from $0.25/gallon to $0.50/gallon. Small GAC units and mobile air strippers are available for very reasonable costs. On-site treatment of the pumping test water may be cost-effective and can be useful for testing the effectiveness of preferred treatment technologies.

Data from representative wells should be averaged (weighted based on the flow per well) to give the **design influent concentrations** for each constituent (Figure 1). The use of concentration data obtained during sustained pumping conditions, rather than during non-pumping or low-flow conditions, reduces the chance of over-designing the system to handle an erroneously high mass removal rate.

Figure 1

Estimating the Design Influent with Data Collected During Sustained Pumping Conditions



Using analytical data collected without sustained pumping (e.g., from ground water monitoring during a Remedial Investigation) leads to a design influent concentration of 18,230 ug/L and a design mass removal rate of 22 lbs per day. Using data collected during sustained pumping conditions leads to a more representative design influent concentration of 1,932 ug/L and a design mass removal rate of 2.3 lbs per day. The use of concentration data obtained during sustained pumping conditions, rather than non-sustained pumping conditions, reduces the chance of over-designing the system to handle an overestimated mass removal rate.

> ***"The use of concentration data obtained during sustained pumping conditions, rather than during non-pumping or low-flow conditions, reduces the chance of over-designing the system..."***

The design influent concentrations should be used with the design flow rate to estimate the system **design mass loading** for each constituent (Exhibit 2), which should be used to estimate GAC usage, sludge production, chemical usage, etc. A factor of safety based on the reliability of the design concentration estimate (generally not exceeding 2) should be applied to the design influent concentration to provide the **maximum influent concentration**. These concentrations should be compared with actual or estimated discharge standards to determine what constituents may need treatment. The treatment system should be capable of treating the maximum influent concentrations.

Even if discharge standards for iron, manganese, hardness, and perhaps other inorganic compounds are not anticipated, treatment of these constituents may help prevent fouling of equipment, such as GAC units. The designer should try to eliminate the need for operator intensive metals removal by considering equipment not prone to fouling or the addition of a sequestering agent to keep metals dissolved. The designer should also consider a temporary metals removal system if inorganics concentrations are expected to decrease soon after continuous pumping begins, as they often do.

Exhibit 2

Sample Method for Calculating Contaminant Mass Loading

Contaminant mass loading for water and air can be calculated for each chemical constituent in the extracted water with the same basic equation. However, the units and conversion factors are different for air than they are for water. To find the total mass loading for a class of constituents (e.g., VOCs), the mass loading for that class of constituents can be calculated by summing the mass loading rates for the individual constituents.

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 in water (lbs / day)
Q_{H_2O} = flow rate in water (gpm)
C_{H_2O} = contaminant concentration (ug / L)

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 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

Basing the influent concentrations on samples obtained during sustained pumping is particularly cost-effective if traditional monitoring well sampling techniques yield organic contaminants with concentrations >1% of their solubility or naturally occurring inorganic compounds are present at levels that may need treatment. In both cases, concentrations under sustained pumping may be sufficiently low compared to traditional monitoring well sampling results to allow for more cost-effective treatment options.

Non-Aqueous Phase Liquid (NAPL)

The presence of NAPL (or even evidence that suggests the presence of NAPL) in the subsurface complicates remedial system design. NAPL can be found in three general types at impacted sites:

- lighter than water NAPL (LNAPL), such as gasoline
- denser than water NAPL (DNAPL), such as chlorinated solvents
- NAPL that has a similar specific gravity to water, such as coal tar, that may be difficult to separate from extracted water by gravity

In addition, NAPL can be found as either free product or as residual product. Free product moves in a separate phase from water and is recoverable via extraction whereas residual product is trapped in the pore spaces. Both free and residual NAPL serve as continuing sources of contamination to the dissolved contaminant ground water plume.

The presence of free LNAPL may impact extraction and treatment component selection. If free LNAPL is present in monitoring wells, it is an indication that LNAPL is also present in the formation around the well, and recovery tests using pumps or bailers should be conducted to determine the potential recovery rate of LNAPL over a period of time. If the LNAPL recovery rate is sufficient to merit automatic extraction, rather than manual collection or another remedial approach, product-only extraction pumps should be considered in conjunction with water table depression pumps. Recovered LNAPL would be handled separately from recovered ground water. For example, if the amount of recovered product is expected to be more than about 10 gallons per day per well, total fluids pumps can be used and a passive phase separator at the head of the treatment system should provide sufficient LNAPL removal for effective operation of downstream units. When recovery rates diminish, other removal technologies, such as soil vapor extraction, can be used to address residual LNAPL.

Denser than water NAPLs may be identified by an interface probe when product accumulates in the bottom of a well, by specialized down-hole indicators (e.g., FLUTe system), by inference based on concentrations over 1% of solubility (*Newell and Ross, 1992*), or by other traditional or innovative methods. DNAPL recovery tests should be considered at extraction wells in areas where free DNAPL is suspected in order to determine if the treatment system influent will have DNAPL that may need removal. Similarly, long-term pumping tests should be considered at extraction wells in areas where either free or residual DNAPL is suspected in order to estimate dissolved influent contaminant concentrations. If DNAPL is expected to be present in treatment system influent, a passive phase separator at the head of the treatment train is usually sufficient.

Coal tar and other NAPLs with a specific gravity near 1.00 may not be effectively removed from the extracted water by a passive phase separator. Recovery tests are often merited to estimate the NAPL recovery rate. If that rate is less than about 10 gallons per day, an oleophilic filter such as organo-clay can be used to remove product, thus protecting downstream treatment units. If a greater volume of NAPL is anticipated, a dissolved air flotation (DAF) unit may be appropriate for product removal. Because DAF units are expensive to install and operate, designers should carefully consider whether one is appropriate for the long-term. If one is appropriate in the short-term, leasing the equipment or using temporary pretreatment storage tanks may be warranted so that if a decrease in product recovery occurs, an over-designed system will not be in place for the duration of the remedy.

> ***"Because DAF units are expensive to install and operate, designers should carefully consider whether one is appropriate..."***

D. EXTRACTION SYSTEM

....

This section presents typical components of a ground water extraction system. The discussion for each item includes rules-of-thumb for selection and design. Selection of the appropriate components of an extraction system should reduce capital expenses in drilling wells and purchasing pumps. It should also reduce long-term maintenance costs. Proper design of an extraction system may also, in some cases, eliminate the need for additional remedy components such as barrier walls, if containment can be provided cost effectively. Prior to installing barrier walls or other remedy components that are meant to augment the P&T system, a remedial alternative analysis should be conducted. It may be more cost-effective, and equally protective, to rely on P&T alone.

Vertical Wells/Angled Wells/Drains

Vertical wells are the type of wells most commonly used for extraction systems. Normally, the vertical well is screened in an impacted zone and pumped so that the water level is drawn down, causing impacted water to enter the well. Vertical wells are the preferred collection method where the ground surface above the plume is accessible, and the aquifer provides relatively high yields (>1 gpm per well) and saturated thicknesses (>10 ft). Vertical wells are the only reasonable collection method for plumes >100 feet below the surface. When contamination is present at distinct intervals along a well, the well can be designed to focus extraction on those intervals that are most contaminated and to reduce the amount of uncontaminated water from other intervals.

Angled wells may be used below buildings or other structures that do not allow access for vertical wells in an appropriate area. Angled wells, however, have limitations. For example, electric submersible pumps are typically not used in angled wells because the pump cannot be properly centered in the well, which may result in damage to the well screen or overheating of the pump. Therefore, pneumatic submersible pumps or pumps with above-ground motors are generally more appropriate in angled wells.

Lateral drains can be effective for shallow plumes where surface features and underground utilities are not obstacles. Drains may be the only reasonable alternative when the saturated thickness is <10 ft and/or hydraulic conductivity is low. Sump(s) are placed in the low points of drains so that water may be collected and pumped.

Wellheads

A wellhead should provide security and protection based on the anticipated traffic loading. If an underground vault is used, it should have access doors that are easy to open and have adequate frost protection for piping, including a heater, if necessary. Access in the well cap should allow for water level measurement or permanent transducer installation. Float switches should be present to prevent a vault from flooding due to a leak. A separate vault or above-ground installation for the electrical junctions and controls is preferable to locating them in a well vault. A separate vault may be needed, depending on the flammability of the contaminants or electrical codes. If possible, a flow measurement device with a totalizer (for systems with electric submersibles), a sampling port, and a flow shut-off valve should be installed in each well vault (or treatment building if each well has dedicated lines). Confined space safety issues should be considered and provide another reason to keep the well in a vault separate from mechanical operating equipment. Investment in properly designed well vaults facilitates maintenance and monitoring in the future. Properly constructing and developing wells will also improve the performance of wells and minimize the need to install additional wells to meet desired yield.

