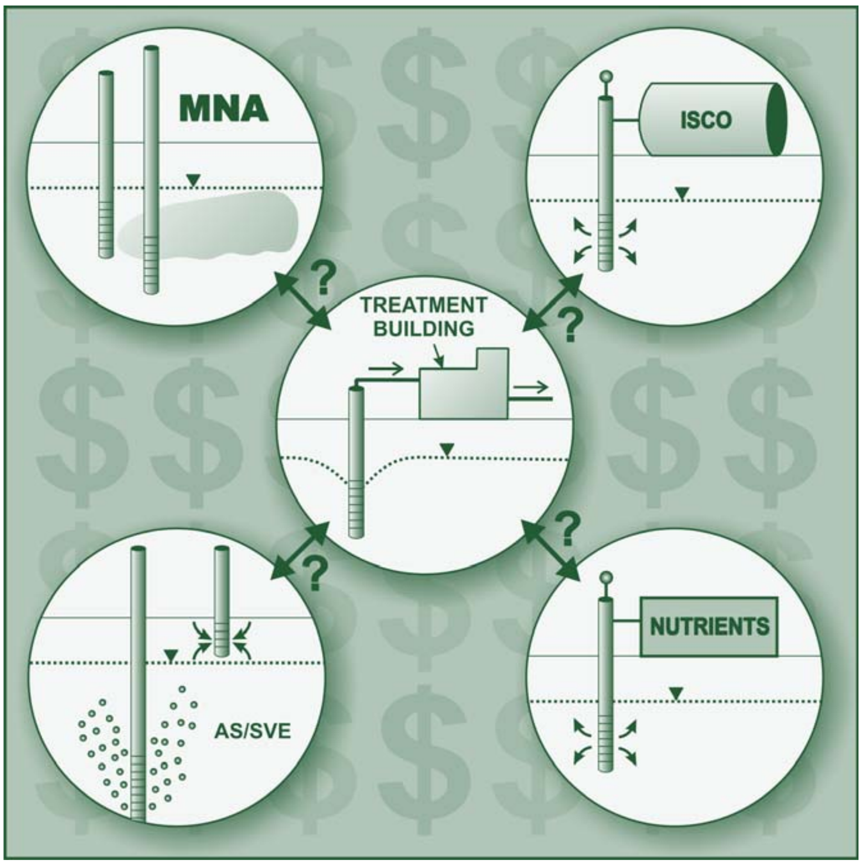
A Cost Comparison Framework for Use in Optimizing Ground Water Pump and Treat Systems



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Office of Solid Waste
and Emergency Response (5203P)

EPA 542-R-07-005
May 2007
www.cluin.org
www.epa.gov/superfund

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DISCLAIMER

This document provides references to technologies and processes in use by outside parties and other Federal Agencies. Mention of these technologies 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 information to EPA, states and others who manage or regulate long-term ground water remedies as part of any cleanup program. 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.

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PREFACE

This fact sheet discusses a framework for comparing costs of remedial alternatives or modifications in conjunction with the optimization of long-term ground water remedies, including 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 to assist the ground water remediation community to effectively and efficiently design and operate 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

- *Options for Discharging Treated Water from Pump and Treat Systems*, EPA 542-R-07-006, May 2007

- *Optimization Strategies for Long-Term Ground Water Remedies (with Particular Emphasis on Pump and Treat Systems),* EPA 542-R-07-007, May 2007

The ideas contained in this series of fact sheets are based on professional experience in designing, operating, and optimizing long-term ground water remedies and on lessons learned from conducting optimization evaluations called Remediation System Evaluations (RSEs) at sites with P&T systems. RSEs have been conducted at Superfund-financed sites, Resource Conservation and Recovery Act (RCRA) sites, and leaking underground storage tanks sites. Reports from RSEs conducted by EPA are available at www.cluin.org/optimization.

The content of these fact sheets is relevant to almost any long-term ground water remedy, particularly those that involve P&T. Therefore, these documents may serve as resources for managers, contractors, or regulators of any P&T system, regardless of the regulatory program.

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

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A. INTRODUCTION

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Federal agencies have conducted optimization evaluations at approximately 100 operating pump and treat (P&T) systems since 2000 and have successfully identified hundreds of potential opportunities for improving effectiveness in protecting human health, reducing operating costs, and speeding progress toward site closure. Each of these opportunities generally requires additional consideration from the remedy project manager. The decision to pursue a potential opportunity for cost reduction can be particularly challenging because the decision often involves consideration of a variety of financial parameters, including capital costs, life-cycle costs, payback period, and return on investment.

This fact sheet has been prepared to provide a framework for conducting cost comparisons to evaluate whether or not to pursue potential opportunities from an optimization evaluation for improving, replacing, or supplementing the P&T system. The target audience for this fact sheet includes environmental project managers from Federal and State agencies, environmental program managers from private organizations, and environmental contractors involved in the operation of long-term ground water remedies, particularly those that involve pump and treat. The cost comparison framework that is discussed in this document assumes that all of the alternatives being evaluated provide adequate protectiveness of human health and the environment. That is, the framework does not encourage the reader to weigh the value of potential cost reductions versus the protectiveness of a remedy.

This document presents the following elements that pertain to cost comparisons associated with long-term ground water remedies:

- applicability of cost comparisons as part of the optimization process
- a framework for conducting cost comparisons
- illustrative examples of applying cost comparisons for various scenarios (see Appendix A)

This document also discusses factors that affect economic decision making, such as discounting future costs to net present value, the appropriateness of pilot studies, and accounting for uncertainty.

The term operation and maintenance (O&M) is used throughout this document to describe the activities involved in operating and maintaining a P&T system. For the purpose of this document, "O&M" 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 ground water restoration 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.

B. COST COMPARISONS AS PART OF THE OPTIMIZATION PROCESS

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P&T systems are generally long-term remedies that can last several decades. Over the course of the remedy, site conditions and/or regulations may change, the site conceptual model may be refined, knowledge and science may improve, and new technologies may emerge. Optimization evaluations consider these factors in an attempt to identify opportunities to improve the remedy. When a recommendation from an optimization evaluation pertains to improving the protection of human health and the environment, it is typically a straightforward decision to implement the recommendation. However, when a recommendation from an optimization evaluation pertains to reducing cost or speeding site closure, there is generally a tradeoff between the capital costs of implementing the recommendation and the resulting reduction in annual costs and/or remedy duration. The cost comparison evaluates those tradeoffs to provide a basis for determining the best alternative.

The following scenarios for three hypothetical sites illustrate situations where a cost comparison is applicable.

> *Hypothetical Site #1*. An optimization evaluation suggests that a P&T system could have lower annual costs if the ultraviolet/oxidation (UV/OX) system used to treat organic compounds in the extracted ground water is replaced by an air stripper with granular activated carbon for off-gas treatment. However, this modification will require a capital cost to implement. The remediation timeframe will not be impacted. How does the project manager determine whether or not it is cost-effective to make the change?

> *Hypothetical Site #2*. A P&T system currently provides hydraulic containment of the leading edge of a contaminant plume and is considered to be protective of human health and the environment. However, because the P&T system will not effectively remediate the source area, P&T will likely continue indefinitely. An optimization evaluation suggests two feasible supplemental technologies to the current P&T system: 1) adding ground water extraction wells in the source area to hydraulically contain the source and increase the potential for ground water restoration downgradient of the source area; or 2) implementing an in-situ technology in the source area, which may successfully remediate the continuing source of ground water contamination, but at a high capital cost and with significant uncertainty regarding likelihood of success. How does the site manager address the trade off between the capital and additional annual costs of adding an extraction well with the high capital costs of an in-situ remedy for the source area?

> *Hypothetical Site #3*. An optimization evaluation suggests that aggressive source removal be considered in an effort to discontinue P&T in favor of monitored natural attenuation (MNA). Site characterization efforts indicate that an MNA remedy will be appropriate, based on hydrogeological and geochemical data, if the source area is successfully remediated. The aggressive source removal requires significant capital costs, but long-term O&M costs will be substantially reduced (O&M costs associated with MNA will continue to be incurred until cleanup standards are met). Additionally, the optimization evaluation suggested potential opportunities to make the operating P&T system more cost effective. The owner is planning to divest the property in the next few years, and the divestiture will be easier without an operating remedy. Does the site owner optimize the P&T system and reject aggressive source removal, or does the owner conduct the aggressive source removal and discontinue the P&T system? Alternatively, does the site manager continue operating the remedy as is?

The decision of whether or not to implement a recommendation, particularly a recommendation pertaining to cost-reduction or speeding site closure, can be difficult to make. Indecision can result in substantial delays in realizing the benefits of optimization, and hasty decisions can result in unnecessary expenditures. Assuming all of the alternatives provide adequate protection of human health and the environment, a cost comparison can be used as a tool to help project teams determine which alternative is most appropriate to implement, or if any more information (e.g., a pilot test) is needed before making a final decision or before full-scale implementation.

A cost comparison does not replace feasibility studies and data collection that would be used to determine if an alternative is protective of human health and the environment or meets other parameters of an organization. For example, Exhibit 1 provides the nine criteria for selecting a remedy at a Superfund site. These factors would also apply to implementing significant changes at a Superfund site, and cost is only one of these nine criteria.

Exhibit 2 illustrates the optimization process, and indicates at what stages a cost comparison is appropriate. Note that a cost comparison is generally conducted before a project team decides to conduct a pilot test. Although a pilot test may provide helpful information for estimating the costs of full-scale implementation, it is generally preferable to know whether or not full-scale implementation will likely be cost-effective based on the range of possible costs estimated prior to performing a pilot test.

Exhibit 1

The Nine Criteria for Remedial Alternatives Evaluation in Superfund
• overall protection of human health and the environment
• compliance with applicable or relevant and appropriate requirements
• long-term effectiveness and performance
• reduction of toxicity, mobility, or volume through treatment
• short-term effectiveness
• implementability
• cost
• state agency acceptance
• community acceptance

C. COST COMPARISON FRAMEWORK

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This section presents a framework for conducting a cost comparison for supplementing, improving, or otherwise modifying an operating P&T system with the intent of reducing cost. The framework considers various financial parameters, including upfront costs, life-cycle costs expressed in net present value, payback periods, and annual percentage return. The framework allows for comparison of the existing P&T system to an optimized form of that P&T system or to other appropriate remedial alternatives.

The five steps are listed below and are discussed in more detail in the remainder of this document. In addition, Appendix A of this document presents three illustrative examples that demonstrate use of the framework.

Step 1: Gather Background Information

1a. *Existing P&T System* – Organize routine annual O&M costs and non-routine costs associated with continuing to operate the current P&T system or a modified version of the P&T system that incorporates changes needed for the remedy to be protective.

1b. *Optimized P&T System* – Consider potential improvements to the P&T system effectiveness and efficiency (e.g., recommendations from an optimization evaluation) and estimate the capital costs for implementing the recommendations, the routine annual O&M costs, and the non-routine costs associated with operating the optimized system.

1c. *New Remedial Approach* – Estimate the value of the costs for a full-scale application of a new approach and/or alternate technology under consideration (either in place of P&T or in addition to P&T), including implementation, routine annual O&M, and non-routine costs.

Step 2: Estimate Life-Cycle Costs

2a. Use the information from Step 1 to document costs for each year of operation for the existing system, optimized system, and new remedial approach.

2b. Apply an appropriate discount rate to the yearly and life-cycle costs for the existing system, optimized system, and alternative remedial approach to obtain their net present value (NPV).

Step 3: Compare Costs of Each Option

Compare various financial parameters for each option, including upfront capital costs, life-cycle costs, payback period, and annual percentage return.

Step 4: Determine the Need for Additional Information

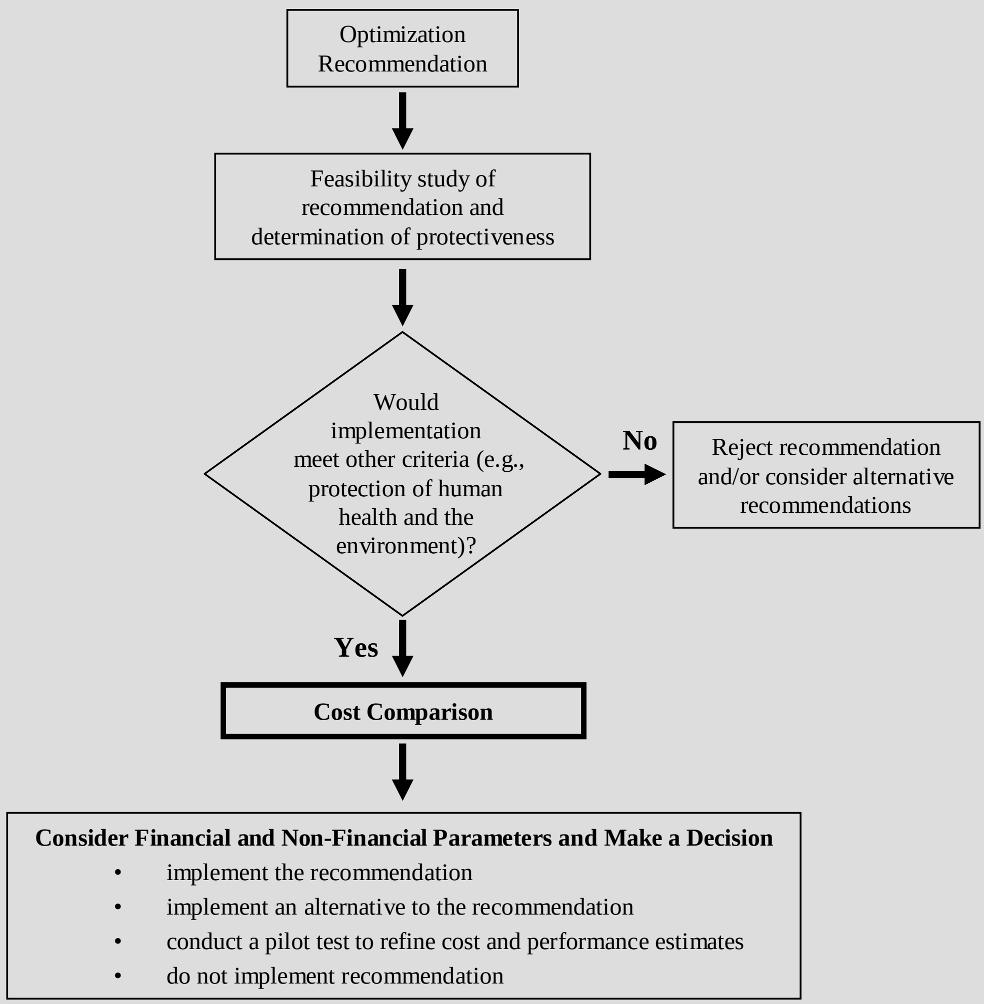
Identify information that, if available, could significantly change the outcome of the analysis, and then estimate the costs of obtaining this information.

Step 5: Make and Document Decisions

Document any decisions about which alternative to implement, and the rationale for those decisions, based on the results of Steps 1 through 4 as well as any other information that was not otherwise quantified as part of the cost comparison.

Exhibit 2

The Optimization Process and the Role of the Cost Comparison



Possible decisions that the cost comparison helps to make include the following:

- continue with the existing P&T system
- continue with a modified P&T system where optimization recommendations are implemented to lower costs and/or reduce system duration
- implement one or more alternate technologies in addition to the existing (or improved) P&T system
- implement an alternate technology in place of P&T
- conduct one or more pilot tests regarding modifications to the current P&T system and/or potential new technologies, to refine the results of the cost comparison prior to making a final decision

Considering Uncertainty

The evaluation of future costs for a remedial option is subject to many types of uncertainty. Some of these uncertainties are presented in Exhibit 3. Identifying the uncertainties may be straightforward, but factoring them into a cost-comparison is relatively complex.

In the absence of significant uncertainty or for a relatively simple cost comparison that does not consider uncertainty, values for costs are estimated for the "most-likely scenario" of each alternative, and the financial parameters from Step 4 for these "most-likely scenarios" are then compared for each alternative. To perform a more robust evaluation that accounts for some of the uncertainties, costs can be assigned for an "optimistic" scenario and a "reasonable worst case" scenario. The likelihood that each scenario will occur would also be specified.

