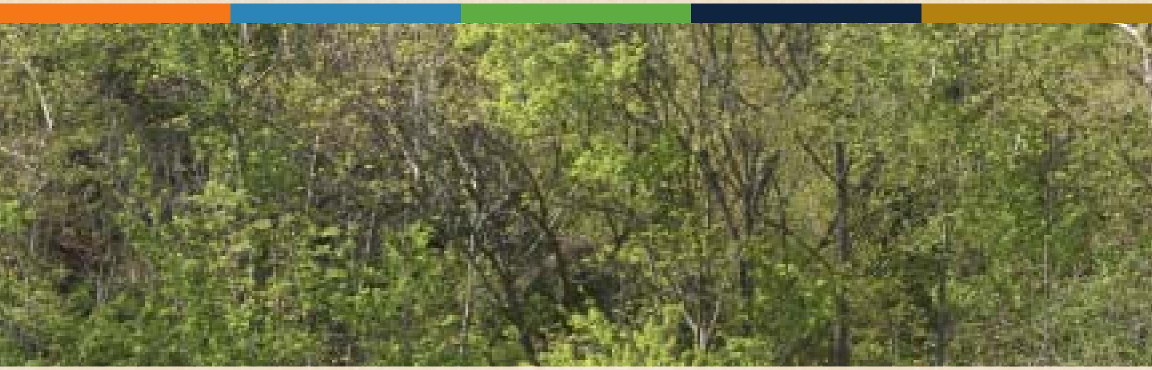
INTERSTATE TECHNOLOGY & REGULATORY COUNCIL

Technology Overview

LIFE CYCLE COST ANALYSIS

First in a Series of Remediation Process Optimization Advanced Topics



March 2006

Prepared by
The Interstate Technology & Regulatory Council
Remediation Process Optimization Team

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Life-Cycle Cost Analysis

Introduction

This overview introduces the reader to the basic concepts of Life-Cycle Cost Analysis. In 2004, the Interstate Technology and Regulatory Council (ITRC) Remediation Process Optimization (RPO) Team developed a technical regulatory guidance document titled, Remediation Process Optimization: Identifying Opportunities for Enhanced and More Efficient Site Remediation. Based on feedback to the RPO training and continued research into the topic, the RPO team identified the need for detailed information on detailed document on Life-Cycle Cost Analysis. This overview will further develop the concepts of life-cycle cost and its potential application to site remediation projects.

Two hypothetical sites have been created and are used to "walk" the practitioner through the life-cycle analysis process as examples. Each example has an existing remedial operation that is not achieving the site's exit strategy on schedule or budget. The examples present the site's remedial objectives, the current remediation status, the life-cycle cost of the current operation, alternative remediation processes for both cost and schedule, and then compares the life-cycle cost of all the options. The benefits and returns are evaluated and summarized for each site.

Who We Are and the Intended Audience

The ITRC is a state-led coalition of regulators, industry experts, citizen stakeholders, academia, and federal partners that work to achieve regulatory acceptance of innovative environmental technologies. This coalition consists of 46 states and a network of some 7,500 people who work to break down barriers, reduce compliance costs, and make it easier to apply new technologies to solve environmental problems. ITRC helps maximize efficient use of state resources by creating a forum where innovative technology and process issues are explored. Together, the team members are building the environmental community's ability to expedite quality decision making while protecting human health and the environment.

This overview has the following intended audience who are involved in either remediation process (RPO) or PBM of hazardous site remediation projects:

- State and federal regulators
- Facility owners and operators
- Engineers and consultants
- Interested stakeholders

States and federal agencies play multiple roles in the RPO and PBM processes: as regulators, and as facility owners and operators when public funds are used to conduct site remediation work. As regulators, state and federal agencies are charged with protecting human health and the environment. Also, facility owners, private or public, have the greatest interest in achieving the goals of the specific site remediation project. In addition, the engineering and consulting community who guide and provide professional opinions to the owners must have a deep working knowledge of techniques that can ensure fast and effective site remediation. To understand life-cycle cost and be full participants in environmental remediation efforts, public stakeholders must not only understand technologies used at sites, but also the underlying technical basis that supports the decision-making process. This document is intended as an introduction to the life-cycle cost. However, users are encouraged to refer to the references provided at the end of the fact sheet for additional information.

This overview is part of a five booklet series: Performance-based Management, Analysis of Above Ground Treatment Technologies, Exit Strategy Analysis, Data Management, Analysis and Visualization Techniques, and Life Cycle Cost Analysis; each is an excellent resource for moving forward on their RPO and PBM projects.

What is the Life-Cycle Cost for a Remediation Project?