The installation of piezometers adjacent to extraction wells is recommended to provide useful data for development of accurate potentiometric surface maps for performance monitoring. This is because water level measurements in an operating extraction well are generally not representative of aquifer water levels due to well losses. These piezometers may also provide an effective delivery point for well-rehabilitation chemicals.

Pumps

Electric submersible pumps are the most commonly used pumps in P&T systems and are appropriate for wells yielding about 1.5 gpm or more. They consist of a coupled electric motor and pump. The motor spins the pump impeller, which pushes water out of the well. Electric submersibles are the preferred choice for flows >12 gpm from a well with depths to water exceeding 30 feet. Certain above-ground electric pumps (e.g., jet pumps) can be used for shallow wells where the depth to water during pumping is not greater than about 25 feet. Electric pumps can be operated with level controls, amperage controls, or throttled to run continuously in wells of any depth. Both submersible and jet pumps are inexpensive (small ones are <$1,000) and reliable in normal conditions. However, if the pump is operating and the water level is below the top of its intake, damage to the pump can occur. Controls should be installed to prevent the pump from operating if the water level in a well falls to the pump intake. These pumps should not pump NAPLs and are not as resistant to fouling as some pneumatic submersibles.

Electric submersible pumps should be sized appropriately. An oversized pump would need to be throttled back, which adversely affects the pump motor and wastes electricity (Example 1). This is another reason why pump tests at extraction wells should be conducted during the design phase. In general, assuming 75% motor efficiency and $0.10/kilowatt-hour (kWh),

$$1 \text{ horsepower} = \$900 / \text{year}$$

Example 1

Costs Associated with Oversized Extraction Pumps

If 1 hp is required in each of four wells, switching from 5 hp pumps to 1 hp pumps can save approximately $14,000 per year.

4 wells × 5 hp/well × $900/year/hp	$18,000/year
4 wells x 1 hp/well × $900/year/hp	- $3,600/year
Excess Cost	$14,400/year

For flows greater than 100 gpm, an electric lineshaft turbine pump, such as those commonly used for water supply, may be warranted. These pumps are similar to electric submersible pumps, but the drive motor is mounted above-ground at the well head, and the pump is easier to service than the large submersible pump that would be needed to provide the same flow rate.

Pneumatic submersible pumps are typically $1,500 to $3,000 and are powered by compressed air. When the pump intake is below the water level in the well, the water enters the pump body. The compressed air then evacuates the pump body and pushes the fluids to the surface through tubing. If the water level drops below the pump intake, the pump can remain online, and no compressed air is used. Many pneumatic submersibles can handle NAPLs and are very resistant to fouling and chemical degradation. They are typically suitable for wells with yields from 0 to 12 gpm where water is up to 300 feet deep. They are the preferred choice for extracting water at flow rates below 1.5 gpm when the water is more than 25 feet deep.

Vacuum pumps generally are suitable for extracting water when more than five well points are necessary to achieve extraction goals, the water is less than approximately 25 feet deep during pumping conditions, and ground water is in a relatively low permeability formation. One pump draws a vacuum on a common header system that has drop tubes in several wells. Vacuum pumps are especially cost-effective when 15 or more well points are necessary. A vacuum pump with an air/water separator, vapor controls, and sump can cost $10,000 to $25,000. The vacuum pump typically has greater maintenance needs than the electric or pneumatic submersibles, but for cases where it replaces many pumps, its life-cycle costs may be lower.

Piston pumps have been used at deep, small-diameter, low yielding wells, especially deep two-inch monitoring wells that have been converted to extraction wells. These pumps often need significant operator attention. Often drilling a larger well and installing a different pump results in lower life-cycle costs than installing a piston pump.

Piping

High-density polyethylene (HDPE) is the pipe material typically used for extraction systems, and it has properties that often make it preferable to alternatives. The pipe is flexible, non-brittle, and relatively chemical resistant. Installation demands specialty equipment and training, but HDPE typically provides for a reliable pipeline. In very unusual cases, polypropylene, PVC, steel, fiberglass, or other materials may be preferred. Single-contained piping (i.e., common piping) is typically employed for conveying impacted ground water and should provide sufficient reliability.

Double-contained piping includes a second wall for additional containment and typically leak detection sumps and probes. It may be requested by regulatory agencies if the lines cross property boundaries or uncontaminated areas. It may also be requested by site stakeholders if leak detection is preferred. Leak detection systems, however, may have false positive alarms due to precipitation, condensation, or other malfunctions that can shut down the P&T system unnecessarily. Double-contained piping can also cost 1.5 times as much as single-contained piping installed below ground. Therefore, systems should typically be designed to minimize the use of double-contained pipe because effective installation and testing of single-contained pipe generally provide a maintenance free piping network.

E. SELECTING THE APPROPRIATE TREATMENT TECHNOLOGY

....

Designing a cost-effective treatment system typically involves selecting the most appropriate technologies to treat contaminants. Generally, selection involves using design parameters defined in Section C to determine the life-cycle costs associated with each treatment technology, comparing the costs and benefits for each technology, and selecting the most appropriate one, with the understanding that concentrations will likely decrease over time and potentially within a few months of operation. The cost comparison should account for the capital expense for installing the system, annual costs for system O&M, and replacement or maintenance costs. For system components with an expected life span that is shorter than the expected remedy duration, include replacement costs. For other items, an annual maintenance allowance as some small percentage of the installed capital cost should be included. A sample calculation of the estimated cost for a single treatment approach is shown in Example 2.

This section provides common treatment options for various phases or classes of contaminants as well as benefits, drawbacks, and general cost information for each technology.

NAPL

NAPL is a potential form or phase of contamination. It may be present in extracted ground water in an emulsified form or in a free flowing form. In either case, the product should be separated from water in order to meet discharge standards and maintain the effectiveness of other treatment processes.

<u>Design Parameters to Consider for NAPL:</u>
- type of NAPL (light, dense, neutral)
- maximum influent flow rate to treatment system

- estimated NAPL recovery rate
- form of NAPL (emulsified or free flowing)

Option 1: Phase Separator
- appropriate for free flowing LNAPL or DNAPL
- easily maintained with little labor
- does not remove emulsified product
- low capital ($15,000 for unit up to 50 gpm) and operating costs

Option 2: Oleophilic Filter (e.g., organoclay)
- removes both free flowing and emulsified product
- removes LNAPL, DNAPL, and NAPL with a specific gravity near 1.0
- easily maintained with little labor
- costly for large volumes of NAPL (e.g., more than 10 gallons of NAPL per day)
- removes approximately its weight in petroleum product (~7 pounds per gallon) at approximately $1 per pound

Option 3: Dissolved Air Flotation (DAF)
- appropriate for large volumes of NAPL with a specific gravity near 1.0
- operator intensive
- produces emissions that may need control technologies
- relatively high capital cost, only cost-effective for large volumes of product
- consider leasing large fractionalization tanks (phase separation) or DAF units on a short term basis to avoid a permanent DAF installation

Organic Compounds

Organic compounds can be subdivided into a number of categories, including volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), and non-volatile organic compounds. Other classifications also exist, including chlorinated vs. non-chlorinated compounds. However, volatility is of particular interest because those contaminants that volatilize often can be removed from the extracted ground water and transferred to the vapor phase where they are addressed more economically.

Removal of organic compounds from ground water is generally accomplished by partitioning them to air and collecting the vapors, by partitioning them to solids, or by destroying them. The most cost-effective and reliable approach will depend on site-specific conditions. The following sections outline the more prevalent treatment approaches and the factors that are used in determining the most appropriate choice. A summary of general advantages and disadvantages for various technologies is provided in Exhibit 3.