When comparing the various remedial approaches that have inherent uncertainty, the "optimistic" scenarios can be compared with each other, "most-likely" scenarios can be compared with each other, and "reasonable worst case" scenarios can be compared with each other. In addition, **expected values** of specific financial parameters can be compared with each other. The expected value of a specific financial parameter is achieved by weighting the parameter value for each potential scenario/outcome based on its likelihood of occurring. The illustrative examples in Appendix A use this more robust evaluation that involves developing "optimistic", "most-likely", and worst-case scenarios". Notes are provided to indicate the assumptions associated with the optimistic and reasonable worst-case scenarios.

Exhibit 3

Typical Uncertainties Associated with Common Ground Water Remedies

Remedial Technology	Typical Uncertainties
Pump and Treat	• mass removal rate and loading to treatment system over time • area of influence and capture provided by extraction wells
In-situ chemical oxidation	• radius of influence of injection points • amount of oxidant lost to dispersion or naturally occurring organic matter • ability to access targeted contaminant mass • unexpected consequences of changing the aquifer's oxidative state (e.g., fouling existing monitoring or extraction wells) • number of applications/injections • ability to reach Maximum Contaminant Levels (MCLs) or target contaminant concentration
Enhanced in-situ bioremediation	• radius of influence of injection points • amount of chemicals required to achieve targeted rate of biodegradation • number of applications/injections • ability to provide complete degradation of site contaminants and reach MCLs or target contaminant concentration • potential to foul existing P&T system (if present) • release of arsenic or other naturally occurring contaminants due to a change in the aquifer's oxidative state • generation of daughter products with greater toxicity
Air sparging and soil vapor extraction	• radius of influence of sparge points and vapor extraction wells • influence of site stratigraphy on sparge zone • relative role of volatilization in mass removal versus contaminant degradation through addition of oxidation • potential to foul existing P&T system (if present) • ability to address all targeted contamination • potential channeling or short-circuiting of sparged air • influent concentrations to SVE system over time
General	• remedy duration • changes in regulatory environment • changes in site conditions • changes in available and practical remedial technologies • changes in discount rate (including effects of inflation) • potential failures in protectiveness and costs for appropriate redundancy

Step 1: Gather Background Information

Step 1a: Organize Cost Information for Current P&T System

The costs of an operating P&T system include routine annual O&M costs as well as non-routine costs that may be expected over the life-time of the remedy. Annual O&M costs include those routine costs that are expected each year to keep the system operating consistently and effectively. Non-routine costs might include replacement of equipment or additional investigations/evaluations. For example, if a P&T system is expected to operate for a number of decades, it may be appropriate to include the cost of replacing major system components at some point, perhaps every 20 years. Exhibit 4 provides a list of cost categories that typically contribute to annual O&M and non-routine costs.

During this step it is also helpful to estimate how long the P&T system will continue to operate. There is typically significant uncertainty associated with this parameter, and it may be appropriate to consider optimistic, most-likely, and reasonable worst-case scenarios.

The illustrative examples in Appendix A include examples of documenting costs and estimated remedy duration associated with an existing P&T system. Basic assumptions associated with the costs are included in a "Notes" section. In the examples, the costs for future years are discounted to net present value as part of Step 2, and this discounting process accounts for inflation. Costs in Step 1, therefore, do not include inflation, but do include cost increases for other reasons.

Step 1b: Estimate Costs for Implementing Efficiency Improvements to the Existing System and Operating the Improved System

If the efficiency of an existing P&T system can be improved as a result of optimization recommendations, it is helpful to consider the expected costs of the modified system in the cost comparison. This is particularly true when an alternative technology to P&T is also being considered (i.e., Step 1c), so that the alternative technology is not just evaluated against the current P&T system, but is also evaluated against a potentially optimized P&T system.

For example, if an optimization evaluation suggests that a component of the treatment system can easily be removed from the treatment process to reduce materials usage or the ground water sampling can be reduced without sacrificing protectiveness, the cost comparison would be more valid if the annual cost savings associated with these changes were documented and included. If it is determined that the operating system needs modifications to be protective of human health and the environment, the costs of making these modifications should be included in Step 1a rather than Step 1b because the cost comparison is designed for comparing remedial alternatives that are protective.

For systems where optimization recommendations are going to be implemented, the costs for the "early years" will typically include the costs of continuing to operate the existing P&T system, plus the costs associated with planning and implementing the optimization changes. The costs for later years (i.e., after system modifications are implemented) would include the costs for operating the optimized P&T system. For this background step, it is important to

Exhibit 4

Typical Cost Categories that Contribute to Costs for P&T System

Routine Annual O&M Costs

- labor
  - project management, reporting, and technical support
  - system operation
  - ground water sampling
- utilities (electric, gas, phone, sewer, etc.)
- consumables (granular activated carbon, chemicals, etc.)
- discharge and/or disposal costs
- laboratory analysis
- other (parts, routine maintenance, etc.)

Non-Routine Costs

- additional evaluations or investigations
- non-routine maintenance, including major system component replacement
- other (non-routine community relations, upgrades to site security, etc.)

estimate how many years the existing system will operate before modifications are implemented.

Optimization evaluations typically include rough estimates for capital costs and changes in annual costs for each of the recommendations. Although these estimates are a good starting point, the site team may choose to obtain more refined estimates prior to completing the cost comparison. This might include a feasibility analysis, gathering additional field information, or performing preliminary design activities associated with implementing optimization alternatives.

The illustrative examples in Appendix A include examples of documenting costs associated with optimizing a P&T system. As is the case with the existing P&T system, basic assumptions are documented in a "Notes" section of each example and the costs do not account for inflation (inflation is considered in Step 2).

<u>Step 1c: Estimate Costs for Implementing and Operating a New Remedial Approach</u>

A new approach may include an alternate remedial technology that augments the P&T system or that replaces the P&T system. Accounting for the costs for a new remedial approach is similar to accounting for costs of an optimized P&T system in that there is continued operation of the existing P&T system while the new approach is planned and implemented.

With a new remedial approach, there may be uncertainty as to the performance of the technology without conducting a pilot test. It is generally helpful to use best estimates of performance for this step of the process and to address the uncertainty by developing "optimistic", "most-likely", and "reasonable worst-case" scenarios. A pilot test can be considered in Steps 4 and 5, and the decision to move forward with a pilot test may be the result of the cost comparison.

The illustrative examples in Appendix A address this step in similar manner to Steps 1a and 1b.

Step 2: Estimate Life-Cycle Costs

<u>Step 2a: Document Costs for Each Year of Operation</u>

Due to changes in O&M costs over time or non-routine costs, the cost for one year of operation may be different from other years. It is therefore helpful to document the estimated costs for each year of operation for each remedial approach that is being evaluated. For some operational years, this cost may be limited to the O&M cost. For other operational years, it may be the O&M cost plus the cost for remedy modifications or an additional evaluation. Documenting the costs for each year also incorporates remedy duration. A remedy with a longer operational life will have more years with "non-zero" costs relative to a remedy with a shorter operational life. By summing the costs from all operational years, the life-cycle cost can be calculated (without discounting). The illustrative examples in Appendix A show documented costs by year for various remedial options. For optimized systems or new remedial approaches, the costs for the "early years" include the costs of continuing to operate the existing P&T system for some time period, plus the costs associated with planning and implementing the optimization changes.

<u>Step 2b: Calculate Life-Cycle Costs in Net Present Value</u>

It is conventional for most organizations, including the Federal government [U.S. OMB, 1992], to compare expected costs of various competing approaches in net present value. This is because the value of money changes over time due to investments and inflation. In general, it is expected that investment returns will exceed inflation so that money spent today has a greater present value than money spent in the future. Exhibit 5 further discusses the discounting of future values to net present value and provides information regarding an appropriate discount rate. Each of the examples in Appendix A calculates the discount factor for each year, discounts the price for each year of operation, and calculates the life-cycle costs in net present value.

Step 3: Compare Costs of Various Remedial Options

Completing the above-mentioned steps should provide enough information to compare the costs of continuing to operate an existing P&T system, optimizing an existing P&T system, or proceeding with a new remedial technology under consideration. It is often helpful to compare various parameters, including upfront costs, life-cycle costs, payback period, and annual return on investment. In addition, when using optimistic, most-likely, and reasonable worst-case scenarios to account for

Exhibit 5

Discounting Future Cash Flows to Net Present Value

The present value for a cash flow in a future year is calculated by applying an appropriate **discount rate** to that cash flow according to the following equation.

$$PV = \frac{FV}{(1+i)^n} = C \times FV$$

where

PV is the present value
FV is the value in year "n" (i.e., future value)
i is the discount rate
C is the discount factor, which equals $1/(1+i)^n$

If there are cash flows in multiple years, the cash flow from each year is discounted to the present value. Cash flows that are far in the future have a lower present value than similar cash flows in earlier years. A higher discount rate will result in a lower present value.

The discount rate varies from organization to organization and is typically linked to the risk-free interest rate that organization pays or receives over time. Each year, the U.S. Office of Management and Budget (OMB) forecasts discount rates to be used for discounting cash flows for Federal government projects. The forecasts (called the "Real Discount Rates") account for inflation and are provided in Appendix C to Circular A-94: Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs [U.S. OMB, 1992]. The rates differ depending on the project duration. The rates for 1995, 2000, and 2005 are listed below for reference.

Year	**Project Duration**			
	5-Year	**7-Year**	**10-Year**	**30-Year**
1995	4.5%	4.6%	4.8%	4.9%
2000	3.9%	4.0%	4.0%	4.2%
2005	2.0%	2.3%	2.5%	3.1%

OMB suggests using linear interpolation for determining appropriate discount rates for projects with intermediate durations. For projects with durations of greater than 30 years, OMB suggests using the 30-year discount rate.

Private organizations will typically have a larger discount rate than that used by the Federal government by 1% to 2%.

uncertainty, it is often helpful to consider a weighted average of the costs for those scenarios called the **expected value**. Exhibit 6 discusses several financial parameters that might be compared, including the expected value.

A comparison of these parameters can help decision makers determine an appropriate allocation of funds. Some organizations may choose an option with lower upfront costs even if the life-cycle costs are higher because there are competing uses for the upfront funding. On the other hand, some organizations may choose an option that includes higher upfront costs in an attempt to reduce the remedy duration and/or life-cycle costs. Comparing these financial parameters, as shown in Appendix A, provides financial decision makers with appropriate information on the various remedial options.

Step 4: Determine the Need for Additional Information

Performing Steps 1 to 3 may help identify uncertainties that may be addressed with additional investigation and/or data collection. It is often preferable to target information gathering to those parameters that most greatly influence the potential cost of one or more of the remedial approaches under consideration. It is also often preferable to determine the cost of gathering additional information, particularly if that information gathering includes field work and/or pilot testing.

In some cases, information gathering may involve pilot testing of one or more technologies or approaches. However, a pilot test is generally only appropriate if the site team has established that there is a potential outcome of the pilot test that could lead to that alternative ultimately being implemented on a full scale basis (presumably based on the results of Step 3). If a full-scale remedial approach is too expensive for a site team to consider implementing, based on the results of Step 3, then it is generally a poor financial decision to move ahead with piloting that remedial approach.

If the information gathering involves additional field work, the site team may want to consider the likelihood of getting reliable information. After all, the field work would be conducted with the purpose of reducing uncertainty, and if the field results will not be of sufficient quality to reduce the uncertainty, then there is generally little merit in moving forward with that specific field work.

Exhibit 6

Financial Parameters Considered When Comparing Costs

Net present value of life-cycle costs – Comparing this parameter for two different scenarios helps determine which scenario will likely be most cost-effective over its operational life. This parameter includes annual and capital costs, short-term and long-term costs, inflation, and the time value of money. It does not consider uncertainty unless multiple life-cycle costs are developed for a remedial approach using different scenarios.

Upfront costs – This parameter represents the costs incurred over the short-term. In some cases, the upfront costs may be those incurred over the first year. In other cases, the upfront costs may be incurred over several years. The upfront costs typically represent the capital being invested in making a particular remedial approach. Upfront costs might include continued operation of an existing P&T system in addition to the costs for designing and implementing an alternative remedial approach. An organization may use this parameter to determine if the necessary funds are available for implementing a particular remedial approach.

Payback – This parameter measures the amount of time it takes for the upfront costs of implementing a change to be paid back by the savings resulting from the implementation. Organizations typically favor shorter paybacks over longer paybacks, with some organizations expecting payback to occur in two to three years.

Average annual percentage return (AAPR) – This parameter helps an organization determine the financial return for an approach so that it can compare that return with other investments it may be considering elsewhere within its organization. For the purpose of this document, the average annual percentage return is calculated between the time of the investment and the end of year 10 of the cost comparison. It can be calculated with the following equation.

$$AAPR = \left(\frac{\text{net savings at year 10}}{\text{invested capital}} \right)^{\frac{1}{\text{period of investment}}}$$

Invested capital refers to the capital costs of making system modifications or implementing a new remedial approach. The period of investment would be the number of years from the initial investment to the end of Year 10. For example, if the investment was made in Year 1, the investment period would be 10 years (e.g., Years 1 through 10). If the investment was made in Year 3, the investment period would be 8 years (e.g., Years 3 through 10).

Expected value (EV) – This is a method of accounting for uncertainty in the above parameters by considering the various outcomes (e.g., optimistic, most-likely, and reasonable worst-case) for a remedial approach and the likelihood of each outcome. It is calculated as the average parameter value for the various scenarios, with each scenario weighted by its likelihood of occurring.

Step 5: Document Decisions and Rationale, Including Pertinent Considerations Not Otherwise Quantified

The last step of this process is to document the decision that results from the financial comparisons and other considerations. As discussed earlier, possible decisions from the cost comparison include the following:

- continue with the existing P&T system
- continue with a modified P&T system where optimization recommendations are implemented to lower costs and/or reduce system duration
- implement one or more alternate technologies in addition to the existing (or improved) P&T system
- implement an alternate technology in place of P&T
- conduct one or more pilot tests regarding modifications to the current P&T system and/or potential new technologies, to refine the results of the cost comparison prior to making a final decision

The alternative selected may not always have the lowest life-cycle cost. In some cases, a particular remedial approach may have the lowest life-cycle costs relative to other approaches under consideration, but the capital costs may be too high for an organization to consider. Similarly, a new remedial approach may substantially reduce costs relative to the existing remedial approach, but an organization may choose to use the capital for other improvements or investments that are more central to their organization's mission. Different organizations also have different decision points regarding a worthwhile investment. For these reasons, this fact sheet does not attempt to tell project teams what decisions to make. Rather, this fact sheet has been made available to provide a framework for conducting these types of evaluations.

Finally, a project team is reminded that cost is only one of the factors that go into making a decision about a remedial approach. Protection of human health and the environment, regulatory acceptance, and community acceptance are just a few of the other factors that may significantly influence the decision making process. Although it may not be practical to quantify some of these factors, it is helpful to document their role selecting an option or making a decision.

D. REFERENCES

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U.S. Office of Management and Budget (OMB) Circular A-94, Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs, October, 29, 1992

APPENDIX A
ILLUSTRATIVE EXAMPLES

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Three examples are provided to illustrate application of the cost comparison framework for various scenarios associated with a P&T remedy. Each example consists of the following:

- brief background for the hypothetical site
- a description of the various remedial measures that are being compared
- a description of the cost-comparison concepts illustrated by the example
- conclusions that can be drawn from the cost comparison
- tables and notes that correspond with the five steps outlined in this document

Hypothetical sites and conditions are used. Approximate costs are provided for the purposes of the example. Although the costs are reasonable based on 2007 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 factors involved in the cost comparison can be effectively and clearly illustrated.