The term "life-cycle cost" refers to the total project cost across the lifespan of a project, including design, construction, O&M, and closeout activities. The cost estimate developed during the RPO is a projection of the life-cycle cost for modifications to an existing remedial action from design through response complete, excluding RI/FS and earlier phases of the existing remedial action (RA). These costs typically include construction costs that are expended at the beginning of a project (such as capital costs) and costs in subsequent years that are required to implement, maintain, and monitor the remedy after the initial construction period (e.g., annual O&M costs, periodic costs).

How is Life-Cycle Cost Used in RPO?

A life-cycle cost analysis is a more realistic method of comparing costs for alternatives than simply comparing initial costs. Life-cycle cost analyses evaluate the total cost of ownership over the life of the project, including cost of money, length of service life of the units or components, maintenance, and operating costs. A life-cycle cost analysis compares the present worth of the total annual costs of ownership for different alternatives by estimating costs in today's dollars and amortizing those costs over the life of the project. The life-cycle costs can be used for:

Cost Comparison of Alternatives

Present-value of the life-cycle cost allows for cost comparisons of different remedial alternatives on the basis of a single cost figure for each alternative. This single number, referred to as the net present value (NPV), is the amount of funding that must be set aside at the beginning of an RA to ensure that funds will be available for the entire duration of an RA, based on certain economic conditions.

Cost Effectiveness Evaluation

Life-cycle cost and performance data could be used to compare cost on a per pound basis of contaminants removed or destroyed through time for different alternatives. In addition, for cost-reduction recommendations, a payback time, derived from life-cycle cost, of less than five years is preferred. Modifications that require a longer payback time are often disregarded because site conditions may change or innovative technologies may become more appropriate over a five-year time period.

Cost/Benefit Analysis

RPO usually assess the costs—in terms of time, resource consumption, public perception, and dollars—associated with implementing each alternative against the benefits (e.g., enhanced protectiveness, reduced time or cost to achieve RA objectives) that would be realized. For example, the O&M costs of the existing remedy can be directly compared to the estimated capital and O&M costs associated with a modified strategy or technology. In such an example case, a cost/benefit analysis can be performed using life-cycle costs and the estimated period of RA operation required to achieve RA objectives.

Where to Find Cost Information?

RPO evaluation compares the actual O&M cost of the existing remediation system against projected cost among other alternatives toward achieving the RA objectives. Cost and performance data typically required include the following:

- Projected (per the feasibility study) and actual O&M costs
- Capital costs for system modifications and upgrades
- Degree of hydraulic containment/capture attained
- Mass of contaminant removed
- Average monthly run time and downtime

The O&M costs should be obtained for the existing remedial system. Any capital costs associated with system upgrades and modifications or unplanned repairs should be included, but these costs should not be amortized even though the capital costs may spread out in several fiscal years during system upgrades and modifications. Amortization of capital costs is used for calculating taxes in a business with revenue that pays income taxes. When comparing the life-cycle cost of two or more systems amortization of capital costs is typically ignored. However, all planned capital costs must be included and the cash must be available in the year when the expenditure is planned. Typical O&M costs for remediation projects include labor, materials, utilities and fuel, monitoring including sampling and analysis, equipment lease/rental, off-site disposal fees, and administrative costs (e.g., permitting fees, reporting, fines for violations).

The life-cycle cost estimating should address the following elements:

- Key cost components for both RA and O&M activities
- Major sources of uncertainty in the cost estimate
- Either discount rates for present value or scale-up factors for future inflation costs
- Time expected to achieve RA objectives
- Periodic capital or O&M costs anticipated in future years of the project (e.g., remedy replacement or rebuilt)
- Decommissioning costs at the project closure (e.g. removal/disposal of remedial system, decontamination, and/or equipment salvage value),
- Methods and resources used for preparing the cost estimate (e.g., estimating guides, vendor quotes, computer cost models)
- Treatability study costs, when applicable

The calculation of the NPV from the life-cycle cost of each alternative must carefully consider the appropriate discount value, so that the NPV can then be used to compare remedial scenarios realistically. NPV can be calculated using the following formulas:

Formula 1–estimating the total costs of remediation considering inflation

Total Costs = Annual Cost in Year 1 + Annual Cost in Year 2 x (1+i) +…
+ Annual cost in Year n x $(1+i)^{n-1}$

Where: Annual Cost in current dollars, including capital, O&M, replacement, etc.
i = annual inflation rate
n = total number of years of remediation

Example: Annual Cost in current dollars for Year One = \$10,000, Annual Cost in future dollars for Year Two with 4% inflation rate = (\$10,000)x(1+0.04) = \$10,400, Annual Cost in future dollars for Year Three with 4% inflation rate = (\$10,000)x(1+0.04)2 = \$10,816, ……Annual Cost in future dollars for Year Fifteen = (\$10,000)x(1+0.04)14 = \$17,317. Thus, Total Costs = \$10,000 + \$10,400 + \$10,816 + ……. + \$17,317 = \$200,236.