Example 2

Sample Cost Analysis of a Potential Treatment Option

Hypothetical Site Conditions
- contaminant: VOCs
- treatment technologies:
  - air stripping
  - GAC for offgas treatment (off-site regeneration)
- design mass removal rate: 2 lbs/day
- system highly automated

Estimated Capital Costs for Air Stripping Option

Category	Estimated Cost
Air stripper (installed)	$60,000
GAC units (installed)	$10,000
Electrical, controls, building, etc.	$50,000
Engineering, startup, contingency	$40,000
Total Capital Costs	$160,000

Estimated Annual O&M Costs for Air Stripping Option

Category	Estimated Units	Estimated Cost
Labor • O&M operator • Engineering	< 8 hours/wk 32 hours/yr	$25,000/yr
Electricity	5 HP	$5,000/yr
Materials • Vapor GAC	7,500 lbs/yr	$20,000/yr
Chemical analysis	3 samples/mo.	$5,000/yr
Maintenance	varies	<$5,000/yr
Total Annual Costs		**$60,000/yr**

Estimated Life-Cycle Costs for Air Stripping Option

Capital Costs	$160,000
Annual Costs (30 years)	$1,800,000
30-year life-cycle costs	$1,960,000
30-year life-cycle costs (discounted at 5%)	$1,082,000

This analysis for air stripping would be compared with an analysis for a competing treatment technology, such as UV/Oxidation. The extraction system, reporting, long-term monitoring, project management, oversight, and contracting costs are not included in the above costs because they are assumed to be the same for each competing treatment option.

Exhibit 3

Summary of Key Aspects of Treatment Technologies

Technology	General Advantages	General Disadvantages
Organic Compounds		
Air Stripping	• appropriate for most VOCs and some SVOCs • low operator labor needs • relatively low O&M costs • relatively low capital costs	• not appropriate for many SVOCs and other non-VOCs • off-gas often needs treatment
GAC	• appropriate for many organic compounds, including VOCs, SVOCs, and other non-VOCs • remove some metals and other inorganics (generally < 90% efficient) • low operator labor needs • relatively low O&M costs (when used for appropriate situations) • relatively low capital costs	• not appropriate for some organic compounds (usually low molecular weight VOCs) • more likely to need pretreatment for solids removal than air stripping
Polymeric Resin	• appropriate for some constituents that are not effectively treated by GAC • low operator labor needs • effective for high contaminant concentrations, especially with on-site regeneration	• contaminant specific and not appropriate for process water with many constituents • more expensive than GAC for many common contaminants at typical concentrations found in ground water
Biological Treatment	• often effective for constituents that are not easily removed by air stripping or GAC (e.g., ketones, ammonia) • fixed-film units reduce nutrient usage	• relatively operator intensive relative to air stripping or GAC • generates solids that may need disposal
UV Oxidation	• destroys all types of organic compounds on-site and does not need off-gas treatment • appropriate for some constituents that are not easily removed by other methods (e.g., 1,4-Dioxane)	• high capital costs relative to air stripping and/or GAC • often has higher O&M costs than air stripping or GAC • more likely to need pre-treatment for metals and/or solids (to prevent fouling) than air stripping or GAC
Inorganic Compounds		
Filtration	• low operator labor needs • often relatively low capital and O&M costs	• may not be sufficient to remove solids and/or metals to discharge standards • bag or cartridge filters might need frequent replacement and disposal
Settling and/or Metals Precipitation	• effective and reliable for metals removal including chromium and arsenic (with proper pH adjustments)	• operator intensive • relatively high capital and O&M costs relative to other treatment components • may generate a substantial amount of solids that need disposal
Solid Phase Partitioning and Ion Exchange	• low operator labor needs • available for various metals	• not cost-effective for high concentrations • not appropriate for multiple constituents needing removal

Air Stripping

Air strippers are widely used to remove VOCs, and, to a limited extent, SVOCs, from ground water. Systems have been in place and reliably treating ground water for decades. The systems are generally reliable and can operate unattended. O&M costs for air stripping are generally low because associated labor and materials are minimal. Power consumption is generally limited to the operation of a blower or fan. Exhibit 4 presents additional information on selecting appropriate air strippers. Appendix A presents an example with a cost analysis for selecting an air stripper as the treatment technology for VOCs. Computer software programs to select an appropriate air stripper based on flow rate, influent concentration, and air and water temperature are readily available from vendors. Selection of an air stripper model can be somewhat conservative as capital and O&M costs do not increase significantly with more efficient models.

Because air stripping transfers contaminants from water to air, the air stripper off-gas may need treatment, which is discussed later in this section.

Exhibit 4

Considerations for Selecting an Appropriate Air Stripper

Design Parameters to Consider when Selecting an Air Stripper:

- hydraulic capacity
- maximum influent concentration
- contaminants of concern
- potential for fouling
- design mass removal rate (to determine potential for off-gas treatment)
- height or space limitations
- visual impact or zoning restrictions

Diffuser: Air is injected into a tank through piping with small holes or slots allowing small bubbles to exit and contact the water. This method is the least susceptible to fouling by iron precipitation, biological growth, or hardness. However, stripping efficiency is relatively low; it is difficult to achieve >95% efficiency. Flow rates above 50 gpm likely need large tanks and high horsepower blowers. This type of stripping should be chosen only for flow rates <50 gpm where lower stripping efficiency is acceptable. It is especially suitable when flow rates are <10 gpm and significant fouling is expected. It is relatively more difficult to capture emissions from this type of stripper if off-gas treatment is included. This aeration method can also be useful as part of a metals precipitation process.

Tray Stripper: Water flows over a series of trays within a chamber where air is blown in and moves upward through small holes in the trays. The water froths on the trays as it flows down to the stripper sump; water does not pour through the holes. The tray holes are susceptible to fouling but can be easily cleaned on a schedule (usually monthly to annually). Stripping efficiencies >99% can easily be achieved and maintained with proper maintenance. The unit size and high horsepower needs compared to packed towers (due to greater air pressure) usually limit the effective range to flow rates of 5 gpm to 500 gpm. Emissions can be easily captured from these units, and they can be easily placed within buildings minimizing any weather issues. The tray stripper is usually the best choice for treating 10 gpm to 300 gpm, especially for sites in colder climates or sites with potential fouling issues and/or needing emissions treatment.

Packed Tower: Water flows from the top of a 15 to 35 foot high tower downward though plastic packing material while air is sent up from the bottom of the tower. The tower packing is susceptible to fouling, especially when influent iron concentrations are above 5 mg/l, and may need regular acid washing, cleaning with peroxide or biocide, and periodic packing changeouts. Stripping efficiencies >99% can easily be achieved and maintained with proper maintenance. The packed tower can be effective for flows from 1 gpm to 5000+ gpm. Capturing emissions from a packed tower is relatively expensive and can lessen stripping effectiveness. The packed tower is usually the best choice for treating >500 gpm and may be chosen for lower flow rates if fouling is minimal.

Common VOCs with Low Air Stripping Efficiencies

Acetone
Naphthalene
2-Butanone (MEK)
t-butyl alcohol (TBA)
1,2-Dichloroethane
MIBK
MTBE
Tetrachloroethane (1,1,1,2 or 1,1,2,2)
1,1,2-Trichloroethane

Solid Phase Partitioning

Option 1: Granular Activated Carbon

In this approach, ground water contaminants are removed by adsorption to GAC. Two units are generally placed in series with regular sampling (perhaps monthly or quarterly) after the first unit to determine when that unit has reached its chemical loading capacity (i.e., when chemical breakthrough occurs). Any contamination that breaks through the first unit in between sampling events is adsorbed in the second unit. When breakthrough of the first vessel is detected, the carbon in the first vessel is changed out and the vessel configuration is changed so that the previous "backup" unit is now used as the lead unit. Many VOCs, SVOCs, and non-volatile organics are readily adsorbed by GAC while others, such as MTBE, TBA, and ketones, are not. The carbon usage depends on the contaminant characteristics and concentrations, (see Exhibit 5) as well as other constituents in the water that may compete for active sorption sites. Estimating usage and sizing vessels can be accomplished with vendor software.

The cost for GAC typically ranges from $1 to $3 per pound for a complete change out, though unit costs may be higher for smaller change outs. Used GAC is usually taken off-site for regeneration so that the GAC can be used again. In some circumstances, used GAC may be disposed of in a landfill. In either case, the $1 to $3 per pound estimate noted above includes the disposal or regeneration costs.

GAC is prone to biological or mineral fouling if process water is not properly filtered or pre-treated. Regularly backwashing the GAC can help alleviate this fouling. If GAC fouls it may need replacement before it has reached its capacity for contaminant removal. In many cases, early replacement is not cost-effective; however, in some limited cases, it may be more cost-effective to increase the replacement frequency than it is to provide pretreatment.

Appendix A presents an illustrative example with a cost analysis for selecting GAC as a treatment technology for VOCs.

Option 2: Polymeric Resin

This technology works in a similar fashion to GAC and can be adapted for on-site regeneration. At high concentrations, the on-site regeneration may make this technology more cost-effective than GAC. Some polymers may also be more effective for some contaminants that are not easily adsorbed by GAC, such as 1,2-dichloroethane, methylene chloride, and ketones. Polymeric resins are engineered for specific chemical characteristics, and resins are available for a variety of contaminants.