Cost Comparison Framework
Illustrative Example #1

Brief Site Description

The site is an active manufacturing facility with a TCE plume migrating off property. The plume is approximately 500 feet wide and 1,500 feet long and the highest ground water concentration is approximately 4,000 ug/L. A P&T system currently operates with two areas of ground water extraction, one to control the source area and the other to capture the downgradient plume. Biological degradation has been observed, and monitored natural attenuation (MNA) is the selected remedy for the dilute portion of the plume that has migrated beyond the downgradient extraction system. The water table aquifer is relatively permeable with a saturated thickness of over 50 feet. The Remedial Investigation and subsequent monitoring suggest that DNAPL is not present. The ground water extraction rate is 80 gpm, and the influent concentration is approximately 500 ug/L. TCE concentrations in ground water and treatment plant influent have decreased during P&T operation, but concentrations are asymptotically approaching a value that is above the cleanup standard. In addition to treating the TCE, the P&T system also needs to remove iron and manganese to meet standards for discharging to surface water.

Although the P&T system operates effectively to control contaminant migration, it is relatively expensive to operate due to the metals removal. The project team is interested in evaluating alternative discharge locations because O&M costs could be substantially reduced if discharge standards would not require treatment for iron and manganese. The site team is also considering other remedial alternatives that do not involve extraction, treatment, and discharge of water.

The tables on the following pages document the project team's cost comparison.

Remedial Considerations for Cost Comparison

The site team is considering the following options:

- Continued operation of the current P&T system
- Continued operation of the current P&T system with reinjection of treated water instead of discharging to surface water
- Full-scale implementation of an enhanced bioremediation system

Concepts Illustrated

- The annual costs for O&M of the existing P&T system ($305,000 per year) are relatively well understood because the cost projections are based on three years of past invoices that demonstrate consistent costs from year to year.
[Step 1a, Table 1]

- The ground water monitoring program was recently optimized. The changes have not been implemented yet, but the site team has a good understanding of what the cost reductions will be. The reduced costs associated with the optimized program ($30,000 per year) are more representative of future O&M costs, so these reduced O&M costs are used in this cost comparison. [Step 1a, Table 1]

- The annual costs for O&M of an optimized P&T system (using a different discharge option) will be lower, but there is some uncertainty as to what those O&M costs will be. As such, a range of costs is used for optimistic ($173,000 per year), most-likely ($197,000 per year), and reasonable worst-case scenarios ($216,000 per year). [Step 1b, Table 3]

- Future non-routine costs, such as replacement of major system components, are included in year 20 for both the current P&T system and the optimized P&T system, but the non-routine costs for the optimized system are lower because the system is simpler than the existing system. [Step 1a, Table 3; Step 1b, Table 5; Step 2a]

- The analysis is conducted assuming that enhanced bioremediation will work. Generic assumptions are used for determining the number of injection wells required in the optimistic, most-likely, and reasonable worst-case scenarios. If the analysis demonstrates that the new remedial approach is worth while, the site team can choose to conduct a pilot test to determine if the technology will work and an appropriate number of injection wells.

Conclusions

The cost comparison shows that either new option (optimizing the system or replacing the system with an enhanced bioremediation remedy) will prove more cost effective than continued operation of the current system. The life-cycle costs for both of these new options are lower than the life-cycle costs for the existing system. In addition, the upfront/short-term costs are very similar to that for the existing system and the payback period for either investment is reasonable. There is a wide range in the potential costs associated with the new remedial approach, but the reasonable worst-case scenario for the new remedial approach is similar financially to the optimistic scenario for the optimized P&T system. Given the potential benefits of this new remedial approach and this wide range in potential costs, it is likely appropriate to conduct a pilot test to determine the effectiveness of the approach and to refine the costs of implementation. The pilot test would likely provide valuable information about the number of injection points, which impacts both the capital costs and the long-term O&M costs associated with injections.

Step 1a: Background Cost Information - Existing P&T System

1. Annual O&M Costs

O&M Category	Optimistic Scenario	Most-Likely Scenario	Reasonable Worst-Case Scenario
Labor: project management, reporting, technical support		$ 50,000	
Labor: system operation		$ 150,000	
Labor: groundwater sampling		$ 30,000	
Utilities (gas, electric, water, sewer, etc.)		$ 30,000	
Consumables (GAC, chemicals, etc.)		$ 15,000	
Discharge or disposal costs		$ 7,500	
Laboratory analysis		$ 15,000	
Other (parts, routine maintenance, etc.)		$ 7,500	
O&M Total	$ -	$ 305,000	$ -

Notes:

- O&M costs were obtained from reviewing past three years of invoices.

- The actual O&M costs are approximately $340,000 per year; however, the groundwater monitoring program was recently optimized, and the site team forecasts a decrease of $35,000 per year due to this optimization (a $20,000 per year reduction in groundwater sampling, a $10,000 per year reduction in reporting costs, and a $5,000 per year reduction in analytical costs). The forecasted costs are reported above because they are the best representation for future O&M costs.

2. Estimated Operational Life

	Optimistic Scenario	Most-Likely Scenario	Reasonable Worst-Case Scenario
Years of Continued O&M Costs of Current P&T System	20 years	30 years	40 years

Notes:

3. Non-Routine Costs

Cost Category	Optimistic Scenario		Most Likely Scenario		Reasonable Worst-Case Scenario	
	Cost	Year(s) Incurred	Cost	Year(s) Incurred	Cost	Year(s) Incurred
Additional evaluation						
system closure evaluation	$ 30,000	20	$ 40,000	30	$ 50,000	40
- Item 2						
- Item 3						
Non-routine maintenance/equipment replacement						
replace/repair treatment components			$200,000	20	$300,000	20
- Item 2						
- Item 3						
Other						
- Item 1						
- Item 2						
- Item 3						

Notes:

- "Year(s) incurred" refers to the number of years from the present as used in Steps 2 and 3 (e.g., use "2" to refer to two years from present and use "5, 10, …" to refer to five-year intervals from the present.)

- A system closure evaluation will likely be conducted to demonstrate that active remediation can be discontinued.

- Replacement of major system components will likely be needed in year 20. For the optimistic scenario, P&T operation will be discontinued before the replacement is needed.

Step 1b: Background Cost Information - Optimized P&T System

1. Years of Continued O&M Costs of Current P&T System During Planning

	Optimistic Scenario	Most-Likely Scenario	Reasonable Worst-Case Scenario
Years of Continued O&M Costs of Current P&T System During Planning	1 year	2 years	2 years

2. Implementing/Planning Costs

Cost Category	Optimistic Scenario		Most-Likely Scenario		Reasonable Worst-Case Scenario	
	Cost	Year(s) Incurred	Cost	Year(s) Incurred	Cost	Year(s) Incurred
Data analysis / Feasibility study	$ 20,000	1	$ 20,000	1	$ 20,000	1
Remedy design, work plans, etc.						
Permitting						
Installation / Oversight						
Other (three injection wells, lump sum)	$100,000	1	$125,000	2	$150,000	2
List 1						
List 2						
List 3						
Total	$ 120,000		$ 145,000		$ 170,000	

- Notes

- "Year(s) incurred" refers to the number of years from the present as used in Steps 2 and 3 (e.g., use "2" to refer to two years from present and use "5, 10, …" to refer to five-year intervals from the present.)

- Analysis needed to determine the best location for injection wells such that injection will not adversely affect plume capture offered by the extraction system.

3. Annual O&M Costs of Optimized Remedy

O&M Category	Optimistic Scenario	Most-Likely Scenario	Reasonable Worst-Case Scenario
Labor: project management, reporting, technical support	$ 50,000	$ 60,000	$ 65,000
Labor: system operation	$ 50,000	$ 60,000	$ 70,000
Labor: groundwater sampling	$ 30,000	$ 30,000	$ 30,000
Utilities (gas, electric, water, sewer, etc.)	$ 20,000	$ 20,000	$ 20,000
Consumables (GAC, chemicals, etc.)	$ 3,000	$ 3,000	$ 3,000
Discharge or disposal costs	$ 1,000	$ 1,000	$ 1,000
Laboratory analysis	$ 15,000	$ 15,000	$ 15,000
Other (parts, routine maintenance, etc.)	$ 4,000	$ 8,000	$ 12,000
O&M Total	$ 173,000	$ 197,000	$ 216,000

Notes:

- As with the costs for the "existing system", the costs above include the costs for the optimized groundwater monitoring program, which are lower than the current costs but are more representative of the future costs to be incurred.

Step 1b: Background Cost

4. Estimated Operational Life

	Optimistic Scenario	Most-Likely Scenario	Reasonable Worst-Case Scenario
Years of Continued O&M Costs of Current P&T System	20 years	30 years	40 years

Notes:

5. Non-Routine Costs of Optimized Remedy

Cost Category	Optimistic Scenario		Most Likely Scenario		Reasonable Worst-Case Scenario	
	Cost	Year(s) Incurred	Cost	Year(s) Incurred	Cost	Year(s) Incurred
Additional evaluation						
site closure evaluation	$ 30,000	20	$ 40,000	30	$ 50,000	40
- Item 2						
- Item 3						
Non-routine maintenance/equipment replacement						
replace/repair treatment components			$ 100,000	20	$ 200,000	20
- Item 2						
- Item 3						
Other						
- Item 1						
- Item 2						
- Item 3						

Notes:

- "Year(s) incurred" refers to the number of years from the present as used in Steps 2 and 3 (e.g., use "2" to refer to two years from present and use "5, 10, …" to refer to five-year intervals from the present.)

- A system closure evaluation will likely be conducted to demonstrate that active remediation can be discontinued.

- Replacement of major system components will likely be needed in year 20. For the optimistic scenario, P&T operation will be discontinued before the replacement is needed. The costs of system replacement for this scenario are lower because the metals removal system will not have been used and will not require replacement.

Step 1c: Background Cost Information - New Remedial Approach

1. Years of Continued O&M Costs of Current P&T System During Planning

	Optimistic Scenario	Most-Likely Scenario	Reasonable Worst-Case Scenario
Years of Continued O&M Costs of Current P&T System During Planning	1 year	2 years	2 years

2. Implementing/Planning Costs

Cost Category	Optimistic Scenario		MostLikely Scenario		Reasonable Worst-Case Scenario	
	Cost	Year(s) Incurred	Cost	Year(s) Incurred	Cost	Year(s) Incurred
Conceptual design	$ 5,000	1	$ 5,000	1	$ 5,000	1
Additional research and investigation						
Pilot testing	$ 75,000	1	$ 100,000	1	$ 125,000	1
Remedy design, work plan, etc.	$ 30,000	1	$ 30,000	1	$ 30,000	1
Permitting	$ 5,000	1	$ 5,000	1	$ 5,000	1
Installation and oversight	$ 150,000	2	$ 250,000	3	$ 500,000	3
Documentation	$ 15,000	2	$ 15,000	3	$ 15,000	3
Other (all of the above, lump sum)						
Total	$ 280,000		$ 405,000		$ 680,000	

Notes:

- "Year(s) incurred" refers to the number of years from the present as used in Steps 2 and 3 (e.g., use "2" to refer to two years from present and use "5, 10, …" to refer to five-year intervals from the present.)

3. Annual O&M Costs of New Remedy

O&M Category	Optimistic Scenario	Most-Likely Scenario	Reasonable Worst-Case Scenario
Labor: project management, reporting, technical support	$ 30,000	$ 30,000	$ 30,000
Labor: system operation	$ 15,000	$ 25,000	$ 50,000
Labor: groundwater sampling	$ 50,000	$ 50,000	$ 50,000
Utilities (gas, electric, water, sewer, etc.)	$ -	$ -	$ -
Consumables (GAC, chemicals, etc.)	$ 7,000	$ 12,000	$ 25,000
Discharge or disposal costs	$ 1,000	$ 1,000	$ 1,000
Laboratory analysis	$ 10,000	$ 10,000	$ 10,000
Other (parts, routine maintenance, etc.)	$ 1,000	$ 1,000	$ 1,000
O&M Total	$ 114,000	$ 129,000	$ 167,000

Notes:

- The primary cost for implementation is installing new injection wells for nutrient addition. The optimistic, most-likely, and reasonable worst-case scenarios respectively assume 15, 25, and 50 injection wells will be needed for adequate nutrient distribution. Pilot testing could refine this estimate.

- The labor and consumables use depends on the number of injection wells.

Step 1c: Background Cost Information - New Remedial Approach (continued)

4. Estimated Operational Life

	Optimistic Scenario	Most Likely Scenario	Reasonable Worst-Case Scenario
Years of Continued O&M Costs of Current P&T System	10 years	15 years	20 years

Notes:

5. Non-Routine Costs of Optimized Remedy

Cost Category	Optimistic Scenario		Most Likely Scenario		Reasonable Worst-Case Scenario	
	Cost	Year(s) Incurred	Cost	Year(s) Incurred	Cost	Year(s) Incurred
Additional evaluation						
system closure evaluation	$ 30,000	10	$ 40,000	15	$ 50,000	20
- Item 2						
- Item 3						
Non-routine maintenance/equipment replacement						
additional injection points					$50,000	5
- item 2						
- item 3						
Other						
- Item 1						
- Item 2						
- Item 3						

Notes:

- "Year(s) incurred" refers to the number of years from the present as used in Steps 2 and 3 (e.g., use "2" to refer to two years from present and use "5, 10, …" to refer to five-year intervals from the present.)

- A system closure evaluation will likely be conducted to demonstrate that active remediation can be discontinued.

- The reasonable worst-case scenario assumes that additional injection points might be required in year 5. The cost for conducting injections in these additional wells are reflected in the average annual O&M costs reported above.

Step 2a: Life-Cycle Costs

Year	Existing P&T System			Optimized P&T System			New Remedial Approach		
	Optimistic	Most-Likely	Reasonable Worst-Case	Optimistic	Most-Likely	Reasonable Worst-Case	Optimistic	Most-Likely	Reasonable Worst-Case
1	$ 305,000	$ 305,000	$ 305,000	$ 325,000	$ 325,000	$ 325,000	$ 420,000	$ 445,000	$ 470,000
2	$ 305,000	$ 305,000	$ 305,000	$ 273,000	$ 322,000	$ 366,000	$ 279,000	$ 394,000	$ 682,000
3	$ 305,000	$ 305,000	$ 305,000	$ 173,000	$ 197,000	$ 216,000	$ 114,000	$ 129,000	$ 167,000
4	$ 305,000	$ 305,000	$ 305,000	$ 173,000	$ 197,000	$ 216,000	$ 114,000	$ 129,000	$ 167,000
5	$ 305,000	$ 305,000	$ 305,000	$ 173,000	$ 197,000	$ 216,000	$ 114,000	$ 129,000	$ 167,000
6	$ 305,000	$ 305,000	$ 305,000	$ 173,000	$ 197,000	$ 216,000	$ 114,000	$ 129,000	$ 217,000
7	$ 305,000	$ 305,000	$ 305,000	$ 173,000	$ 197,000	$ 216,000	$ 114,000	$ 129,000	$ 167,000
8	$ 305,000	$ 305,000	$ 305,000	$ 173,000	$ 197,000	$ 216,000	$ 114,000	$ 129,000	$ 167,000
9	$ 305,000	$ 305,000	$ 305,000	$ 173,000	$ 197,000	$ 216,000	$ 114,000	$ 129,000	$ 167,000
10	$ 305,000	$ 305,000	$ 305,000	$ 173,000	$ 197,000	$ 216,000	$ 114,000	$ 129,000	$ 167,000
11	$ 305,000	$ 305,000	$ 305,000	$ 173,000	$ 197,000	$ 216,000	$ 144,000	$ 129,000	$ 167,000
12	$ 305,000	$ 305,000	$ 305,000	$ 173,000	$ 197,000	$ 216,000	$ -	$ 129,000	$ 167,000
13	$ 305,000	$ 305,000	$ 305,000	$ 173,000	$ 197,000	$ 216,000	$ -	$ 129,000	$ 167,000
14	$ 305,000	$ 305,000	$ 305,000	$ 173,000	$ 197,000	$ 216,000	$ -	$ 129,000	$ 167,000
15	$ 305,000	$ 305,000	$ 305,000	$ 173,000	$ 197,000	$ 216,000	$ -	$ 129,000	$ 167,000
16	$ 305,000	$ 305,000	$ 305,000	$ 173,000	$ 197,000	$ 216,000	$ -	$ 169,000	$ 167,000
17	$ 305,000	$ 305,000	$ 305,000	$ 173,000	$ 197,000	$ 216,000	$ -	$ -	$ 167,000
18	$ 305,000	$ 305,000	$ 305,000	$ 173,000	$ 197,000	$ 216,000	$ -	$ -	$ 167,000
19	$ 305,000	$ 305,000	$ 305,000	$ 173,000	$ 197,000	$ 216,000	$ -	$ -	$ 167,000
20	$ 335,000	$ 505,000	$ 605,000	$ 173,000	$ 297,000	$ 416,000	$ -	$ -	$ 167,000
21	$ -	$ 305,000	$ 305,000	$ 203,000	$ 197,000	$ 216,000	$ -	$ -	$ 217,000
22	$ -	$ 305,000	$ 305,000	$ -	$ 197,000	$ 216,000	$ -	$ -	$ -
23	$ -	$ 305,000	$ 305,000	$ -	$ 197,000	$ 216,000	$ -	$ -	$ -
24	$ -	$ 305,000	$ 305,000	$ -	$ 197,000	$ 216,000	$ -	$ -	$ -
25	$ -	$ 305,000	$ 305,000	$ -	$ 197,000	$ 216,000	$ -	$ -	$ -
26	$ -	$ 305,000	$ 305,000	$ -	$ 197,000	$ 216,000	$ -	$ -	$ -
27	$ -	$ 305,000	$ 305,000	$ -	$ 197,000	$ 216,000	$ -	$ -	$ -
28	$ -	$ 305,000	$ 305,000	$ -	$ 197,000	$ 216,000	$ -	$ -	$ -
29	$ -	$ 305,000	$ 305,000	$ -	$ 197,000	$ 216,000	$ -	$ -	$ -
30+	$ -	$ 345,000	$ 2,943,485	$ -	$ 426,874	$2,203,592	$ -	$ -	$ -
Totals	$ 6,130,000	$ 9,390,000	$ 12,088,485	$ 3,915,000	$ 6,492,874	$ 8,926,592	$ 1,755,000	$ 2,685,000	$ 4,425,000
	Likelihood that Each Scenario Will Occur			**Likelihood that Each Scenario Will Occur**			**Likelihood that Each Scenario Will Occur**		
	30%	40%	30%	30%	40%	30%	20%	50%	30%

Notes:

-Noted costs are based on information provided in Steps 1a, 1b, and 1c. Costs are not discounted in this Step. They are discounted in Step 2b.