Formula 2–Calculating Net Present Value (NPV)

$$NPV = \sum_{1}^{n} \frac{Annual\ Cost\ in\ Year\ t\ with\ inflation}{(1+r)^{t-1}}$$

Where: r = annual discount rate

Example: NPV for Year Two = ($10,400)/(1+0.065) = $9,765, NPV for Year Three = ($10,816)/(1+ 0.065)2 = $9,536…… NPV for Year Fifteen = ($17,317)/(1+ 0.065)14 = $7,171, and the total NPV = 10,000 + $9,765 + $9,536 + … + $7,171= $127,692.

Example 1–Solvent Plume Case

Site Background

Description/Waste Source:

The sites property contains soil and groundwater contamination at levels requiring remedial action. Soil and groundwater at the site are contaminated with chlorinated solvents, primarily PCE, TCE, and cis-1,2-DCE, as well as LNAPL. Suspected releases from site operations, including overflow from an underground storage tank (UST), spills, and on-site land disposal.

Period of Operation:
June 1991 to present

Contaminants:
Tetrachlorethene (PCE), Trichlorathene (TCE), Cis-1.2-dichlorethene (DCE), Halogenated-Volatiles.

- Volatile organic compounds (VOCs) detected in soil at concentrations as high as 0.09 mg/kg (PCE), 5.5 mg/kg (TCE), and 10 mg/kg (1,2-DCE).
- VOCs in groundwater detected at concentrations as high as 920 µg/L (PCE), 11,000 µg/L (TCE), 13,000 µg/L (1,2-DCE), and 106 µg/L (vinyl chloride).

Site noted to also have light non-aqueous phase liquids (LNAPLs)

Technology:
Groundwater pump and treat (P&T), air sparging, and soil vapor extraction (SVE).

Type/Quantity of Media Treated:
Soil and groundwater

- The soil consists of gravel with sand, silt, and clay, and is approximately 50 ft thick on-site. The upper soil materials consist of unconsolidated silty, sandy gravel with cobbles and boulders. The base is an indurated sandstone.
- Depth to groundwater averages–10 to 12 ft bgs.

Regulatory Requirements/Cleanup Goals:
Groundwater µg/L: PCE–5, TCE–5, cis-1,2-DCE–70, and vinyl chloride–2
Soil (mg/kg): PCE–0.3, TCE–0.4, cis1,2-DCE–4.0, and vinyl chloride–0.008

Results:
As of 2004, a total of 958 pounds of VOCs were removed over the 14 year period, consisting of 561 pounds removed from groundwater, 377 pounds removed from soil, and 20 pounds removed as LNAPL. In addition the TCE plume in the groundwater was significantly reduced. While the concentrations of the contaminants have been reduced, the concentrations remain above cleanup levels.

Costs:

- Total cost for soil vapor extraction to date (without disposal of residues) is approximately $406,000.
- Total cost for groundwater extraction to date (without disposal of residues) is approximately $2,028,000.
- For the 958 pounds of VOC removed by the system to date the unit cost amounts to $2,540 per pound of VOC removed.

Calculating the Present Value
For this exercise, the alternative of in-situ chemical oxidation (ISCO) with continued monitoring of natural attenuation is considered to compare with the continued operation of the existing pump and treat system. The current pump and treat system has bee operating for the past fourteen (14) years. While the current yearly operating cost is $144,462, this yearly operating cost considers the following:

Annual Operation & Maintenance
Engineer
Technician
Replacement Materials
Electricity
Fuel (catalytic oxidizer)
Sewer Disposal Fee
Carbon Disposal
Waste Disposal

Annual Monitoring/Reporting
Air Stripper Influent
Air Stripper Effluent
Monitoring Wells
Sampling Materials
Technician
Engineer

Periodic Maintenance, Every 5 Years
Pulse Pumps
Air Compressor
Air Stripper Feed Pump
Blower
Catalyst Replacement
Stripper Sump Pump
Miscellaneous Materials
Technician

Periodic Maintenance, Every 10 Years
Air Stripper
Catalytic Oxidizer
Water Flow Meters
Air Flow Meter
Technician
Miscellaneous Materials

It is anticipated based on the current removal rates that the system will need to operate an additional ten (10) to fifteen (15) years. Inflation forecasts for the period are 4.0% and the discount rate forecast for the period is 6.5%. For this exercise, the annual inflation rate will increase the cost of operation each year by the inflation rate, and each year's operating funds need to be available at the beginning of each year. Therefore, as shown in Table 1, in the beginning of year two $150,240 needs to be available, and in years ten and fifteen $213,838 and $250,160 need to be available respectively.