Contaminant Destruction

Option 1: UV/Oxidation and Ozonation

This technology destroys organic contaminants by oxidizing them. Therefore, when comparing costs of this technology to that of air stripping, the treatment of air stripping off-gas treatment associated with air off-gas associated with the air stripping should be included. UV/Oxidation is more prevalent than ozonation. Because other constituents can compete for oxidants, obscure the UV light source, or otherwise foul the reaction chamber, pre-treatment and filtering is often needed, more so than for other technologies. Frequent cleaning or replacement of a UV/oxidation system or its components is generally not a potential alternative to pre-treatment, as it is for air stripping or GAC.

UV/Oxidation can be used for a variety of organic compounds, including some that are not easily removed by air strippers or GAC, such as 1,4-Dioxane. Treatment efficiencies can be as high as 99%, but are much lower for some constituents.

O&M costs can be relatively high due to replacement parts (lamps, seals, and other parts), high concentration hydrogen peroxide, and electricity needed to power the lamps (often 30 kW). Utilities and maintenance items alone may cost over $50,000 per year. Appendix A presents an illustrative example with a cost analysis for considering UV/oxidation as a treatment technology for VOCs.

Option 2: Bioreactors

Bioreactors utilize microbes to degrade organic contaminants and consist of a fixed-film media (such as sand or activated carbon) within a tank or canister. The organic contaminants serve as nutrients to the microbes, and the fixed media provides a surface where the contaminants accumulate and the microbes can grow. By accumulating contaminants near the microbes, the fixed media allows bioreactors to function at lower contaminant concentrations than

Exhibit 5

Sample Method for Calculating Preliminary GAC Design Estimates

There are two values that are typically used to determine the practicality and cost-effectiveness of GAC: the GAC usage and the size of the GAC units. Both of these can best be estimated by a GAC vendor, but the following calculations allow for a rough estimate of both values for a single chemical constituent in the process water. The estimated total GAC usage and GAC unit size is the sum of the usage and unit size for each constituent.

GAC usage for organic compounds is both chemical and concentration dependent and can be estimated using a Freundlich isotherm as follows:

1. Calculate the ratio of pounds of each contaminant to pounds of GAC needed, *R*, given the design influent concentration.

$$R = \frac{1}{1000} \times K \times C^{1/N}$$

where

K = is a tabulated partitioning coefficient (see below) with units $(\mathrm{mg/g})(\mathrm{L/mg})^{1/N}$
$1/N$ = a tabulated dimensionless parameter (see below)
C = design influent concentration with units mg/L

2. Calculate the GAC usage rate (*GUR*) in pounds per day for each contaminant based on design mass removal rate.

$$GUR = \frac{MRR}{R}$$

where

MRR = the mass removal rate (see Exhibit 2) with units pounds/day
R = ratio of pounds of each contaminant to pounds of GAC needed (no units)

Sizing a GAC unit should account for empty bed contact time (EBCT) between the process water and the GAC as well as a convenient GAC changeout schedule. The EBCT should generally be between 15 and 30 minutes per vessel. The approximate vessel size in “pounds of GAC” can then be calculated as follows:

$$\text{Vessel Size} = EBCT \times \text{Hydraulic Capacity} \times \frac{1\text{ft}^3}{7.48\text{gal}} \times \frac{30\text{lbs of GAC}}{\text{ft}^3}$$

where the hydraulic capacity is provided in gpm.

Ideally, the vessel should be sized to allow changeouts to occur on a quarterly or semi-annual basis when other site activities are conducted.

The (K) and (1/N) parameters for some common compounds are provided below.

Contaminant	**Toluene**	**Chlorobenzene**	**Lindane**	**PCE**	**TCE**	**Methylene Chloride**
K $(\mathrm{mg/g})(\mathrm{L/mg})^{1/N}$	100	100	285	51	28	1.3
$1/N$	0.45	0.35	0.43	0.56	0.62	1.16

Parameters from Dobbs and Cohen, 1980 (EPA-600/8-80-023).

See Appendix A for an example calculation of GAC usage and vessel sizing.

Bioreactors may be sensitive to oxygen concentrations and may be difficult to start up. They may be most appropriate for some organic contaminants that need treatment but are not easily stripped or adsorbed to GAC, such as ketones, and for some inorganic contaminants, such as perchlorate, nitrate, or ammonia. Systems capable of treating up to several hundred gpm are readily available. Solids generated from microbial biomass are generated during operation and need proper disposal. As with UV/Oxidation and ozonation, bioreactors typically become less cost-effective as contaminant concentrations decrease over time. The cost-effectiveness should be periodically evaluated against GAC and other alternatives.

Inorganics in Ground Water

Removal of inorganics in ground water, primarily metals, is generally achieved by some combination of metals precipitation, settling, and filtering or by ion exchange. In some cases, filtering media may be enhanced by activated alumina or carbon to adsorb metals. In limited cases, reverse osmosis (a form of filtering) can be used, but due to the high potential for fouling, other technologies are generally more cost-effective. Exhibit 3 provides general advantages and disadvantages for common metals removal approaches.

Metals in ground water may be dissolved in the water or sorbed to suspended particles, including colloids and larger particles. The removal of dissolved metals generally is performed with chemical precipitation, whereas removal of metals that are sorbed to particles might be achieved through filtration alone.

With the exception of filtration alone, metals removal is typically expensive, both in terms of capital and annual costs, relative to the technologies for other contaminants of concern. Therefore, installation and long-term operation of metals removal systems should be avoided, when possible. If filtering alone does not provide sufficient metals removal during treatability tests, site teams should thoroughly consider alternate discharge options, pumping locations, and even alternative remedial strategies not using ground water extraction prior to installing a permanent metals removal system with a high expected mass removal rate (> 10 pounds per day of dry solids).

Metals removal is often not needed for ground water remediation but is needed to preserve other treatment processes or to meet discharge standards. Iron, for example, may be present in ground water at sufficient concentrations to foul a UV/oxidation system, an air stripper, or GAC, or may simply exceed the discharge standards. In such instances, cost-effective alternatives to metals removal may include adding sequestering agents to keep the metals in solution, increasing maintenance and cleaning of other treatment processes, or utilizing other discharge options.

Metals removal, at least in the short term, is generally unavoidable when the constituents of concern are metals or when the design influent concentrations for iron or other nuisance constituents exceed 15 mg/L or mass loading exceeds 10 pounds per day of dry solids, respectively.

Aquifer conditions change once pumping begins. As a result, metals removal may appear necessary based on initial data but may only be needed for the short-term (i.e., less than a year) or not at all. For this reason, the need for a permanent metals removal system should be thoroughly evaluated prior to installation. Leasing of a system over several months may be more cost-effective than installing a system, operating it, and heating the large space used to house it over the long-term. In addition, leasing the system may allow various approaches for metals removal to be pilot tested under site-specific conditions.

Exhibit 6 presents a potential framework for evaluating the need for metals removal system. In addition, Appendix A presents an example of how high metals concentrations at a hypothetical site may be addressed during design.