-The likelihoods for each remedial option adds to 100%. These likelihoods are based on professional judgment and experience with previous applications of the technology by the project team.

-Inflation is not considered in this step. The application of the discount rate in Step 2b accounts for inflation.

- Costs that are incurred after year 30 have been included as discounted values in year 30 using the discount rate from Step 2b.

-Operation of the optimized P&T system and the new remedial approach begin in the year that the capital expenses are made.

Step 2b: Net Present Value of Life-Cycle Costs

Year	Discount Factor	Existing P&T System Annual Costs in Present Value			Optimized P&T System Annual Costs in Present Value			New Remedial Approach Annual Costs in Present Value		
	3.1%	Optimistic	Most-likely	Reasonable Worst-Case	Optimistic	Most-likely	Reasonable Worst-Case	Optimistic	Most-likely	Reasonable Worst-Case
1	1.000	$ 305,000	$ 305,000	$ 305,000	$ 325,000	$ 325,000	$ 325,000	$ 420,000	$ 445,000	$ 470,000
2	0.970	$ 295,829	$ 295,829	$ 295,829	$ 264,791	$ 312,318	$ 354,995	$ 270,611	$ 382,153	$ 661,494
3	0.941	$ 286,934	$ 286,934	$ 286,934	$ 162,753	$ 185,331	$ 203,206	$ 107,248	$ 121,359	$ 157,108
4	0.912	$ 278,307	$ 278,307	$ 278,307	$ 157,859	$ 179,759	$ 197,096	$ 104,023	$ 117,710	$ 152,384
5	0.885	$ 269,939	$ 269,939	$ 269,939	$ 153,113	$ 174,354	$ 191,170	$ 100,895	$ 114,171	$ 147,803
6	0.858	$ 261,822	$ 261,822	$ 261,822	$ 148,509	$ 169,111	$ 185,422	$ 97,861	$ 110,738	$ 186,280
7	0.833	$ 253,950	$ 253,950	$ 253,950	$ 144,044	$ 164,027	$ 179,846	$ 94,919	$ 107,408	$ 139,048
8	0.808	$ 246,314	$ 246,314	$ 246,314	$ 139,713	$ 159,095	$ 174,439	$ 92,065	$ 104,179	$ 134,867
9	0.783	$ 238,908	$ 238,908	$ 238,908	$ 135,512	$ 154,311	$ 169,194	$ 89,297	$ 101,046	$ 130,812
10	0.760	$ 231,724	$ 231,724	$ 231,724	$ 131,437	$ 149,671	$ 164,106	$ 86,612	$ 98,008	$ 126,879
11	0.737	$ 224,757	$ 224,757	$ 224,757	$ 127,485	$ 145,171	$ 159,172	$ 106,115	$ 95,061	$ 123,064
12	0.715	$ 217,999	$ 217,999	$ 217,999	$ 123,652	$ 140,806	$ 154,386	$ -	$ 92,203	$ 119,363
13	0.693	$ 211,444	$ 211,444	$ 211,444	$ 119,934	$ 136,572	$ 149,744	$ -	$ 89,431	$ 115,774
14	0.672	$ 205,087	$ 205,087	$ 205,087	$ 116,328	$ 132,466	$ 145,242	$ -	$ 86,742	$ 112,293
15	0.652	$ 198,920	$ 198,920	$ 198,920	$ 112,830	$ 128,483	$ 140,875	$ -	$ 84,133	$ 108,917
16	0.633	$ 192,939	$ 192,939	$ 192,939	$ 109,437	$ 124,620	$ 136,639	$ -	$ 106,907	$ 105,642
17	0.614	$ 187,138	$ 187,138	$ 187,138	$ 106,147	$ 120,873	$ 132,530	$ -	$ -	$ 102,466
18	0.595	$ 181,511	$ 181,511	$ 181,511	$ 102,955	$ 117,238	$ 128,545	$ -	$ -	$ 99,385
19	0.577	$ 176,053	$ 176,053	$ 176,053	$ 99,860	$ 113,713	$ 124,680	$ -	$ -	$ 96,396
20	0.560	$ 187,556	$ 282,733	$ 338,720	$ 96,857	$ 166,281	$ 232,905	$ -	$ -	$ 93,498
21	0.543	$ -	$ 165,625	$ 165,625	$ 110,236	$ 106,978	$ 117,295	$ -	$ -	$ 117,838
22	0.527	$ -	$ 160,645	$ 160,645	$ -	$ 103,761	$ 113,768	$ -	$ -	$ -
23	0.511	$ -	$ 155,815	$ 155,815	$ -	$ 100,641	$ 110,348	$ -	$ -	$ -
24	0.496	$ -	$ 151,130	$ 151,130	$ -	$ 97,615	$ 107,030	$ -	$ -	$ -
25	0.481	$ -	$ 146,586	$ 146,586	$ -	$ 94,680	$ 103,812	$ -	$ -	$ -
26	0.466	$ -	$ 142,178	$ 142,178	$ -	$ 91,833	$ 100,690	$ -	$ -	$ -
27	0.452	$ -	$ 137,903	$ 137,903	$ -	$ 89,072	$ 97,663	$ -	$ -	$ -
28	0.439	$ -	$ 133,757	$ 133,757	$ -	$ 86,394	$ 94,726	$ -	$ -	$ -
29	0.425	$ -	$ 129,735	$ 129,735	$ -	$ 83,796	$ 91,878	$ -	$ -	$ -
30+	0.413	$ -	$ 142,337	$ 1,214,396	$ -	$ 176,116	$ 909,138	$ -	$ -	$ -
Totals		$ 4,652,131	$ 6,213,020	$ 7,341,066	$ 2,988,452	$ 4,330,084	$ 5,495,540	$ 1,569,645	$ 2,256,249	$ 3,501,311
		Likelihood that Each Scenario Will Occur			**Likelihood that Each Scenario Will Occur**			**Likelihood that Each Scenario Will Occur**		
	N/A	30%	40%	30%	30%	40%	30%	20%	50%	30%

Notes:

- A discount rate of 3.1% has been used based on U.S. Office of Management and Budget Circular A-94, Guidelines and Discount Rates for Cost-Benefit Analysis of Federal Programs. This rate includes the affect of inflation, so inflation is not considered separately. A higher discount rate would result in lower present value costs.

Step 3: Cost Comparison

Year	Optimized P&T System Cum. Cash Flow (NPV) Relative to Most-Likely Case for Existing System			New Remedial Approach Cum. Cash Flow (NPV) Relative to Most Likely Case for Existing System		
	Optimistic	Most-Likely	Reasonable Worst-Case	Optimistic	Most-Likely	Reasonable Worst-Case
1	$ (20,000)	$ (20,000)	$ (20,000)	$ (115,000)	$ (140,000)	$ (165,000)
2	$ 11,038	$ (36,489)	$ (79,166)	$ (89,782)	$ (226,324)	$ (530,664)
3	$ 135,219	$ 65,114	$ 4,563	$ 89,905	$ (60,749)	$ (400,838)
4	$ 255,667	$ 163,662	$ 85,773	$ 264,189	$ 99,848	$ (274,916)
5	$ 372,493	$ 259,247	$ 164,542	$ 433,233	$ 255,616	$ (152,780)
6	$ 485,806	$ 351,958	$ 240,943	$ 597,193	$ 406,700	$ (77,238)
7	$ 595,712	$ 441,881	$ 315,046	$ 756,224	$ 553,242	$ 37,664
8	$ 702,314	$ 529,100	$ 386,922	$ 910,473	$ 695,377	$ 149,111
9	$ 805,710	$ 613,697	$ 456,636	$ 1,060,084	$ 833,239	$ 257,207
10	$ 905,997	$ 695,751	$ 524,254	$ 1,205,197	$ 966,955	$ 362,053
11	$ 1,003,269	$ 775,337	$ 589,838	$ 1,323,839	$ 1,096,651	$ 463,746
12	$ 1,097,616	$ 852,530	$ 653,451	$ 1,541,838	$ 1,222,447	$ 562,382
13	$ 1,189,126	$ 927,402	$ 715,151	$ 1,753,283	$ 1,344,461	$ 658,052
14	$ 1,277,885	$ 1,000,023	$ 774,996	$ 1,958,369	$ 1,462,806	$ 750,845
15	$ 1,363,975	$ 1,070,460	$ 833,042	$ 2,157,289	$ 1,577,592	$ 840,848
16	$ 1,447,477	$ 1,138,779	$ 889,342	$ 2,350,228	$ 1,663,624	$ 928,145
17	$ 1,528,467	$ 1,205,044	$ 943,949	$ 2,537,366	$ 1,850,762	$ 1,012,817
18	$ 1,607,023	$ 1,269,317	$ 996,915	$ 2,718,877	$ 2,032,273	$ 1,094,944
19	$ 1,683,216	$ 1,331,657	$ 1,048,288	$ 2,894,930	$ 2,208,326	$ 1,174,600
20	$ 1,869,092	$ 1,448,110	$ 1,098,116	$ 3,177,663	$ 2,491,059	$ 1,363,836
21	$ 1,924,482	$ 1,506,757	$ 1,146,446	$ 3,343,288	$ 2,656,684	$ 1,411,623
22	$ 2,085,127	$ 1,563,641	$ 1,193,323	$ 3,503,933	$ 2,817,330	$ 1,572,268
23	$ 2,240,942	$ 1,618,815	$ 1,238,790	$ 3,659,748	$ 2,973,144	$ 1,728,083
24	$ 2,392,072	$ 1,672,330	$ 1,282,890	$ 3,810,878	$ 3,124,274	$ 1,879,213
25	$ 2,538,658	$ 1,724,236	$ 1,325,665	$ 3,957,464	$ 3,270,860	$ 2,025,799
26	$ 2,680,836	$ 1,774,581	$ 1,367,153	$ 4,099,642	$ 3,413,038	$ 2,167,977
27	$ 2,818,739	$ 1,823,412	$ 1,407,393	$ 4,237,546	$ 3,550,942	$ 2,305,880
28	$ 2,952,496	$ 1,870,775	$ 1,446,424	$ 4,371,302	$ 3,684,699	$ 2,439,637
29	$ 3,082,231	$ 1,916,714	$ 1,484,281	$ 4,501,037	$ 3,814,434	$ 2,569,372
30	$ 3,224,568	$ 1,882,936	$ 717,480	$ 4,643,374	$ 3,956,771	$ 2,711,709
	Likelihood that Each Scenario Will Occur			Likelihood that Each Scenario Will Occur		
	30%	40%	30%	20%	50%	30%

Notes:

- The indicated values represent the cumulative difference in costs between the various scenarios for the indicated remedial option and the most-likely scenario for continuing with existing P&T system as noted in Step 2b. This difference in costs over time can be used to track the "investment" made in optimizing the P&T system or moving forward with the alternative remedial approach.

- Values in parentheses indicate an investment (i.e., a greater expenditure for the indicated remedial approach than for the most-likely scenario for the existing P&T system). Values without parentheses indicates income (i.e., savings relative to the costs associated with the mostly likely scenario for the existing P&T system).

- The likelihoods for each remedial option adds to 100%. These likelihoods are based on professional judgment and experience with previous applications of the technology by the project team.

Step 3: Cost Comparison (continued)

	Existing P&T System		Optimized P&T System				New Remedial Approach			
	Most-Likely Scenario	Expected Value	Most-Likely Scenario		Expected Value		Most Likely Scenario		Expected Value	
			Total	Net Change Compared to Existing System	Total	Net Change Compared to Existing System	Total	Net Change Compared to Existing System	Total	Net Change Compared to Existing System
NPV of Life-Cycle Costs	$ 6,213,020	$ 6,083,167	$ 4,330,084	$ (1,882,936)	$ 4,277,231	$ (1,805,936)	$ 2,256,249	$ (3,956,771)	$ 2,492,447	$ (3,590,720)
Year 1 cash flow	$ (305,000)	$ (305,000)	$ (325,000)	$ (20,000)	$ (325,000)	$ (20,000)	$ (420,000)	$ (115,000)	$ (447,500)	$ (142,500)
Year 2 cash flow (discounted)	$ (295,829)	$ (295,829)	$ (312,318)	$ (16,489)	$ (310,863)	$ (15,034)	$ (270,611)	$ 25,218	$ (443,647)	$ (147,818)
Year 3 cash flow (discounted)	$ (286,934)	$ (286,934)	$ (185,331)	$ 101,603	$ (183,920)	$ 103,014	$ (107,248)	$ 179,687	$ (129,262)	$ 157,673
Cum. cash flow at year 5 (discounted)	$ (1,436,009)	$ (1,436,009)	$ (1,176,762)	$ 259,247	$ (1,171,200)	$ 264,809	$ (1,002,777)	$ 433,233	$ (1,267,389)	$ 168,621
Total investment*	N/A	N/A	$ 145,000	$ 145,000	$ 145,000	$ 145,000	$ 405,000	$ 405,000	$ 442,500	$ 442,500
Year with highest investment*	N/A	N/A	2		1.70		3		2.80	
Year of payback**	N/A	N/A	Year 3		Year 3		Year 4		Year 5	
Net cum. cash flow at year 10	N/A	N/A	$ 695,751	$ 695,751	$ 707,375	$ 707,375	$ 966,955	$ 966,955	$ 833,133	$ 833,133
Average Annual Percentage Return (AAPR) as of Year 10**	N/A	N/A	21.6%		22.6%		16.48%		15.84%	

Notes:

- "Net Change Compared to Existing System" is taking the "Total" and substracting the corresponding value from the existing system.

** Investment refers to capital costs "invested" in system modifications or a new remedial technology (based on information documented in Step 1).*

*** Payback is defined as the number of years (from the year with the highest investment) that it takes to get a positive cumulative cash flow.*

**** For this example, AARP is calculated using the following parameters:*

- *"Total investment" from the above table corresponds to the "invested capital" from Exhibit 6.*
- *"Net cum. cash flow at Year 10" from the above table corresponds to the "net savings at year 10" from Exhibit 6.*
- *The number of years from the "Year with the highest investment" to Year 10 corresponds to the "period of investment" from Exhibit 6.*

Step 4: Information Gathering

1. Information to Gather

Information	Optimistic Scenario	Most Likely Scenario	Reasonable Worst-Case Scenario
	Cost	Cost	Cost
Pilot test (lump sum)	$ 75,000	$ 100,000	$ 125,000
- item 2			
- item 3			
- item 4			
- item 5			
- item 6			
- item 7			
- item 8			
- item 9			
- item 10			
- item 11			
- item 12			
- item 13			
- item 14			
Total	$ 75,000	$ 100,000	$ 125,000

Notes:

- The pilot test would be conducted to help determine the spacing and number of injection points, which could impact both capital costs for implementation and long-term O&M costs.

Step 5: Conclusions and Decision

Conclusion

The cost comparison shows that either new option (optimizing the system or replacing the system with an enhanced bioremediation remedy) will prove more cost effective than continued operation of the current system. The life-cycle costs for both of these new options are lower than the life-cycle costs for the existing system. In addition, the upfront/short-term costs are very similar to that for the existing system and the payback period for either investment is reasonable. The reasonable worst-case scenario for the bioremediation option is comparable financially to the optmistic case for the optimized P&T system, suggesting that further consideration of the bioremediation option is merited.

Decision

The bioremediation option merits further consideration because of its potential to shorten the duration of the remedy and reduce life-cycle costs. The organization has decided to pursue a pilot test to test the feasibility of the technology at this site and to help refine the costs of implementation. The decision to move forward with a full-scale bioremediation option will be based on the outcome of the pilot test.

Cost Comparison Framework
Illustrative Example #2

Brief Site Description

The site is the location of a former metal finishing plant where a leak in an underground waste storage tank resulted in a release of TCE to soil and ground water. The water table aquifer is highly permeable with a saturated thickness of over 50 feet. The Remedial Investigation and subsequent monitoring suggest that DNAPL is not present. The maximum ground water concentration at the site after 10 years of P&T operation is approximately 200 ug/L (at one monitoring well in the source area). The P&T system effectively captures the TCE plume. The ground water extraction rate is 100 gpm, and the influent concentration is approximately 20 ug/L. TCE concentrations in ground water and the treatment plant influent have decreased during P&T operation, but the concentrations have asymptotically approached their current values. There is no evidence of reductive dechlorination at the site.

Although the P&T system operates effectively to control contaminant migration, it is uncertain how long the system will continue to operate efficiently. The project team is interested in how the cost of aggressive treatment of the source area with the potential shut down of the P&T system compares to continuing to operate the existing P&T system.

The tables on the following pages document the project team's cost comparison.

Remedial Considerations for Cost Comparison

The site team is considering the following options:

- Continued operation of the current P&T system
- Continued operation of the current P&T system with an additional extraction well in the source area
- Full-scale implementation of an air sparging and soil vapor extraction (AS/SVE) system in the source area in place of P&T

Concepts Illustrated

- The annual costs for O&M of the P&T system ($117,000 per year) are relatively well understood because the cost projections are based on three years of past invoices that demonstrate consistent costs from year to year. The primary source of uncertainty is how long the system will operate (20, 30, or 40 years). [Step 1a, Tables 1 and 2]

- The P&T system with a new extraction well in the source area is considered an optimized P&T system in this cost comparison. Implementation of AS/SVE is considered the “new remedial approach”.

Conclusions

The cost comparison demonstrates that the discounted life-cycle costs for both the optimized P&T system and the new remedial approach are lower than continuing to operate the existing system. The short term costs for the optimized P&T system are marginally higher than short term costs for the existing system, but the investment for the new remedial approach has the same approximate value as three years of operating the existing system. Although the optimized P&T approach provides a low life-cycle cost coupled with a low implementation cost, the new remedial approach has the potential to achieve closure at the site faster, and the reasonable worst-case scenario for the new remedial approach is financially similar to the optimistic case for the optimized P&T system. Therefore, it makes sense to move forward with the new remedial approach. An appropriate step would be to begin with the modeling effort and pilot test to determine which of the three new remedial approach scenarios is most likely to occur and to assist in planning and design of a full-scale air sparging system.

Step 1a: Background Cost Information - Existing P&T System

1. Annual O&M Costs

O&M Category	Optimistic Scenario	Most-Likely Scenario	Reasonable Worst-Case Scenario
Labor: project management, reporting, technical support		$ 40,000	
Labor: system operation		$ 30,000	
Labor: groundwater sampling		$ 15,000	
Utilities (gas, electric, water, sewer, etc.)		$ 15,000	
Consumables (GAC, chemicals, etc.)		$ 3,000	
Discharge or disposal costs		$ 1,500	
Laboratory analysis		$ 7,500	
Other (parts, routine maintenance, etc.)		$ 5,000	
O&M Total	$ -	$ 117,000	$ -

Notes:

- *O&M costs were obtained from reviewing past three years of invoices.*
- *System has been performing reliably and was recently optimized.*
- *Ground water sampling and reporting conducted annually.*

2. Estimated Operational Life

	Optimistic Scenario	Most-Likely Scenario	Reasonable Worst-Case Scenario
Years of Continued O&M Costs of Current P&T System During Planning	20 years	30 years	40 years

Notes:

3. Non-Routine Costs

Cost Category	Optimistic Scenario		Most-Likely Scenario		Reasonable Worst-Case Scenario	
	Cost	Year(s) Incurred	Cost	Year(s) Incurred	Cost	Year(s) Incurred
Additional evaluation						
- item 1						
- Item 2						
- Item 3						
Non-routine maintenance/equipment replacement						
Replace/repair components for 10 more years of operation					$100,000	30
- Item 2						
- Item 3						
Other						
- Item 1						
- Item 2						
- Item 3						

Notes:

- *"Year(s) incurred" refers to the number of years from the present as used in Steps 2 and 3 (e.g., use "2" to refer to two years from present and use "5, 10, …" to refer to five-year intervals from the present.)*

Step 1b: Background Cost Information - Optimized P&T System

1. Years of Continued O&M Costs of Current P&T System During Planning

	Optimistic Scenario	Most Likely Scenario	Reasonable Worst-Case Scenario
Years of Continued O&M Costs of Current P&T System During Planning	1 year	2 years	2 years

2. Implementing/Planning Costs

Cost Category	Optimistic Scenario		Most-Likely Scenario		Reasonable Worst-Case Scenario	
	Cost	Year(s) Incurred	Cost	Year(s) Incurred	Cost	Year(s) Incurred
Data analysis / Feasibility study						
Remedy design, work plans, etc.						
Permitting						
Installation / Oversight						
Other (one extraction well, lump sum)	$30,000	1	$35,000	2	$40,000	2
List 1						
List 2						
List 3						
Total	$ 30,000		$ 35,000		$ 40,000	

3. Annual O&M Costs of Optimized Remedy

O&M Category	Optimistic Scenario	Most-Likely Scenario	Reasonable Worst-Case Scenario
Labor: project management, reporting, technical support		$ 40,000	
Labor: system operation		$ 30,000	
Labor: groundwater sampling		$ 15,000	
Utilities (gas, electric, water, sewer, etc.)		$ 16,000	
Consumables (GAC, chemicals, etc.)		$ 3,000	
Discharge or disposal costs		$ 1,500	
Laboratory analysis		$ 8,000	
Other (parts, routine maintenance, etc.)		$ 5,000	
O&M Total	$ -	$ 118,500	$ -

Notes:

- O&M costs for system with new well represent a small increase in costs for utilities and laboratory analysis.

Step 1b: Background Cost Information - Optimized P&T System (continued)

4. Estimated Operational Life

	Optimistic Scenario	Most-Likely Scenario	Reasonable Worst-Case Scenario
Years of Continued O&M Costs of Current P&T System	10 years	20 years	30 years

Notes:

5. Non-Routine Costs of Optimized Remedy

Cost Category	Optimistic Scenario		Most-Likely Scenario		Reasonable Worst-Case Scenario	
	Cost	Year(s) Incurred	Cost	Year(s) Incurred	Cost	Year(s) Incurred
Additional evaluation						
- item 1						
- Item 2						
- Item 3						
Non-routine maintenance/equipment replacement						
- item 1						
- Item 2						
- Item 3						
Other						
- Item 1						
- Item 2						
- Item 3						

Notes:

- "Year(s) incurred" refers to the number of years from the present as used in Steps 2 and 3 (e.g., use "2" to refer to two years from present and use "5, 10, …" to refer to five-year intervals from the present.)

Step 1c: Background Cost Information - New Remedial Approach

1. Years of Continued O&M Costs of Current P&T System During Planning

	Optimistic Scenario	Most-Likely Scenario	Reasonable Worst-Case Scenario
Years of Continued O&M Costs of Current P&T System During Planning	1 year	2 years	2 years

2. Implementing/Planning Costs

Cost Category	Optimistic Scenario		Most-Likely Scenario		Reasonable Worst-Case Scenario	
	Cost	Year(s) Incurred	Cost	Year(s) Incurred	Cost	Year(s) Incurred
Conceptual design						
Additional research and investigation						
Pilot testing						
Remedy design, work Plan, etc.						
Permitting						
Installation and oversight						
Documentation						
Other (all of the above, lump sum)	$ 350,000	2	$ 400,000	2	$ 450,000	3
Total	$ 350,000		$ 400,000		$ 450,000	

Notes:

- "Year(s) incurred" refers to the number of years from the present as used in Steps 2 and 3 (e.g., use "2" to refer to two years from present and use "5, 10, …" to refer to five-year intervals from the present.)

3. Annual O&M Costs of New Remedy

O&M Category	Optimistic Scenario	Most-Likely Scenario	Reasonable Worst-Case Scenario
Labor: project management, reporting, technical support	$ 30,000	$ 30,000	See note
Labor: system operation	$ 15,000	$ 15,000	See note
Labor: groundwater sampling	$ 15,000	$ 15,000	See note
Utilities (gas, electric, water, sewer, etc.)	$ 15,000	$ 15,000	See note
Consumables (GAC, chemicals, etc.)	$ 3,000	$ 3,000	See note
Discharge or disposal costs	$ 500	$ 500	See note
Laboratory analysis	$ 4,000	$ 4,000	See note
Other (parts, routine maintenance, etc.)	$ 1,000	$ 1,000	See note
O&M Total	$ 83,500	$ 83,500	See note

Notes:

- For the reasonable worst case scenario, the sparge system would operate for four years at $83,500 per year, but that after air sparging is completed, monitoring would suggest that the remaining portion of the plume is not stable, and operation of the P&T system would resume for another 5 years at $117,000 per year.

Step 1c: Background Cost Information - New Remedial Approach (continued)

4. Estimated Operational Life

	Optimistic Scenario	Most-Likely Scenario	Reasonable Worst-Case Scenario
Years of Continued O&M Costs of Current P&T System	1 year	3 years	See note

Notes:

- For the reasonable worst-case scenario, the sparge system would operate for four years at $83,500 per year, but after air sparging is completed, monitoring would suggest that the remaining portion of the plume is not stable, and operation of the P&T system would resume for another 5 years at $117,000 per year.

5. Non-Routine Costs of Optimized Remedy

Cost Category	Optimistic Scenario		Most-Likely Scenario		Reasonable Worst-Case Scenario	
	Cost	Year(s) Incurred	Cost	Year(s) Incurred	Cost	Year(s) Incurred
Additional evaluation						
- item 1						
- Item 2						
- Item 3						
Non-routine maintenance/equipment replacement						
- restart P&T system					$50,000	4
- item 2						
- item 3						
Other						
- Item 1						
- Item 2						
- Item 3						

Notes:

- "Year(s) incurred" refers to the number of years from the present as used in Steps 2 and 3 (e.g., use "2" to refer to two years from present and use "5, 10, …" to refer to five-year intervals from the present.)

- The optimistic and most-likely scenarios assume that the air sparging system will address remaining contamination and allow for air sparging system shut down in 1 and 2 years, respectively.

- The reasonable worst-case scenario assumes that P&T must resume after air sparging is completed. It is assumed that up to $50,000 would be required to restart the P&T system after four years of not operating.

Step 2a: Life-Cycle Costs

	Existing P&T System			Optimized P&T System			New Remedial Approach		
Year	**Optimistic**	**Most-Likely**	**Reasonable Worst-Case**	**Optimistic**	**Most-Likely**	**Reasonable Worst-Case**	**Optimistic**	**Most-Likely**	**Reasonable Worst-Case**
1	$ 117,000	$ 117,000	$ 117,000	$ 147,000	$ 117,000	$ 117,000	$ 117,000	$ 117,000	$ 117,000
2	$ 117,000	$ 117,000	$ 117,000	$ 118,500	$ 152,000	$ 157,000	$ 467,000	$ 517,000	$ 117,000
3	$ 117,000	$ 117,000	$ 117,000	$ 118,500	$ 118,500	$ 118,500	$ 83,500	$ 83,500	$ 567,000
4	$ 117,000	$ 117,000	$ 117,000	$ 118,500	$ 118,500	$ 118,500	$ -	$ 83,500	$ 83,500
5	$ 117,000	$ 117,000	$ 117,000	$ 118,500	$ 118,500	$ 118,500	$ -	$ 83,500	$ 83,500
6	$ 117,000	$ 117,000	$ 117,000	$ 118,500	$ 118,500	$ 118,500	$ -	$ -	$ 83,500
7	$ 117,000	$ 117,000	$ 117,000	$ 118,500	$ 118,500	$ 118,500	$ -	$ -	$ 83,500
8	$ 117,000	$ 117,000	$ 117,000	$ 118,500	$ 118,500	$ 118,500	$ -	$ -	$ 167,000
9	$ 117,000	$ 117,000	$ 117,000	$ 118,500	$ 118,500	$ 118,500	$ -	$ -	$ 117,000
10	$ 117,000	$ 117,000	$ 117,000	$ 118,500	$ 118,500	$ 118,500	$ -	$ -	$ 117,000
11	$ 117,000	$ 117,000	$ 117,000	$ -	$ 118,500	$ 118,500	$ -	$ -	$ 117,000
12	$ 117,000	$ 117,000	$ 117,000	$ -	$ 118,500	$ 118,500	$ -	$ -	$ 117,000
13	$ 117,000	$ 117,000	$ 117,000	$ -	$ 118,500	$ 118,500	$ -	$ -	$ -
14	$ 117,000	$ 117,000	$ 117,000	$ -	$ 118,500	$ 118,500	$ -	$ -	$ -
15	$ 117,000	$ 117,000	$ 117,000	$ -	$ 118,500	$ 118,500	$ -	$ -	$ -
16	$ 117,000	$ 117,000	$ 117,000	$ -	$ 118,500	$ 118,500	$ -	$ -	$ -
17	$ 117,000	$ 117,000	$ 117,000	$ -	$ 118,500	$ 118,500	$ -	$ -	$ -
18	$ 117,000	$ 117,000	$ 117,000	$ -	$ 118,500	$ 118,500	$ -	$ -	$ -
19	$ 117,000	$ 117,000	$ 117,000	$ -	$ 118,500	$ 118,500	$ -	$ -	$ -
20	$ 117,000	$ 117,000	$ 117,000	$ -	$ 118,500	$ 118,500	$ -	$ -	$ -
21	$ -	$ 117,000	$ 117,000	$ -	$ -	$ 118,500	$ -	$ -	$ -
22	$ -	$ 117,000	$ 117,000	$ -	$ -	$ 118,500	$ -	$ -	$ -
23	$ -	$ 117,000	$ 117,000	$ -	$ -	$ 118,500	$ -	$ -	$ -
24	$ -	$ 117,000	$ 117,000	$ -	$ -	$ 118,500	$ -	$ -	$ -
25	$ -	$ 117,000	$ 117,000	$ -	$ -	$ 118,500	$ -	$ -	$ -
26	$ -	$ 117,000	$ 117,000	$ -	$ -	$ 118,500	$ -	$ -	$ -
27	$ -	$ 117,000	$ 117,000	$ -	$ -	$ 118,500	$ -	$ -	$ -
28	$ -	$ 117,000	$ 117,000	$ -	$ -	$ 118,500	$ -	$ -	$ -
29	$ -	$ 117,000	$ 117,000	$ -	$ -	$ 118,500	$ -	$ -	$ -
30+	$ -	$ 117,000	$ 1,209,960	$ -	$ -	$ 118,500	$ -	$ -	$ -
Totals	$ 2,340,000	$ 3,510,000	$ 4,602,960	$ 1,213,500	$ 2,402,000	$ 3,592,000	$ 667,500	$ 884,500	$ 1,770,000
	Likelihood that Each Scenario Will Occur			**Likelihood that Each Scenario Will Occur**			**Likelihood that Each Scenario Will Occur**		
	30%	40%	30%	30%	40%	30%	20%	50%	30%

Notes:

-Noted costs are based on information provided in Steps 1a, 1b, and 1c. Costs are not discounted in this Step. They are discounted in Step 2b.