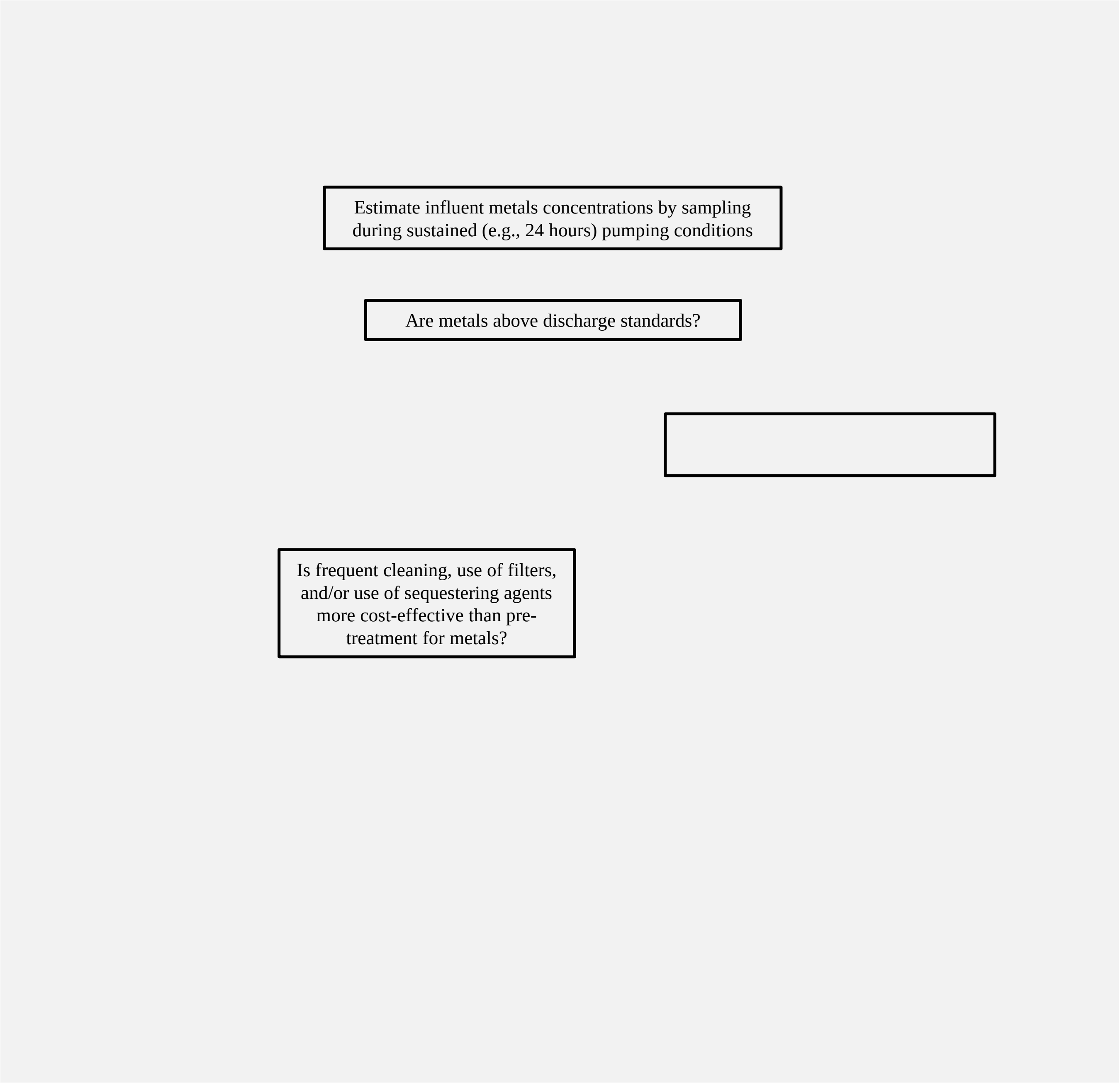
Filtration/Reverse Osmosis

Filtration of process water can be used for pre-treatment to remove suspended particles, after metals precipitation/settling to remove precipitated particles that have not settled, or near the end of the treatment process to prevent injection wells from fouling due to solids loading.

If a clarifier or settling tank is included in a treatment plant, filters comprised of sand, anthracite, and some other media can be used. These filters can be backwashed rather than replaced. Backwashing can be automated, based on the pressure differential across the media, and some continuously backwashing units are also available. Rebedding of the media is likely needed periodically (on the order of years). The backwash, with particulates, is directed to the clarifier for settling and eventual removal as sludge, which then needs proper disposal.

Cartridge or bag filters with disposable media can be used to remove particulates of 100 microns down to <1 micron. During regular operation, bag filters become increasingly clogged with particulates and need

Exhibit 6


Estimate influent metals concentrations by sampling during sustained (e.g., 24 hours) pumping conditions
Are metals above discharge standards?
Is frequent cleaning, use of filters, and/or use of sequestering agents more cost-effective than pre-treatment for metals?

per day. In most ground water applications, a lamella (inclined-plate) clarifier is used to minimize space needs, and filtration is generally performed after the clarifier.

Precipitation/clarification and associated maintenance need regular operator monitoring. Because metals precipitation results in the generation of solids, additional operator labor may be needed for sludge handling. Therefore, operator labor is a large cost driver for metals precipitation systems. The disposal of solids, particularly if they are considered hazardous, will also contribute to the cost of the remedy. Sludge dewatering is often conducted with a filter press to reduce the amount of sludge needing disposal. In many cases, the concentration of metals in the influent is overestimated, and the filter presses are used infrequently. In such cases, it may not be cost-effective to purchase, operate, and maintain a filter press. If sludge generation is likely, consideration should be given to using engineered sludge drying beds or potentially disposing of sludge in liquid form.

Solid Phase Partitioning/Ion Exchange

Activated alumina, activated carbon, and other media may be used for solids filtering and will also provide some adsorption of metals and other inorganics. Using adsorption alone is potentially applicable for treating water that does not need 90+% removal of a specific compound.

With ion exchange, the ground water contaminant is removed by passing ground water through a canister containing a resin. This resin adsorbs a higher valent inorganic by exchanging it for a lower valent one (sodium is used in many home systems). The resin needs periodic regeneration (generally done off-site) based on the contaminant mass removed. Compared to metals precipitation systems, these units can operate unattended and need little maintenance. However, periodic regeneration can be costly if the mass removal rate is high. The resin can also foul if solids are present and not sufficiently filtered. In general, these units are preferable to metals precipitation for hexavalent chromium or other metals with relatively clean water (low suspended solids). Ion exchange can also be effective for non-metal inorganics, such as perchlorate.

Off-Gas Treatment

Treatment of off-gas from a P&T system may be needed due to regulatory requirements or a preference for not transferring contamination from ground water to the atmosphere. The technologies in this category can be used to effectively treat off-gas from air strippers or other systems. Selection is dependent on the analysis of life-cycle costs. When comparing the costs of air stripping with other technologies, the cost of off-gas treatment should be included.

Granular Activated Carbon

GAC also adsorbs the volatile organics present in off-gas, though it should be noted that GAC units designed for water treatment are not interchangeable with GAC units designed for vapor or off-gas treatment. The GAC usage rate can be estimated using software programs available from vendors. GAC usage is usually much more favorable for vapor phase treatment with GAC than it is for liquid phase treatment with GAC. In general, a given mass of GAC adsorbs 4-10 times more contaminant mass in the vapor phase than in the liquid phase. Depending on the amount of GAC use projected, it may be regenerated on-site or off-site. A reasonably accurate estimate of contaminant mass loading (see Exhibit 2) should be used for determining carbon usage and the best option for regeneration.

Off-site Regeneration/Disposal: This is the most common method of GAC regeneration. Capital costs for installation are relatively low, involving only the carbon container and duct work (on the order of $10,000 for mid-size units). This technology is generally preferred at long-term carbon usage rates up to 200 pounds per day or more. GAC replacement costs (including regeneration or disposal) may range from $1 to $5 per pound.

On-Site Regeneration: This technology includes a capital investment of at least $150,000, as well as significant operator attention and energy costs when regeneration is needed. It may be appropriate if carbon usage is projected to be over 500 pounds per day for long-term operation and the BTU content of the off-gas is low. Given the difference in capital costs between on-site and off-site regeneration, the design mass removal rate should be carefully estimated with concentration data that are representative of pumping conditions. On-site regeneration is rarely cost-effective, especially when designers consider decreases in influent concentrations over time. Because the adsorbed contaminant is removed on-site, equipment and procedures for properly storing and disposing of the recovered product are necessary.

Polymeric Resins

This technology is similar in capital cost and operation to activated carbon with on-site regeneration. It is appropriate for treating contaminants, such as 1,2-dichloroethane, that are not readily adsorbed by carbon. When fewer regenerations are needed, the operator labor and energy costs are reduced. As with on-site regeneration of GAC, equipment and procedures for properly storing and disposing of the recovered product are necessary.

Thermal/Catalytic Oxidation

VOCs are destroyed at a temperature of 800 (catalytic) to 1500 (thermal) degrees Fahrenheit. Because contaminants are destroyed, there are no treatment residuals that need further handling or disposal. However, if chlorinated hydrocarbons are present in the treated vapors, an acid gas scrubber may be needed to meet emission standards, and equipment replacement schedules will likely be accelerated due to corrosion issues.

A small unit (e.g., for a gas station SVE system operating at 100 cubic feet per minute) costs about $50,000, but most off-gas oxidizers cost at least $500,000. Natural gas is used to supplement the contaminant vapor during operation. Few ground water treatment systems have off-gas concentrations high enough to warrant this technology, and natural gas costs may be as high as $20,000 per month. When combined with an SVE system, the technology may be cost-effective for a short term; however, as mass loading decreases, another form of off-gas treatment generally becomes more cost-effective. This technology is generally considered for short-term leasing until contaminant concentrations decrease so that a more cost-effective technology may be used.