-The likelihoods for each remedial option adds to 100%. These likelihoods are based on professional judgment and experience with previous applications of the technology by the project team.

-Inflation is not considered in this step. The application of the discount rate in Step 2b accounts for inflation.

- Costs that are incurred after year 30 have been included as discounted values in year 30 using the discount rate from Step 2b.

- Costs for system replacement are not included for the "most-likely" scenario of the "new remedial approach" because it is assumed that the existing components will last for the remaining few years of operation.

-Operation of the optimized P&T system and the new remedial approach begin in the year that the capital expenses are made.

Step 2b: Net Present Value of Life-Cycle Costs

Year	Discount Factor	Existing P&T System Annual Costs in Present Value			Optimized P&T System Annual Costs in Present Value			New Remedial Approach Annual Costs in Present Value		
	3.1%	Optimistic	Most-likely	Reasonable Worst-Case	Optimistic	Most-likely	Reasonable Worst-Case	Optimistic	Most-likely	Reasonable Worst-Case
1	1.000	$ 117,000	$ 117,000	$ 117,000	$ 147,000	$ 117,000	$ 117,000	$ 117,000	$ 117,000	$ 117,000
2	0.970	$ 113,482	$ 113,482	$ 113,482	$ 114,937	$ 147,430	$ 152,279	$ 452,958	$ 501,455	$ 113,482
3	0.941	$ 110,070	$ 110,070	$ 110,070	$ 111,481	$ 111,481	$ 111,481	$ 78,554	$ 78,554	$ 533,416
4	0.912	$ 106,760	$ 106,760	$ 106,760	$ 108,129	$ 108,129	$ 108,129	$ -	$ 76,192	$ 76,192
5	0.885	$ 103,550	$ 103,550	$ 103,550	$ 104,878	$ 104,878	$ 104,878	$ -	$ 73,901	$ 73,901
6	0.858	$ 100,437	$ 100,437	$ 100,437	$ 101,724	$ 101,724	$ 101,724	$ -	$ -	$ 71,679
7	0.833	$ 97,417	$ 97,417	$ 97,417	$ 98,666	$ 98,666	$ 98,666	$ -	$ -	$ 69,524
8	0.808	$ 94,488	$ 94,488	$ 94,488	$ 95,699	$ 95,699	$ 95,699	$ -	$ -	$ 134,867
9	0.783	$ 91,647	$ 91,647	$ 91,647	$ 92,822	$ 92,822	$ 92,822	$ -	$ -	$ 91,647
10	0.760	$ 88,891	$ 88,891	$ 88,891	$ 90,031	$ 90,031	$ 90,031	$ -	$ -	$ 88,891
11	0.737	$ 86,218	$ 86,218	$ 86,218	$ -	$ 87,324	$ 87,324	$ -	$ -	$ 86,218
12	0.715	$ 83,626	$ 83,626	$ 83,626	$ -	$ 84,698	$ 84,698	$ -	$ -	$ 83,626
13	0.693	$ 81,111	$ 81,111	$ 81,111	$ -	$ 82,151	$ 82,151	$ -	$ -	$ -
14	0.672	$ 78,673	$ 78,673	$ 78,673	$ -	$ 79,681	$ 79,681	$ -	$ -	$ -
15	0.652	$ 76,307	$ 76,307	$ 76,307	$ -	$ 77,285	$ 77,285	$ -	$ -	$ -
16	0.633	$ 74,013	$ 74,013	$ 74,013	$ -	$ 74,962	$ 74,962	$ -	$ -	$ -
17	0.614	$ 71,787	$ 71,787	$ 71,787	$ -	$ 72,708	$ 72,708	$ -	$ -	$ -
18	0.595	$ 69,629	$ 69,629	$ 69,629	$ -	$ 70,521	$ 70,521	$ -	$ -	$ -
19	0.577	$ 67,535	$ 67,535	$ 67,535	$ -	$ 68,401	$ 68,401	$ -	$ -	$ -
20	0.560	$ 65,505	$ 65,505	$ 65,505	$ -	$ 66,344	$ 66,344	$ -	$ -	$ -
21	0.543	$ -	$ 63,535	$ 63,535	$ -	$ -	$ 64,349	$ -	$ -	$ -
22	0.527	$ -	$ 61,625	$ 61,625	$ -	$ -	$ 62,415	$ -	$ -	$ -
23	0.511	$ -	$ 59,772	$ 59,772	$ -	$ -	$ 60,538	$ -	$ -	$ -
24	0.496	$ -	$ 57,974	$ 57,974	$ -	$ -	$ 58,718	$ -	$ -	$ -
25	0.481	$ -	$ 56,231	$ 56,231	$ -	$ -	$ 56,952	$ -	$ -	$ -
26	0.466	$ -	$ 54,541	$ 54,541	$ -	$ -	$ 55,240	$ -	$ -	$ -
27	0.452	$ -	$ 52,901	$ 52,901	$ -	$ -	$ 53,579	$ -	$ -	$ -
28	0.439	$ -	$ 51,310	$ 51,310	$ -	$ -	$ 51,968	$ -	$ -	$ -
29	0.425	$ -	$ 49,767	$ 49,767	$ -	$ -	$ 50,405	$ -	$ -	$ -
30+	0.413	$ -	$ 48,271	$ 499,194	$ -	$ -	$ 48,890	$ -	$ -	$ -
Totals		$ 1,778,145	$ 2,334,071	$ 2,784,994	$ 1,065,366	$ 1,831,934	$ 2,399,837	$ 648,512	$ 847,102	$ 1,540,443
		Likelihood that Each Scenario Will Occur			Likelihood that Each Scenario Will Occur			Likelihood that Each Scenario Will Occur		
	N/A	30%	40%	30%	30%	40%	30%	25%	50%	25%

Notes:

- A discount rate of 3.1% has been used based on U.S. Office of Management and Budget Circular A-94, Guidelines and Discount Rates for Cost-Benefit Analysis of Federal Programs. This rate includes the affect of inflation, so inflation is not considered separately. A higher discount rate would result in lower present value costs.

Step 3: Cost Comparison

Year	Optimized P&T System Cum. Cash Flow (NPV) Relative to Most-Likely Case for Existing System			New Remedial Approach Cum. Cash Flow (NPV) Relative to Most Likely Case for Existing System		
	Optimistic	Most-Likely	Reasonable Worst-Case	Optimistic	Most-Likely	Reasonable Worst-Case
1	$ (30,000)	$ -	$ -	$ -	$ -	$ -
2	$ (31,455)	$ (33,948)	$ (38,797)	$ (339,476)	$ (387,973)	$ -
3	$ (32,866)	$ (35,359)	$ (40,208)	$ (307,960)	$ (356,457)	$ (423,346)
4	$ (34,235)	$ (36,727)	$ (41,577)	$ (201,200)	$ (325,889)	$ (392,778)
5	$ (35,562)	$ (38,055)	$ (42,905)	$ (97,650)	$ (296,240)	$ (363,129)
6	$ (36,850)	$ (39,343)	$ (44,192)	$ 2,787	$ (195,803)	$ (334,371)
7	$ (38,099)	$ (40,592)	$ (45,441)	$ 100,204	$ (98,386)	$ (306,478)
8	$ (39,310)	$ (41,803)	$ (46,653)	$ 194,691	$ (3,899)	$ (346,858)
9	$ (40,485)	$ (42,978)	$ (47,828)	$ 286,338	$ 87,748	$ (346,858)
10	$ (41,625)	$ (44,118)	$ (48,967)	$ 375,229	$ 176,639	$ (346,858)
11	$ 44,593	$ (45,223)	$ (50,073)	$ 461,447	$ 262,857	$ (346,858)
12	$ 128,219	$ (46,295)	$ (51,145)	$ 545,073	$ 346,483	$ (346,858)
13	$ 209,331	$ (47,335)	$ (52,185)	$ 626,184	$ 427,594	$ (265,746)
14	$ 288,003	$ (48,344)	$ (53,193)	$ 704,857	$ 506,267	$ (187,074)
15	$ 364,310	$ (49,322)	$ (54,172)	$ 781,164	$ 582,574	$ (110,767)
16	$ 438,323	$ (50,271)	$ (55,120)	$ 855,177	$ 656,587	$ (36,754)
17	$ 510,110	$ (51,191)	$ (56,041)	$ 926,964	$ 728,374	$ 35,033
18	$ 579,739	$ (52,084)	$ (56,933)	$ 996,593	$ 798,003	$ 104,662
19	$ 647,274	$ (52,950)	$ (57,799)	$ 1,064,128	$ 865,538	$ 172,197
20	$ 712,778	$ (53,789)	$ (58,639)	$ 1,129,632	$ 931,042	$ 237,702
21	$ 776,313	$ 9,745	$ (59,454)	$ 1,193,167	$ 994,577	$ 301,237
22	$ 837,938	$ 71,370	$ (60,244)	$ 1,254,792	$ 1,056,202	$ 362,861
23	$ 897,710	$ 131,142	$ (61,010)	$ 1,314,563	$ 1,115,973	$ 422,633
24	$ 955,684	$ 189,116	$ (61,753)	$ 1,372,538	$ 1,173,948	$ 480,607
25	$ 1,011,915	$ 245,347	$ (62,474)	$ 1,428,769	$ 1,230,179	$ 536,839
26	$ 1,066,456	$ 299,888	$ (63,173)	$ 1,483,310	$ 1,284,720	$ 591,379
27	$ 1,119,356	$ 352,789	$ (63,852)	$ 1,536,210	$ 1,337,620	$ 644,280
28	$ 1,170,666	$ 404,098	$ (64,509)	$ 1,587,520	$ 1,388,930	$ 695,590
29	$ 1,220,434	$ 453,866	$ (65,148)	$ 1,637,287	$ 1,438,697	$ 745,357
30+	$ 1,268,704	$ 502,137	$ (65,766)	$ 1,685,558	$ 1,486,968	$ 793,628
	Likelihood that Each Scenario Will Occur			**Likelihood that Each Scenario Will Occur**		
	30%	40%	30%	20%	50%	30%

Notes:
- The indicated values represent the cumulative difference in costs between the various scenarios for the indicated remedial option and the most-likely scenario for continuing with existing P&T system as noted in Step 2b. This difference in costs over time can be used to track the "investment" made in optimizing the P&T system or moving forward with the alternative remedial approach.
- Values in parentheses indicate an investment (i.e., a greater expenditure for the indicated remedial approach than for the most-likely scenario for the existing P&T system). Values without parentheses indicates income (i.e., savings relative to the costs associated with the mostly likely scenario for the existing P&T system).
- The likelihoods for each remedial option adds to 100%. These likelihoods are based on professional judgment and experience with previous applications of the technology by the project team.

Step 3: Cost Comparison (continued)

	Existing P&T System		Optimized P&T System				New Remedial Approach			
	Most-Likely Scenario	Expected Value	Most-Likely Scenario		Expected Value		Most Likely Scenario		Expected Value	
			Total	Net Change Compared to Existing System	Total	Net Change Compared to Existing System	Total	Net Change Compared to Existing System	Total	Net Change Compared to Existing System
NPV of Life-Cycle Costs	$ 2,334,071	$ 2,302,570	$ 1,831,934	$ (502,137)	$ 1,772,335	$ (530,235)	$ 847,102	$ (1,486,968)	$ 970,790	$ (1,331,780)
Year 1 cash flow	$ (117,000)	$ (117,000)	$ (117,000)	$ -	$ (126,000)	$ (9,000)	$ (117,000)	$ -	$ (117,000)	$ -
Year 2 cash flow (discounted)	$ (113,482)	$ (113,482)	$ (147,430)	$ (33,948)	$ (139,137)	$ (25,655)	$ (501,455)	$ (387,973)	$ (392,338)	$ (278,855)
Year 3 cash flow (discounted)	$ (110,070)	$ (110,070)	$ (111,481)	$ (1,411)	$ (111,481)	$ (1,411)	$ (78,554)	$ 31,516	$ (192,270)	$ (82,200)
Cum. cash flow at year 5 (discounted)	$ (550,863)	$ (550,863)	$ (588,918)	$ (38,055)	$ (589,625)	$ (38,762)	$ (847,102)	$ (296,240)	$ (427,577)	$ 123,286
Total investment*	N/A	N/A	$ 35,000	$ 35,000	$ 35,000	$ 35,000	$ 400,000	$ 400,000	$ 400,000	$ 400,000
Year with highest investment*	N/A	N/A	2		1.70		2		2.30	
Year of payback**	N/A	N/A	Year 21		Year 21		Year 9		Year 11	
Net cum. cash flow at year 10	N/A	N/A	$ (44,118)	$ (44,118)	$ (44,825)	$ (44,825)	$ 176,639	$ 176,639	$ 59,308	$ 59,308
Average Annual Percentage Return (AAPR) as of Year 10**	N/A	N/A	Net Loss		Net Loss		4.15%		1.60%	

Notes:

- "Net Change Compared to Existing System" is taking the "Total" and substracting the corresponding value from the existing system.

** Investment refers to capital costs "invested" in system modifications or a new remedial technology (based on information documented in Step 1).*

*** Payback is defined as the number of years (from the year with the highest investment) that it takes to get a positive cumulative cash flow.*

**** For this example, AARP is calculated using the following parameters:*

- *"Total investment" from the above table corresponds to the "invested capital" from Exhibit 6.*
- *"Net cum. cash flow at Year 10" from the above table corresponds to the "net savings at year 10" from Exhibit 6.*
- *The number of years from the "Year with the highest investment" to Year 10 corresponds to the "period of investment" from Exhibit 6.*

Step 4: Information Gathering

1. Information to Gather

Information	Optimistic Scenario	Most Likely Scenario	Reasonable Worst-Case Scenario
	Cost	Cost	Cost
Pilot test (lump sum)		$ 50,000	
Modeling effort and analysis		$ 25,000	
- item 3			
- item 4			
- item 5			
- item 6			
- item 7			
- item 8			
- item 9			
- item 10			
- item 11			
- item 12			
- item 13			
- item 14			
Total	$ -	$ 75,000	$ -

Notes:

- The pilot test would be conducted to help determine the spacing for the sparge points and soil vapor extraction points.

- The modeling effort and analysis would be conducted to determine if the plume would be stable and/or decreasing in area if the source area were addressed. If the modeling effort demonstrates that the plume would be stable and/or decreasing, then the P&T system would likely be shut down once air sparging was implemented. If the modeling effort demonstrates that the plume would not be stable after the source area was addressed, continued P&T might still be required as is represented in the reasonable worst-case scenario for the "new remedial approach" in Steps 1, 2, and 3.

Step 5: Conclusions and Decision

Conclusion

The cost comparison demonstrates that the discounted life-cycle costs for both the optimized system and the new remedial approach with air sparging are lower than continuing to operate the existing system. Both of these options, however, also have capital costs associated with them. For the optimized P&T system, the capital costs are paid back by approximately Year 20. For the new remedial approach, the payback will likely be around Year 10. Over the first 10 years, the only option that is likely to provide a positive return is the air sparging option; however, that return on investment is relatively low compared to some other investment options. With the air sparging option, it is relatively likely that the site can be closed substantially earlier than continuing with P&T.