F. DISCHARGE OPTIONS

……

The treatment system design should consider the discharge standards, which will vary based on the discharge method selected. Four common discharge methods for treated water are discussed below. The discussion includes how each option may impact the design.

Surface Water/Storm Sewer (NPDES)

Under the National Pollution Discharge Elimination System (NPDES), treated water may potentially be discharged directly to a nearby surface water body or indirectly through a storm sewer.

Potential Advantages

- Discharge typically is not subject to a flow-based fee, but some storm sewer systems will.

Potential Disadvantages

- Discharge standards are based on ambient water quality and may be comparable or more stringent than drinking water standards. Reporting may also be more rigorous than other discharge options.
- Natural constituents in ground water may need to be removed before treated water is discharged.
- Environmental toxicity testing may be needed.
- Access to a nearby surface water body or storm sewer is needed.

Cost Information

- Piping effluent from the treatment system to a surface water body or storm sewer is needed.
- This discharge option is preferable in many cases and is commonly selected. It is usually significantly more cost-effective than POTW discharge for high flows.
- Monthly sampling of influent and effluent for many parameters is typically needed.

Publicly Owned Treatment Works (POTW)

Extracted water is discharged to the POTW, where it is treated prior to discharge to a surface water body. In some cases, discharge can occur with no other treatment needed. Appendix B presents an example with considerations for selecting either surface water or a POTW for discharge.

Potential Advantages

- This option often has less stringent discharge standards and monitoring requirements, especially for organics. Generally, municipalities use a discharge limit of 2.13 mg/L for total toxic organics, which is a higher concentration than the influent to many P&T systems.
- Ketones and ammonia, which are difficult to treat with P&T systems, are easily treated by POTWs.
- The POTW provides a secondary treatment for some constituents to prevent (except in extreme cases) damage to surface water receptors.

Potential Disadvantages

- If the POTW is near capacity, it may not accept treated ground water discharge.
- In certain areas where ground water is the sole source of drinking water, reinjection of treated water may be necessary.
- The POTW may be reluctant to accept water that has certain constituents or is relatively "clean" compared to typical sewer water.

Cost Information

- Capital expenditures involve piping discharge to a sanitary sewer connection point.
- The POTW typically charges \$0.003 to \$0.03 per gallon (2003 dollars). Discharge to the POTW, if available, may be a good option for low (<30 gpm) flows and in situations where meeting discharge to surface water criteria is difficult and/or expensive.
- Regular sampling of constituents may be needed, but the frequency may be reduced (to quarterly or semi-annually) once the P&T system has been proven reliable, and conditions are stable.

Reinjection

Treated water is reinjected to the subsurface through wells, galleries, or basins.

Potential Advantages

- Discharge standards are typically similar to drinking water standards, but for some constituents, such as ammonia, standards may be more relaxed than those for discharging to surface water.
- Unlike discharge to surface water, there generally are not requirements to remove some natural ground water constituents prior to reinjection.
- Reinjection can be used for assisting hydraulic containment or flushing of a contaminant source. In these situations, the effects of reinjection should be considered in the extraction system design.
- Reinjection of treated water helps conserve ground water as a natural resource, which is particularly beneficial in areas where ground water serves as a sole source for drinking water or where dewatering is a concern.

Potential Disadvantages

- Reinjection into the heart of the plume may compromise plume capture by spreading the plume. Additional hydrogeological analysis (perhaps including modeling) may be necessary in designing the extraction/injection systems.
- Reinjection systems may need more maintenance than other discharge options, especially due to solids or biological fouling.

Cost Information

Reinjection systems typically involve greater capital expenses than other discharge methods, unless other discharge locations are unusually distant. Therefore, reinjection may be selected for discharge if the distance to other discharge points is excessive or if discharge back to the aquifer is necessary to meet system goals.

Reinjection systems may need frequent cleaning and maintenance because they are prone to fouling by solids, iron, biological growth, and calcium carbonate.

Reuse

Treated water is reused at an active industrial facility or is used for irrigation or potable water supply.

Potential Advantages

- Reuse of treated water reduces or eliminates the need for a facility or organization to use water from other sources, thereby conserving water as a natural resource.
- Reuse of treated water may also eliminate costs associated with discharging the water and the costs of using water from other sources.

Potential Disadvantages

- For use in irrigation or drinking water supply, specific Federal and State regulations may be applicable, or relevant and appropriate. Additional testing relative to other discharge options may be needed.
- Additional system conservatism (e.g., an additional GAC vessel) may be desired compared to treatment systems without direct discharge to human receptors.
- Reusing water in industrial processes may involve additional treatment relative to discharging the water elsewhere. Reused water should be treated

to meet the facility standards and any downstream discharge standards. Treating to facility standards may be more costly than discharging to another location and using public water at the facility.

- Facilities may only operate on a part-time basis, and the P&T system may need to operate continuously. If continuous extraction and batch treatment during facility hours is not available, reuse may not be feasible.
- A backup discharge point should be available in case the needs of the facility change.
- Contaminants that are undetected using current analytical techniques or contaminants that are present as tentatively identified compounds (TICs) may not be removed by treatment, causing a potential risk to end users of the water.

Cost Information

- Cost information is facility and site dependent.

G. CONTROLS/REDUNDANCY/FAILSAFES

....

An effective P&T system should have the following characteristics:

- down time of <5%
- no releases of untreated water to the environment
- appropriate automation of system controls so that minimum operator time is needed without excessive capital expense

However, unlike a municipal waste water treatment system, ground water moves relatively slowly, and a P&T system typically can be stopped temporarily without adversely affecting human health or the environment. The amount of time that a P&T system can be non-operational due to maintenance or other issues depends on the natural ground water flow and other site-specific factors that can be addressed through hydrogeological analysis that potentially includes ground water flow modeling.

Exhibit 7 provides typical labor needs for different types of treatment systems. The amount of labor is indicative of the degree of failsafes, alarms, and automation involved. For some systems, sufficient maintenance and supervision is needed full-time. However, 24-hour attention is rarely, if ever, necessary.

Exhibit 7

General Guidelines for Labor Typically Needed 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	• weekly checks by local operator (8-12 hours/week) • quarterly checks by engineer
• filtration • UV/Oxidation • GAC	• weekly or semi-weekly checks by local operator (8-16 hours/week) • quarterly checks by engineer
• metals removal • filtration	• one full-time operator (1× 40 hours/week)
• metals removal • filtration ***and one or more of the following*** • air stripping • GAC • biotreatment • UV/oxidation	• one full-time operator with potential for part time assistance (40 - 60 hours/week)

Redundant and Spare Equipment

Process pumps, blowers, and filters that are continually in use and key to system operation should have redundant units piped in parallel to allow servicing without downtime. These devices are typically a small percentage of the treatment system's cost, and a redundant unit is worthwhile to avoid system downtime. It is not typically worthwhile to have redundant or spare treatment units that do not have active mechanical/electrical parts. For example, redundant units are not needed for tray air strippers (excluding the blower), equalization or reaction tanks, and clarifiers. Also, redundancy is not appropriate for units that are used infrequently (e.g., most sludge handling systems) and units that are a high percentage of a system's cost (e.g., UV/Oxidation system). It is also not typically worthwhile to have a redundant power supply for a P&T system, given that power outages are typically limited to less than 24 hours. It is worthwhile to install appropriate surge protection and, depending on the system location, a lightning arrestor to limit damage from line surges and lightning strikes.

Spares for key mechanical and electrical equipment that have a specific service life or operate in harsh environments (e.g., UV/Oxidation system lamps, transducers, double diaphragm pump diaphragms, submersible pumps, small GAC units) should be kept at the treatment system and replaced by the system operator as necessary.

Failsafes/Alarms

P&T systems should have alarms for any parameter value that is outside of the typical operating range. These alarms should interface with the system controls to prevent a release of untreated water or any other problem from occurring by shutting down system components or the entire system as appropriate. The following are typical parameters for which failsafe alarms are installed:

- high tank levels
- high differential pressure across a filter
- high or low air stripper blower air pressure
- well vault or building sump water accumulation
- low water flow in the treatment system
- other system specific items

Providing these failsafes and alarms should allow operator attention to be reduced and protectiveness to be maintained cost-effectively.

Automation/Remote Monitoring

Except for the simplest systems (e.g., liquid GAC, oil/water separator, filtration), an unmanned P&T system should have an autodialer to inform the system operator of an alarm condition. In many cases, remote monitoring of the system is worthwhile to reduce operator labor. There is a wide array of remote capabilities available depending on the price, such as the ability to view the water levels in wells or tanks, check on alarm status, start and stop motors, and open and close valves remotely. The degree of automation appropriate for a specific site should be based on the amount of operator labor time and expense (including travel) that is saved by the automation capabilities (with equivalent protectiveness) for the expected life of the system.

H. OTHER DESIGN CONSIDERATIONS

....

Other factors that may affect the construction and operation of a P&T system are described below. However, these factors generally do not affect the selection or sizing of treatment components.

Climate

Sites in colder climates may be exposed to freezing temperatures. Most treatment components are housed in a climate-controlled building, but some components, such as tanks, well heads, and some piping may be left exposed. Proper insulation and heating should be considered to reduce the potential for upsets and additional maintenance in the future.

Community Issues

The surrounding community may also affect long-term operation of the system. Appropriate consideration of noise and potential emissions or odors will reduce the impact of the system on the surrounding community and facilitate community relations. Appropriate security measures will reduce the potential for vandalism, which can lead to system upsets and additional costs during O&M. However, excessive security can add substantially to annual O&M costs.

Remoteness

For sites that are fairly remote, designers might consider additional automation or remote telemetry capabilities to minimize the need for operator visits and the associated expense. Designers might also include additional system redundancies that allow the system to keep running until the operator can visit the site.

I. POST-CONSTRUCTION

....

Although design and construction of a P&T system marks a significant milestone in remedy implementation, it typically does not represent the end of the cleanup process. The post-construction period generally involves operation, maintenance, and monitoring that may last decades or indefinitely. Therefore, the success of a P&T remedy is not based only on the design and construction of the system. Because operating a remedy inherently changes the site conditions (i.e., changes ground water flow patterns and removes mass), O&M should be a dynamic process and should include periodic optimization evaluations.

A discussion of O&M and optimization of the O&M is beyond the scope of this document, but the reader is referred to other fact sheets in this series, which are available at the www.cluin.org/optimization website.

Elements for Effective Management of Operating Pump and Treat Systems, December 2002
(EPA 542-R-02-009, OSWER 9355.4-27FS-A)

Effective Contracting Approaches for Operating Pump and Treat Systems, April 2005 (EPA 542-R-05-009, OSWER 9283.1-21FS)

O&M Report Template for Ground Water Remedies (with Emphasis on Pump and Treat Systems), April 2005 (EPA 542-R-05-010, OSWER 9283.1-22FS)

For further information on topics covered in this document and for access to a broader spectrum of EPA documents, the reader is directed to www.cluin.org.

J. CITED REFERENCES

....

Dobbs, R.A. and J.M. Cohen, *Carbon Adsorption Isotherms for Toxic Organics*, EPA 600/8-80-023, April 1980.

Newell, C.J. and R.R. Ross, *Estimating Potential for Occurrence of DNAPL at Superfund Sites*. EPA 9355.4-07FS, January 1992.

APPENDICES

ADDITIONAL ILLUSTRATIVE EXAMPLES

....

Two examples are provided to illustrate design considerations for a cost-effective P&T system. Hypothetical sites and conditions are used. Approximate costs are provided for the purposes of the example. Although the costs are reasonable based on 2003 dollars, they are estimates for illustrative purposes only, and do not reflect rigorous pricing through vendors. The site conditions are typical of what may be found at a particular site, but the description is simplified so that the design aspects discussed in this document can be effectively and clearly illustrated.

Appendix A (Page 1 of 3)

Sample: Design Considerations for TCE Treatment at a Hypothetical Site with High Iron Concentrations

Remedy Goal and Strategy:

- hydraulic containment at site property boundary and eventual cleanup of site ground water to MCLs
- control source area with pumping to allow other wells to restore remainder of the property to MCLs

Remedial Investigation Results: The TCE source area, a former lagoon, is 200 feet upgradient from the property line. The maximum TCE concentration in a source area well is 50,000 ug/L. Monitoring well data from locations outside of the source area have TCE concentrations of 5,000 ug/L. TCE breakdown products are present at levels <500 ug/L and iron concentrations average 15 mg/L.

Extraction System Parameters: Ground water modeling indicates that one well pumping with an extraction rate of 10 gpm is sufficient to control the source area (i.e., monitoring data shows TCE concentrations of 50,000 ug/L). Two downgradient wells, each pumping 25 gpm are likely to be needed to provide containment at the property line and mass removal (i.e., monitoring data shows TCE concentrations of 5,000 ug/L).

Design Considerations:

- The TCE and iron concentrations are extremely high for a relatively transmissive aquifer. Extraction wells should be installed and pumping tests conducted to better estimate influent concentrations prior to selection of the treatment technology. It is very likely that influent iron and TCE concentrations will decrease under sustained pumping.
- Air stripping with off-gas treatment, GAC, and UV/oxidation are the competing technologies for TCE. At this flow rate a tray aerator air stripper could be used, which is easier to clean than a packed tower. UV/oxidation will very likely need pretreatment if the influent iron concentration is above 1 mg/L. GAC will also have a tendency to foul. The tray aerator may perform well with a frequent, but reasonable cleaning schedule.
- Both reinjection and surface water are potential discharge options. Discharge to surface water may be contingent on an iron concentration below a specified standard (e.g., 600 ug/L). Fouling would be a concern for reinjection through reinjection wells, but can be easily addressed with an infiltration gallery.
- During the pumping tests half of the produced water should be treated with a leased tray aerator and the other half should be treated with GAC to determine how much impact iron fouling will have on each technology if a metals precipitation system is not installed.

Pumping Test Results:

- Iron concentrations during 24-hour pump tests drop to below 5 mg/L. Further decreases are expected with long-term sustained pumping, but iron concentrations at 5 mg/L may need pre-treatment for any of the technologies considered for VOC treatment.
- TCE concentrations in source area well decreases to 20,000 ug/L during pumping. TCE concentrations in the downgradient locations drop to 2,500 ug/L. Further decreases will likely occur during long-term sustained pumping. 1,2-DCE (TCE breakdown product) concentrations decreased during pumping to less than 100 ug/L.

Appendix A (Page 2 of 3)

Sample: Design Considerations for TCE Treatment at a Hypothetical Site with High Iron Concentrations
(continued)

Design Parameters:

Design flow rate: 60 gpm
Hydraulic capacity: 120 gpm (assuming a factor of safety of 2.0)
Design TCE influent concentration (weighted average from pump test data): ~5,500 ug/L
Maximum TCE influent concentration: 11,000 ug/L (assuming a factor of safety of 2.0)
Design mass removal rate: 3.96 pounds per day (see Exhibit 2)
TCE discharge criteria: 5 ug/L (for discharge to surface water or reinjection)
Iron discharge criteria: 600 ug/L for discharge to surface water
Iron discharge critera: “none” for reinjection

Technology Evaluation:

Capital costs for the potential VOC treatment systems (air stripping with off-gas treatment, and UV/oxidation) are all comparable and are low relative to O&M over 10 or more years. The costs of each remedy are similar with the exception of utilities and consumables.

Air Stripping Costs: A tray aerator with a 10 HP blower will remove the TCE to MCLs. The blower has a motor efficiency of ~75%, and electricity cost per kilowatt-hour (KWh) is $0.10. Carbon vendor for off-gas treatment reports carbon adsorbs 8.9% TCE by weight at a cost of $2.50 per pound.

$$\textit{Power Cost} = 10HP \times \frac{0.75KW}{HP} \times \frac{1}{75\%\ \textit{efficiency}} \times \frac{24h}{day} \times \frac{365days}{year} \times \frac{\$0.10}{KWh} = \frac{\$8{,}760}{year}$$

$$\textit{Off - gas Cost} = \frac{3.96\ lbs\ TCE}{day} \times \frac{100\ lbs\ carbon}{8.9\ lbs\ TCE} \times \frac{365days}{year} \times \frac{\$2.50}{lb\ carbon} = \frac{\$40{,}600}{year}$$

$$\textit{Total Comparison Cost} = \frac{\$8{,}760}{year} + \frac{\$40{,}600}{year} = \frac{\$49{,}360}{year}$$

GAC Costs: The parameters for calculating GAC usage based on chemical loading are provided in Exhibit 5. Iron fouling, however, may result in more frequent replacement of GAC and therefore a higher usage rate. Costs for GAC to treat dissolved contamination are assumed at $2 per pound. Ratio of pounds of TCE to pounds of GAC needed (*R*)

$$R = \frac{1kg}{1000g} \times \frac{28g\ TCE}{kg\ GAC}\left(\frac{L}{mg}\right)^{0.62} \times \left(\frac{5.5mg}{L}\right)^{0.62} = \frac{8.06kg\ TCE}{100kg\ GAC} = \frac{8.06lbs\ TCE}{100lbs\ GAC}$$