Decision

The cost comparison demonstrates that for this organization, the potential benefits of reducing cost and closing the site earlier are worth the capital investment of gathering more information about an air sparging option. The organization will proceed with a modeling effort to determine the likelihood of the plume to remain stable or decrease in size in the absence of pumping after the source is addressed with air sparging. If the modeling suggests this is likely, then the organization will proceed with a pilot test to determine the appropriate spacing for sparge points and soil vapor extraction wells. If the pilot test demonstrates that air sparging is practical, then the organization will move forward with a full-scale application.

Cost Comparison Framework
Illustrative Example #3

Brief Site Description

The site is the location of a former chemical manufacturing plant where several thousand gallons of benzene and chlorinated benzene compounds (e.g., chlorobenzene, dichlorobenzene, and trichlorobenzene) where released into the subsurface. The water table aquifer (50 feet of saturated thickness) is impacted by both dissolved phase contamination and DNAPL. The dissolved plume is over 10 acres in area and the DNAPL plume (both free and residual phase) is approximately 2 acres. A P&T system has been operating at the site for over five years and has effectively prevented further horizontal or vertical migration of dissolved contamination. The shallow aquifer, which extends to a depth of 100 feet below ground surface, is underlain by a silt/clay aquitard that is approximately 50 feet thick and has effectively prevented additional vertical migration of DNAPL. The DNAPL plume has been relatively stable and no horizontal migration of DNAPL has been observed since the Remedial Investigation over 10 years ago.

The P&T system has an extraction rate of approximately 50 gpm and a total VOC influent concentration of approximately 2,000 ug/L. Ground water extraction occurs downgradient of the source area. The treatment system consists of an air stripper, off-gas treatment with vapor phase GAC, and discharge of treated water to a nearby creek. Although the P&T system operates effectively to control contaminant migration, it is expected to operate for an “indefinite period”, and the project team is interested in the cost-effectiveness of aggressive removal of the DNAPL to substantially reduce the operational life-time of the P&T system.

The tables on the following pages document the project team’s cost comparison.

Remedial Considerations for Cost Comparison

The site team is considering the following options:

- Continued operation of the current P&T system (which has recently been optimized)

- Full scale in-situ chemical oxidation in the source area to restore that portion of the aquifer and hopefully allow for P&T system shutdown within 15 years

Concepts Illustrated

- The annual costs for O&M of the P&T system (with or without the application of in-situ chemical oxidation) are relatively well understood because the cost projections are based on three years of past invoices that demonstrate consistent costs from year to year. As such, only "most-likely" annual O&M costs ($160,000 per year) are entered, with a likelihood of 100%. [Step 1a, Table 1]

- Future non-routine costs, such as replacement of major system components, are included in year 20. Costs for evaluations associated with Five-Year Reviews are included every five years. Alternatively, these costs could have been averaged into the annual costs. [Step 1a, Table 3]

- In cases where a remedy is expected to operate for more than 30 years, the discounted costs of continuing remediation beyond year 30 are included as a one lump cost. For the "Existing P&T System", the costs for years 30 to 60 are included under the "most-likely" scenario and for years 30 to 90 under the "reasonable worst-case" scenario. The costs for these "out years" is determined by averaging the annual cost (including non-routine costs) and applying that average cost over the specified time frame using the discount factor from Step 2b. [Step 2a, "Year 30+"]

- The system was recently optimized, so the sections of the form dealing with an optimized system were not used. However, if the site team wished to include an option that might lower the annual O&M costs after an up-front capital investment, the information could have been entered into the "optimized system" sections of the form. [Step 1b]

Conclusions

The conclusion from the cost comparison and the decision made by the hypothetical organization are provided on the last page of this example. The cost comparison for the chemical oxidation alternative shows lower life-cycle costs but a relatively long payback period and a negative return on investment over the first 10 years. Different organizations might interpret these results differently. An organization that wants a chance at removing the environmental liability from its balance sheet in a relatively short time frame, and does not have a competing use for the money, might elect to move forward with the new remedial approach. Similarly, an organization that chooses not to discount future costs would notice a substantial decrease in life-cycle costs associated with the chemical oxidation alternative (see "Totals" under Step 2a). However, an organization that has a competing use for additional capital associated with the new remedial approach (such as investing in its product line or advertising) may opt for the competing use of the money because it is a better investment for that organization over the long term. This particular project team does not see the value in proceeding with the new remedial approach on a full-scale basis, it has decided against a pilot test, and costs that would have been incurred for conducting a pilot test can be reserved for other activities at the site (or within the organization).

Step 1a: Background Cost Information - Existing P&T System

1. Annual O&M Costs

O&M Category	Optimistic Scenario	Most-Likely Scenario	Reasonable Worst-Case Scenario
Labor: project management, reporting, technical support		$ 40,000	
Labor: system operation		$ 30,000	
Labor: groundwater sampling		$ 25,000	
Utilities (gas, electric, water, sewer, etc.)		$ 15,000	
Consumables (GAC, chemicals, etc.)		$ 32,500	
Discharge or disposal costs		$ 2,500	
Laboratory analysis		$ 10,000	
Other (parts, routine maintenance, etc.)		$ 5,000	
O&M Total	$ -	$ 160,000	$ -

Notes:

- *O&M costs were obtained from reviewing past three years of invoices.*
- *System has been performing reliably and was recently optimized.*
- *No additional optimization opportunities forcasted.*
- *Ground water sampling and reporting conducted annually.*

2. Estimated Operational Life

	Optimistic Scenario	Most-Likely Scenario	Reasonable Worst-Case Scenario
Years of Continued O&M Costs of Current P&T System During Planning	30 years	60 years	90 years

Notes: The operational life for the P&T system is "indefinite". Three separate time frames are provided to demonstrate the effect of operational life on the cost comparison with the remedial alternative.

3. Non-Routine Costs

Cost Category	Optimistic Scenario		Most-Likely Scenario		Reasonable Worst-Case Scenario	
	Cost	Year(s) Incurred	Cost	Year(s) Incurred	Cost	Year(s) Incurred
Additional evaluation						
- Five-year review			$ 20,000	5,10,15…		
- Item 2						
- Item 3						
Non-routine maintenance/equipment replacement						
- Replace air stripper			$ 100,000	20,40,…		
- Building repairs			$ 10,000	20,40,…		
- Replace other system components			$ 50,000	20,40,…		
Other						
- Item 1						
- Item 2						
- Item 3						

Notes:

- *"Year(s) incurred" refers to the number of years from the present as used in Steps 2 and 3 (e.g., use "2" to refer to two years from present and use "5, 10, …" to refer to five-year intervals from the present.)*
- *Five-year reviews are expected to be conducted every five years.*
- *Replacement of major system components will likely be needed every 20 years.*

Step 1b: Background Cost Information - Optimized P&T System

1. Years of Continued O&M Costs of Current P&T System During Planning

	Optimistic Scenario	Most-Likely Scenario	Reasonable Worst-Case Scenario
Years of Continued O&M Costs of Current P&T System During Planning	N/A	N/A	N/A

2. Implementing/Planning Costs

Cost Category	Optimistic Scenario		Most-Likely Scenario		Reasonable Worst-Case Scenario	
	Cost	Year(s) Incurred	Cost	Year(s) Incurred	Cost	Year(s) Incurred
Data analysis / Feasibility study	N/A		N/A		N/A	
Remedy design, work plans, etc.	N/A		N/A		N/A	
Permitting	N/A		N/A		N/A	
Installation / Oversight	N/A		N/A		N/A	
Other	N/A		N/A		N/A	
List 1	N/A		N/A		N/A	
List 2	N/A		N/A		N/A	
List 3	N/A		N/A		N/A	
Total	$ -		$ -		$ -	

3. Annual O&M Costs of Optimized Remedy

O&M Category	Optimistic Scenario	Most-Likely Scenario	Reasonable Worst-Case Scenario
Labor: project management, reporting, technical support	N/A	N/A	N/A
Labor: system operation	N/A	N/A	N/A
Labor: groundwater sampling	N/A	N/A	N/A
Utilities (gas, electric, water, sewer, etc.)	N/A	N/A	N/A
Consumables (GAC, chemicals, etc.)	N/A	N/A	N/A
Discharge or disposal costs	N/A	N/A	N/A
Laboratory analysis	N/A	N/A	N/A
Other (parts, routine maintenance, etc.)	N/A	N/A	N/A
O&M Total	$ -	$ -	$ -

Notes:

Step 1b: Background Cost Information - Optimized P&T System (continued)

4. Estimated Operational Life

	Optimistic Scenario	Most-Likely Scenario	Reasonable Worst-Case Scenario
Years of Continued O&M Costs of Current P&T System During Planning	N/A	N/A	N/A

Notes:

5. Non-Routine Costs of Optimized Remedy

Cost Category	Optimistic Scenario		Most-Likely Scenario		Reasonable Worst-Case Scenario	
	Cost	Year(s) Incurred	Cost	Year(s) Incurred	Cost	Year(s) Incurred
Additional evaluation						
- item 1						
- Item 2						
- Item 3						
Non-routine maintenance/equipment replacement						
- item 1						
- Item 2						
- Item 3						
Other						
- Item 1						
- Item 2						
- Item 3						

Notes:

- No additional optimzation likely… system already optimized.

Step 1c: Background Cost Information - New Remedial Approach

1. Years of Continued O&M Costs of Current P&T System During Planning

	Optimistic Scenario	Most-Likely Scenario	Reasonable Worst-Case Scenario
Years of Continued O&M Costs of Current P&T System During Planning	2 years	2 years	3 years

2. Implementing/Planning Costs

Cost Category	Optimistic Scenario		Most-Likely Scenario		Reasonable Worst-Case Scenario	
	Cost	Year(s) Incurred	Cost	Year(s) Incurred	Cost	Year(s) Incurred
Conceptual design						
Additional research and investigation						
Pilot testing						
Remedy design, work Plan, etc.						
Permitting						
Installation and oversight						
Documentation						
Other (all of the above, lump sum)	$ 1,250,000	3	$1,500,000	3	$ 1,750,000	4
Total	$ 1,250,000		$1,500,000		$ 1,750,000	

Notes:

- "Year(s) incurred" refers to the number of years from the present as used in Steps 2 and 3 (e.g., use "2" to refer to two years from present and use "5, 10, …" to refer to five-year intervals from the present.)

3. Annual O&M Costs of New Remedy

O&M Category	Optimistic Scenario	Most-Likely Scenario	Reasonable Worst-Case Scenario
Labor: project management, reporting, technical support		$ 40,000	
Labor: system operation		$ 30,000	
Labor: groundwater sampling		$ 25,000	
Utilities (gas, electric, water, sewer, etc.)		$ 15,000	
Consumables (GAC, chemicals, etc.)		$ 16,000	
Discharge or disposal costs		$ 1,000	
Laboratory analysis		$ 10,000	
Other (parts, routine maintenance, etc.)		$ 5,000	
O&M Total	$ -	$ 142,000	$ -

Notes:

- The primary cost for implementation is in-situ chemical oxidation. Costs for in-situ chemical oxidation is based on detailed, site-specific estimates provided by multiple vendors. The estimates do not provide a guarantee of performance.

- All cases assume approximately 100 injection points, 50 in the shallow/intermediate portion of the water table aquifer and 50 in the deep portion of the water table aquifer.

Step 1c: Background Cost Information - New Remedial Approach (continued)

4. Estimated Operational Life

	Optimistic Scenario	Most Likely Scenario	Reasonable Worst-Case Scenario
Years of Continued O&M Costs of Current P&T System During Planning	10	15	30+

Notes:

- Time frames indicated denote operational life after the implementation of chemical oxidation.

5. Non-Routine Costs of Optimized Remedy

Cost Category	Optimistic Scenario		Most Likely Scenario		Reasonable Worst-Case Scenario	
	Cost	Year(s) Incurred	Cost	Year(s) Incurred	Cost	Year(s) Incurred
Additional evaluation						
- Five-Year Review	$ 20,000	5,10,…	$ 20,000	5,10,…	$ 20,000	5,10,…
- Item 2						
- Item 3						
Non-routine maintenance/equipment replacement						
- replace air stripper					$ 100,000	20,40,…
- building repairs					$ 10,000	20,40,…
- replace other system components					$ 50,000	20,40,…
Other						
- Item 1						
- Item 2						
- Item 3						

Notes:

- "Year(s) incurred" refers to the number of years from the present as used in Steps 2 and 3 (e.g., use "2" to refer to two years from present and use "5, 10, …" to refer to five-year intervals from the present.)

- The optimistic case assumes two applications of Fenton's reagent followed by two confirmation monitoring events. The P&T system can be shut down in 10 years.

- The most likely case assumes three applications of Fentons' reagent, including three progress/confirmation monitoring events. The P&T system can be shut down in 15 years.

- The reasonable worst-case assumes four applications of Fentons' reagent, including four progress/confirmation monitoring events. The P&T system will continue to operate for 30 or more years.

Step 2a: Life-Cycle Costs

	Existing P&T System			Optimized P&T System			New Remedial Approach		
Year	Optimistic	Most-Likely	Reasonable Worst-Case	Optimistic	Most-Likely	Reasonable Worst-Case	Optimistic	Most-Likely	Reasonable Worst-Case
1	$ 160,000	$ 160,000	$ 160,000	$ -	$ -	$ -	$ 160,000	$ 160,000	$ 160,000
2	$ 160,000	$ 160,000	$ 160,000	$ -	$ -	$ -	$ 160,000	$ 160,000	$ 160,000
3	$ 160,000	$ 160,000	$ 160,000	$ -	$ -	$ -	$ 1,250,000	$ 1,500,000	$ 160,000
4	$ 160,000	$ 160,000	$ 160,000	$ -	$ -	$ -	$ 143,500	$ 143,500	$ 1,750,000
5	$ 180,000	$ 180,000	$ 180,000	$ -	$ -	$ -	$ 163,500	$ 163,500	$ 162,000
6	$ 160,000	$ 160,000	$ 160,000	$ -	$ -	$ -	$ 143,500	$ 143,500	$ 142,000
7	$ 160,000	$ 160,000	$ 160,000	$ -	$ -	$ -	$ 143,500	$ 143,500	$ 142,000
8	$ 160,000	$ 160,000	$ 160,000	$ -	$ -	$ -	$ 143,500	$ 143,500	$ 142,000
9	$ 160,000	$ 160,000	$ 160,000	$ -	$ -	$ -	$ 143,500	$ 143,500	$ 142,000
10	$ 180,000	$ 180,000	$ 180,000	$ -	$ -	$ -	$ 163,500	$ 163,500	$ 162,000
11	$ 160,000	$ 160,000	$ 160,000	$ -	$ -	$ -	$ 143,500	$ 143,500	$ 142,000
12	$ 160,000	$ 160,000	$ 160,000	$ -	$ -	$ -	$ 143,500	$ 143,500	$ 142,000
13	$ 160,000	$ 160,000	$ 160,000	$ -	$ -	$ -	$ 143,500	$ 143,500	$ 142,000
14	$ 160,000	$ 160,000	$ 160,000	$ -	$ -	$ -	$ -	$ 143,500	$ 142,000
15	$ 180,000	$ 180,000	$ 180,000	$ -	$ -	$ -	$ -	$ 163,500	$ 162,000
16	$ 160,000	$ 160,000	$ 160,000	$ -	$ -	$ -	$ -	$ 143,500	$ 302,000
17	$ 160,000	$ 160,000	$ 160,000	$ -	$ -	$ -	$ -	$ 143,500	$ 142,000
18	$ 160,000	$ 160,000	$ 160,000	$ -	$ -	$ -	$ -	$ 143,500	$ 142,000
19	$ 160,000	$ 160,000	$ 160,000	$ -	$ -	$ -	$ -	$ -	$ 142,000
20	$ 340,000	$ 340,000	$ 340,000	$ -	$ -	$ -	$ -	$ -	$ 162,000
21	$ 160,000	$ 160,000	$ 160,000	$ -	$ -	$ -	$ -	$ -	$ 142,000
22	$ 160,000	$ 160,000	$ 160,000	$ -	$ -	$ -	$ -	$ -	$ 142,000
23	$ 160,000	$ 160,000	$ 160,000	$ -	$ -	$ -	$ -	$ -	$ 142,000
24	$ 160,000	$ 160,000	$ 160,000	$ -	$ -	$ -	$ -	$ -	$ 142,000
25	$ 180,000	$ 180,000	$ 180,000	$ -	$ -	$ -	$ -	$ -	$ 162,000
26	$ 160,000	$ 160,000	$ 160,000	$ -	$ -	$ -	$ -	$ -	$ 142,000
27	$ 160,000	$ 160,000	$ 160,000	$ -	$ -	$ -	$ -	$ -	$ 142,000
28	$ 160,000	$ 160,000	$ 160,000	$ -	$ -	$ -	$ -	$ -	$ 142,000
29	$ 160,000	$ 160,000	$ 160,000	$ -	$ -	$ -	$ -	$ -	$ 142,000
30+	$ 180,000	$ 3,561,160	$ 4,916,186	$ -	$ -	$ -	$ -	$ -	$ 668,466
Totals	$ 5,080,000	$ 8,461,160	$ 9,816,186	$ -	$ -	$ -	$ 3,045,000	$ 4,032,500	$ 6,708,466
	Likelihood that Each Scenario Will Occur			**Likelihood that Each Scenario Will Occur**			**Likelihood that Each Scenario Will Occur**		
	30%	40%	30%	N/A	N/A	N/A	25%	50%	25%

Notes:

-Noted costs are based on information provided in Steps 1a, 1b, and 1c. Costs are not discounted in this Step. They are discounted in Step 2b.