GAC Usage Rate (*GUR*)

$$GUR = \frac{3.96\ lbs\ TCE}{day} \times \frac{365days}{year} \times \frac{100\ lbs\ GAC}{8.06\ lbs\ TCE} = \frac{17{,}933\ lbs\ GAC}{year}$$

Appendix A (Page 3 of 3)

Sample: Design Considerations for TCE Treatment at a Hypothetical Site with High Iron Concentrations
(continued)

UV/Oxidation Costs: A system with (2) 30 KW lamps could likely treat the influent to MCLs. In addition to the power, lamp replacements and seals will cost about $15,000/yr and hydrogen peroxide about $25,000/yr.

$$\textit{Power Cost} = 60\,KW \times \frac{24h}{day} \times \frac{365days}{year} \times \frac{\$0.10}{KWh} = \frac{\$52{,}560}{year}$$

$$\textit{Total Comparison Cost} = \frac{\$52{,}560}{year} + \frac{\$15{,}000}{year} + \frac{\$25{,}000}{year} = \frac{\$92{,}560}{year}$$

Polymer resin adsorption systems generally would become competitive if the flow rate and/or VOC concentrations were higher so that consumable costs exceed $200,000/yr, but it would be worth verifying this status with vendors.

Recommendations:

- GAC offers the cheapest annual cost for TCE treatment at this site. Air stripping is a 37% increase in cost ($14,000/yr more), and UV/oxidation is a 158% increase in cost ($57,000/yr more).
- Iron removal will likely be needed for any of these three remedies with an estimated iron influent concentration of 5 mg/L, for an additional cost of at least $150,000/yr in labor and materials. However, if the iron influent decreases to 3 mg/L over time, air stripping may become effective with frequent cleaning but without iron removal, whereas GAC and UV/oxidation would likely still need iron removal.
- Over time, the VOC influent concentrations will decrease. This decrease will lower consumable and utility costs for the air stripping and GAC systems by a much greater amount than it will lower UV/Oxidation system consumable and utility costs.
- Given a relatively strong possibility that iron concentrations will drop below 3 mg/L within the first year of operation, design should include air stripping with off-gas treatment and leasing of an iron removal system (metals precipitation with clarification and filtering) for several months. Iron pretreatment will occur over this time period allowing the air stripper to function. If iron levels decrease sufficiently, iron removal can be discontinued.
- If iron levels do not decrease sufficiently, the iron removal system can be purchased. Pilot studies can be conducted to determine if metals precipitation is needed or filtering is sufficient.
- While all three of the alternatives can be operated with periodic site visits, the UV/Oxidation system is more difficult to operate than the alternatives, will perpetuate metals treatment indefinitely, and is more prone to downtime (especially if there are upsets with the iron removal system).
- If additional extraction wells will improve progress to reaching site goals, they can be added as the concentrations decrease at the initial wells so that consumable costs do not increase substantially. The stripper can easily be designed to accommodate additional flow.
- Discharge should be to the reinfiltration gallery or basin so that iron removal can be discontinued even if influent iron concentrations are above 600 ug/L.
- Consider excavation or in-situ treatment of the source area.

Appendix B (Page 1 of 2)

Sample: Design Considerations for Treatment of Ketones and Constituents at a Hypothetical Site with High Iron Concentrations and the Potential for Discharge to the POTW

Remedy Goal: The goal at this landfill site is to provide hydraulic containment of the contaminated ground water at the property line.

Remedial Investigation Results:
Monitoring wells in likely extraction areas have the following contaminants and average concentrations.

Contaminant/Constituent	Concentration
Ammonia	20 mg/L
Acetone	5,000 ug/L
MEK	1,000 ug/L
MIBK	700 ug/L
Benzene	200 ug/L
Toluene	500 ug/L
1,2-DCA	300 ug/L
Iron	40 mg/L

Extraction System Parameters: Simplistic analytical modeling based on historical potentiometric surface maps and a hydraulic conductivity estimate from one pumping test suggest a total pumping rate of 45 gpm from three wells (15 gpm each) is sufficient for capture. A factor of safety of between 2.0 and 3.0 would be recommended to determine the hydraulic capacity.

Design Considerations:

- Discharge to surface water would likely need treatment of VOCs to Federal MCLs and treatment of ammonia to 1 mg/L; there is no iron concentration discharge limit. A treatment system consisting of metals precipitation, a fixed film biological treatment unit, filtration and liquid GAC at a minimum would be appropriate to treat this water to meet MCLs. Capital costs of this system including the building would exceed $1,000,000.

- Alternatively the POTW would agree to a long-term contract to take the untreated water for $0.02/gallon. The cost of this approach is heavily dependent on the design flow rate. More accurate estimates of the flow rate should be obtained. Pump tests should be conducted near each well. Investment in a numerical ground water model is worthwhile. Capital costs would be on the order of $250,000.

Pump Test Results: Interpretation of the pump test results and the development and use of a numerical model suggest that an extraction rate of 30 gpm from three wells (10 gpm each) is sufficient for capture. A factor of safety of approximately 1.5 can be used to determine the hydraulic capacity. Concentrations decreased during pumping, but not significantly.

Technology Evaluation:

POTW Discharge: Water would be pumped and discharged directly to the POTW. At 30 gpm and a discharge cost of $0.02 per gallon, the cost for discharge to the POTW is approximately $315,000/yr. Additional costs, on the order of $50,000 per year would likely be needed for maintenance, discharge monitoring, and reduced project management relative to the treatment system.

Appendix B (Page 2 of 2)

Sample: Design Considerations for Treatment of Ketones and Constituents at a Hypothetical Site with High Iron Concentrations and the Potential for Discharge to the POTW (continued)

Pump and Treat System: Water would be pumped to a treatment system and then discharged to surface water. Such a system would have the following estimated costs for O&M.

Cost Category	Estimated Annual Cost
Operator labor (two full-time employees)	$200,000/yr
Process monitoring and analytical	$30,000/yr
Chemicals and materials (including GAC)	$30,000/yr
Non-hazardous sludge disposal	$20,000/yr
Power for system and building heating	$60,000/yr
Project management and reporting	$50,000/yr
Total Estimated Annual Cost	**$390,000/yr**

Recommendations:

- The O&M for the P&T and POTW options are within 10% (the POTW option costing less). The capital cost for the POTW option is $750,000 less than the P&T option.

- The POTW cost estimate is flow dependent. If 45 gpm (rather than 30 gpm) is needed, an additional $160,000 per year would be incurred for discharging. In this "worst case scenario", the POTW option is still more cost-effective for the first five years due to the lower capital costs.

- The POTW discharge provides much greater security against problems. Contracts to discharge at the same rate for 10 or more years, without a minimum payment, are common. This would protect against inflating operating costs. No startup costs, discharge limit excursions, system downtime and other problems inherent with operating a complex treatment system would occur with POTW discharge.

- Because the landfill is a continuing source of the contaminants present, it is unlikely that the P&T system operation costs would decrease due to discontinued treatment system components. If conditions improved so that a simple treatment system (e.g., GAC only) could be installed, the POTW discharge could be discontinued.

- If, over time, conditions allow select extraction wells to discontinue pumping, the overall flow rate may decrease and the POTW option would provide greater savings. The conditions that would allow discontinuing pumping from a well (at least for a trial period) should be clearly stated ahead of time.

Lesson Learned: Had the pump tests and modeling not been conducted, the estimated design flow rate would have made the P&T option more attractive. It still may not have clearly been the best option, but many parties would have chosen it. The investment in the model and pump tests helped avoid excess capital expenditures of $750,000 and a myriad of problems that may have been encountered while running a complex water treatment system.

NOTICE:

The U.S. Environmental Protection Agency funded the preparation of this document by GeoTrans, Inc. under General Service Administration Contract GS06T02BND0723 to S&K Technologies, Inc., Bremerton, Washington; EPA Contract No. 68-C-02-092 to Dynamac Corporation, Ada, Oklahoma; and EPA Contract No. 68-W90-0065 to ICF Consulting, Inc., Fairfax, Virginia. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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

U.S. EPA NSCEP
P.O. Box 42419
Cincinnati, OH 45242-2419
Phone: (800) 490-9198 or (513) 489-8190
Fax: (513) 489-8695

United States
Environmental Protection
Agency

Office of Solid Waste and
Emergency Response

OSWER 9283.1-20FS
EPA 542-R-05-008
April 2005
www.cluin.org
www.epa.gov/superfund