-The likelihoods for each remedial option adds to 100%. These likelihoods are based on professional judgment and experience with previous applications of the technology by the project team.

-Inflation is not considered in this step. The application of the discount rate in Step 2b accounts for inflation.

- Costs that are incurred after year 30 have been included as discounted values in year 30 using the discount rate from Step 2b.

- Costs for system replacement are not included for the "most-likely" scenario of the "new remedial approach" because it is assumed that the existing components will last for the remaining few years of operation.

-Operation of the new remedial approach begins in the year after the capital expenses are made.

Step 2b: Net Present Value of Life-Cycle Costs

Year	Discount Factor	Existing P&T System Annual Costs in Present Value			Optimized P&T System Annual Costs in Present Value			New Remedial Approach Annual Costs in Present Value		
	3.1%	Optimistic	Most-likely	Reasonable Worst-Case	Optimistic	Most-likely	Reasonable Worst-Case	Optimistic	Most-likely	Reasonable Worst-Case
1	1.000	$ 160,000	$ 160,000	$ 160,000	$ -	$ -	$ -	$ 160,000	$ 160,000	$ 160,000
2	0.970	$ 155,189	$ 155,189	$ 155,189	$ -	$ -	$ -	$ 155,189	$ 155,189	$ 155,189
3	0.941	$ 150,523	$ 150,523	$ 150,523	$ -	$ -	$ -	$ 1,175,960	$ 1,411,152	$ 150,523
4	0.912	$ 145,997	$ 145,997	$ 145,997	$ -	$ -	$ -	$ 130,941	$ 130,941	$ 1,596,842
5	0.885	$ 159,308	$ 159,308	$ 159,308	$ -	$ -	$ -	$ 144,705	$ 144,705	$ 143,377
6	0.858	$ 137,349	$ 137,349	$ 137,349	$ -	$ -	$ -	$ 123,185	$ 123,185	$ 121,898
7	0.833	$ 133,220	$ 133,220	$ 133,220	$ -	$ -	$ -	$ 119,481	$ 119,481	$ 118,232
8	0.808	$ 129,214	$ 129,214	$ 129,214	$ -	$ -	$ -	$ 115,889	$ 115,889	$ 114,677
9	0.783	$ 125,329	$ 125,329	$ 125,329	$ -	$ -	$ -	$ 112,404	$ 112,404	$ 111,229
10	0.760	$ 136,755	$ 136,755	$ 136,755	$ -	$ -	$ -	$ 124,219	$ 124,219	$ 123,080
11	0.737	$ 117,905	$ 117,905	$ 117,905	$ -	$ -	$ -	$ 105,746	$ 105,746	$ 104,641
12	0.715	$ 114,360	$ 114,360	$ 114,360	$ -	$ -	$ -	$ 102,567	$ 102,567	$ 101,495
13	0.693	$ 110,922	$ 110,922	$ 110,922	$ -	$ -	$ -	$ 99,483	$ 99,483	$ 98,443
14	0.672	$ 107,586	$ 107,586	$ 107,586	$ -	$ -	$ -	$ -	$ 96,492	$ 95,483
15	0.652	$ 117,395	$ 117,395	$ 117,395	$ -	$ -	$ -	$ -	$ 106,634	$ 105,656
16	0.633	$ 101,214	$ 101,214	$ 101,214	$ -	$ -	$ -	$ -	$ 90,776	$ 191,041
17	0.614	$ 98,171	$ 98,171	$ 98,171	$ -	$ -	$ -	$ -	$ 88,047	$ 87,126
18	0.595	$ 95,219	$ 95,219	$ 95,219	$ -	$ -	$ -	$ -	$ 85,399	$ 84,507
19	0.577	$ 92,356	$ 92,356	$ 92,356	$ -	$ -	$ -	$ -	$ -	$ 81,966
20	0.560	$ 190,355	$ 190,355	$ 190,355	$ -	$ -	$ -	$ -	$ -	$ 90,699
21	0.543	$ 86,885	$ 86,885	$ 86,885	$ -	$ -	$ -	$ -	$ -	$ 77,111
22	0.527	$ 84,273	$ 84,273	$ 84,273	$ -	$ -	$ -	$ -	$ -	$ 74,792
23	0.511	$ 81,739	$ 81,739	$ 81,739	$ -	$ -	$ -	$ -	$ -	$ 72,543
24	0.496	$ 79,281	$ 79,281	$ 79,281	$ -	$ -	$ -	$ -	$ -	$ 70,362
25	0.481	$ 86,510	$ 86,510	$ 86,510	$ -	$ -	$ -	$ -	$ -	$ 77,859
26	0.466	$ 74,585	$ 74,585	$ 74,585	$ -	$ -	$ -	$ -	$ -	$ 66,194
27	0.452	$ 72,343	$ 72,343	$ 72,343	$ -	$ -	$ -	$ -	$ -	$ 64,204
28	0.439	$ 70,168	$ 70,168	$ 70,168	$ -	$ -	$ -	$ -	$ -	$ 62,274
29	0.425	$ 68,058	$ 68,058	$ 68,058	$ -	$ -	$ -	$ -	$ -	$ 60,401
30+	0.413	$ 74,263	$ 1,469,232	$ 2,028,276	$ -	$ -	$ -	$ -	$ -	$ 275,790
Totals		$ 3,356,471	$ 4,751,440	$ 5,310,484	$ -	$ -	$ -	$ 2,669,770	$ 3,372,310	$ 4,737,634
		Likelihood that Each Scenario Will Occur			**Likelihood that Each Scenario Will Occur**			**Likelihood that Each Scenario Will Occur**		
	N/A	30%	40%	30%	N/A	N/A	N/A	25%	50%	25%

Notes:

- A discount rate of 3.1% has been used based on U.S. Office of Management and Budget Circular A-94, Guidelines and Discount Rates for Cost-Benefit Analysis of Federal Programs. This rate includes the affect of inflation, so inflation is not considered separately. A higher discount rate would result in lower present value costs.

Appendix A

Step 3: Cost Comparison

Year	Optimized P&T System Cum. Cash Flow (NPV) Relative to Most-Likely Case for Existing System			New Remedial Approach Cum. Cash Flow (NPV) Relative to Most Likely Case for Existing System		
	Optimistic	Most-Likely	Reasonable Worst-Case	Optimistic	Most-Likely	Reasonable Worst-Case
1	$ -	$ -	$ -	$ -	$ -	$ -
2	$ -	$ -	$ -	$ -	$ -	$ -
3	$ -	$ -	$ -	$ (1,025,437)	$ (1,260,630)	$ -
4	$ -	$ -	$ -	$ (1,010,381)	$ (1,245,574)	$ (1,450,845)
5	$ -	$ -	$ -	$ (995,778)	$ (1,230,970)	$ (1,434,915)
6	$ -	$ -	$ -	$ (981,614)	$ (1,216,806)	$ (1,419,463)
7	$ -	$ -	$ -	$ (967,876)	$ (1,203,068)	$ (1,404,476)
8	$ -	$ -	$ -	$ (954,551)	$ (1,189,743)	$ (1,389,939)
9	$ -	$ -	$ -	$ (941,626)	$ (1,176,818)	$ (1,375,840)
10	$ -	$ -	$ -	$ (929,090)	$ (1,164,282)	$ (1,362,164)
11	$ -	$ -	$ -	$ (916,931)	$ (1,152,123)	$ (1,348,900)
12	$ -	$ -	$ -	$ (905,138)	$ (1,140,330)	$ (1,336,034)
13	$ -	$ -	$ -	$ (893,699)	$ (1,128,891)	$ (1,323,555)
14	$ -	$ -	$ -	$ (786,113)	$ (1,117,796)	$ (1,311,452)
15	$ -	$ -	$ -	$ (668,717)	$ (1,107,035)	$ (1,299,712)
16	$ -	$ -	$ -	$ (567,503)	$ (1,096,597)	$ (1,389,540)
17	$ -	$ -	$ -	$ (469,333)	$ (1,086,474)	$ (1,378,496)
18	$ -	$ -	$ -	$ (374,114)	$ (1,076,654)	$ (1,367,783)
19	$ -	$ -	$ -	$ (281,758)	$ (984,298)	$ (1,357,393)
20	$ -	$ -	$ -	$ (91,403)	$ (793,943)	$ (1,257,737)
21	$ -	$ -	$ -	$ (4,518)	$ (707,058)	$ (1,247,962)
22	$ -	$ -	$ -	$ 79,755	$ (622,785)	$ (1,238,482)
23	$ -	$ -	$ -	$ 161,494	$ (541,046)	$ (1,229,286)
24	$ -	$ -	$ -	$ 240,775	$ (461,765)	$ (1,220,367)
25	$ -	$ -	$ -	$ 327,285	$ (375,255)	$ (1,211,716)
26	$ -	$ -	$ -	$ 401,870	$ (300,670)	$ (1,203,325)
27	$ -	$ -	$ -	$ 474,213	$ (228,327)	$ (1,195,186)
28	$ -	$ -	$ -	$ 544,381	$ (158,160)	$ (1,187,293)
29	$ -	$ -	$ -	$ 612,438	$ (90,102)	$ (1,179,636)
30	$ -	$ -	$ -	$ 2,081,670	$ 1,379,130	$ 13,806
	Likelihood that Each Scenario Will Occur			**Likelihood that Each Scenario Will Occur**		
	N/A	N/A	N/A	25%	50%	25%

Notes:

- The indicated values represent the cumulative difference in costs between the various scenarios for the indicated remedial option and the most-likely scenario for continuing with existing P&T system as noted in Step 2b. This difference in costs over time can be used to track the "investment" made in optimizing the P&T system or moving forward with the alternative remedial approach.

- Cumulative cost differences are not indicated for an optimized P&T system because an optimized P&T system is not being considered.

- Values in parentheses indicate an investment (i.e., a greater expenditure for the indicated remedial approach than for the most-likely scenario for the existing P&T system). Values without parentheses indicates income (i.e., savings relative to the costs associated with the mostly likely scenario for the existing P&T system).

- The likelihoods for each remedial option adds to 100%. These likelihoods are based on professional judgment and experience with previous applications of the technology by the project team.

Step 3: Cost Comparison (continued)

	Existing P&T System		Optimized P&T System				New Remedial Approach			
	Most-Likely Scenario	Expected Value	Most-Likely Scenario		Expected Value		Most Likely Scenario		Expected Value	
			Total	Net Change Compared to Existing System	Total	Net Change Compared to Existing System	Total	Net Change Compared to Existing System	Total	Net Change Compared to Existing System
NPV of Life-Cycle Costs	$ 4,751,440	$ 4,500,663	N/A	N/A	N/A	N/A	$ 3,372,310	$ (1,379,130)	$ 3,538,006	$ (962,656)
Year 1 cash flow	$ (160,000)	$ (160,000)	N/A	N/A	N/A	N/A	$ (160,000)	$ -	$ (160,000)	$ -
Year 2 cash flow (discounted)	$ (155,189)	$ (155,189)	N/A	N/A	N/A	N/A	$ (155,189)	$ -	$ (155,189)	$ -
Year 3 cash flow (discounted)	$ (150,523)	$ (150,523)	N/A	N/A	N/A	N/A	$ (1,411,152)	$ (1,260,630)	$ (1,037,197)	$ (886,674)
Cum. cash flow at year 5 (discounted)	$ (771,017)	$ (771,017)	N/A	N/A	N/A	N/A	$ (1,766,795)	$ (995,778)	$ (1,994,176)	$ (1,223,159)
Total investment*	N/A	N/A	N/A	N/A	N/A	N/A	$ 1,500,000	$ 1,500,000	$ 1,500,000	$ 1,500,000
Year with highest investment*	N/A	N/A	N/A	N/A	N/A	N/A	3		3.25	
Year of payback**	N/A	N/A	N/A	N/A	N/A	N/A	Year 30		~ Year 30	
Net cum. cash flow at year 10	N/A	N/A	N/A	N/A	N/A	N/A	$ (1,164,282)	$ (1,164,282)	$ (1,154,955)	$ (1,154,955)
Average Annual Percentage Return (AAPR) as of Year 10**	N/A	N/A	N/A	N/A	N/A	N/A	Net Loss		Net Loss	

Notes:

- "Net Change Compared to Existing System" is taking the "Total" and substracting the corresponding value from the existing system.

** Investment refers to capital costs "invested" in system modifications or a new remedial technology (based on information documented in Step 1).*

*** Payback is defined as the number of years (from the year with the highest investment) that it takes to get a positive cumulative cash flow.*

**** For this example, AARP is calculated using the following parameters:*

- "Total investment" from the above table corresponds to the "invested capital" from Exhibit 6.

- "Net cum. cash flow at Year 10" from the above table corresponds to the "net savings at year 10" from Exhibit 6.

- The number of years from the "Year with the highest investment" to Year 10 corresponds to the "period of investment" from Exhibit 6.

Step 4: Information Gathering

1. Information to Gather

Information	Optimistic Scenario		Most Likely Scenario		Reasonable Worst-	
	Cost	Year Incurred	Cost	Year Incurred	Cost	Year Incurred
Pilot test (lump sum)						
- item 2						
- item 3						
- item 4						
- item 5						
- item 6						
- item 7						
- item 8						
- item 9						
- item 10						
- item 11						
- item 12						
- item 13						
- item 14						
Total	$ -		$ -		$ -	

Notes:
- Based on Steps 1 to 3, collection of additional information is not being considered.

Step 5: Conclusions and Decision

Conclusion

The cost comparison demonstrates that the discounted life-cycle costs for the new remedial approach (aggressive source remediation) are lower than continuing to operate the existing system. However, up-front capital costs and are not paid back for 20 to 30 years. In addition, the return on investment over a 10-year period, as measured by the average annual percentage return, is negative, indicating a net loss over a 10-year period.

Decision

Based on the cost comparison, this organization decided that the capital costs associated with implementing the "new remedial approach" (i.e., chemical oxidation) should be reserved for other activities. These activities could be in another division within the organization or might involve a different remedial alternative that is considered in the future. Because a full-scale application of chemical oxidation will not be applied at this site, no further study (such as a pilot test) will be conducted for that technology at this site. This decision does not indicate a shortcoming of chemical oxidation as a remedial technology; rather, it indicates that the organization believes it is better applied at other sites. An organization that wants a chance at removing the environmental liability from its balance sheet in a relatively short time frame, and does not have a competing use for the money, might elect to move forward with the new remedial approach.

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EPA 542-R-07-005
May 2007
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