In addition, for this exercise, the discount rate is constant and there are no taxes on the interest earned or the principal. To meet year two funding requirements $141,070 needs to be put in an investment in the beginning of year one. For years ten and fifteen $116,656, and $103,592 need to be put in an investment at the beginning of year one. Cumulatively, $1,301,186 (Life-Cycle Cost) needs to be put in an investment for ten year's of operation and $1,844,652 (Life-Cycle Cost) needs to be put in an investment for fifteen years of operation.

Table 1: Example 2 P&T Values

Year	Inflation Value	Net Present Value	Year 1 Investment
1	$144,462	($144,462)	$144,462
2	$150,240	($141,070)	$285,532
3	$156,250	($137,759)	$423,291
4	$162,500	($134,525)	$557,816
5	$169,000	($131,367)	$689,183
6	$175,760	($128,284)	$817,467
7	$182,790	($125,272)	$942,739
8	$190,102	($122,332)	$1,065,070
9	$197,706	($119,460)	$1,184,530
10	$205,614	($116,656)	$1,301,186
11	$213,838	($113,917)	$1,415,103
12	$222,392	($111,243)	$1,526,346
13	$231,288	($108,632)	$1,634,978
14	$240,539	($106,082)	$1,741,060
15	$250,161	($103,592)	$1,844,652

For the alternative of in-situ chemical oxidation (ISCO) with continued monitoring of natural attenuation, the present value for the monitored natural attenuation (MNA) for three years is $65,488, as shown in Table 2. The Life-Cycle Cost for the ISCO technology is the sum of the one-time chemical application costs of $945,000 and the present value of the MNA: ISCO Life-Cycle Cost = $945,000 + $65,488 = $1,010,488.

After the life-cycle costs are projected for the two technologies, probability factors can be factored into the decision on which technology should be used. Based on past data, the probability that the P&T operation will meet the exit strategy contaminant levels in ten years is only 60%. The same performance data yields a probability factor of 95% for fifteen years of operation of the P&T system.

The probability for the ISCO treatment has been calculated to be 85% for three years of MNA and 95% for five years of MNA. The present value for five years of MNA is $106,625 for a life-cycle cost of $1,051,625.

Therefore, the comparative differential cost of the two technologies, with a 95% probability, is $793,027 in favor of ISCO. At an 85% probability for ISCO/MNA and a 60% probability for P&T, the comparative differential cost is $290,698 again in favor of ISCO/MNA. In addition to the remediation costs advantage, the ISCO/MNA also has a shorter time frame to achieve the same remedial goals. Certain tangible and intangible social-economical benefits may be realized through early or improved property reuse and added to the overall life-cycle cost/benefit analysis.

Table 2: Example 2 MNA Values

Year	Inflation Value	Net Present Value	Year 1 Investment
1	$22,350	($22,350)	$22,350
2	$23,244	($21,825)	$44,175
3	$24,174	($21,313)	$65,488
4	$25,141	($20,813)	$86,301
5	$26,146	($20,324)	$106,625
6	$27,192	($19,847)	$126,472
7	$28,280	($19,381)	$145,853
8	$29,411	($18,926)	$164,780
9	$30,588	($18,482)	$183,262
10	$31,811	($18,048)	$201,310
11	$33,083	($17,624)	$218,934
12	$34,407	($17,211)	$236,145
13	$35,783	($16,807)	$252,952
14	$37,214	($16,412)	$269,364
15	$38,703	($16,027)	$285,391

Example 2–Underground Storage Tank Case

Background

Leaking tanks were discovered in 1990 when the they were removed under the orders of a bankruptcy court. Efforts were made to have additional remediation measures undertaken by the property owner. The property owner failed to respond to a New Jersey Spill Act Directive to perform additional remediation measures due to lack of funds. In 1992, the property was effectively abandoned and the case was transferred to the New Jersey Department of Environmental Protection's (NJDEP) publicly funded site remediation division. The NJDEP determined that the groundwater was heavily contaminated with non-aqueous phase liquid (NAPL) petroleum products.

Geology

The depth to ground water at the site is approximately 20 feet. The Cohansey formation is approximately 65 feet thick in this area and consists of fine grained quartzose sand at the surface, lens of light-colored clay, and lens of gravel.

Below the Cohansey lies the Kirkwood formation, very fine to course grained quartzose micaceous sand, silt, and clay. Ground water flow in the area is in a southerly direction. Calculated velocity for groundwater flow in the immediate vicinity of the site is 0.04 feet/day.

Historic & Ongoing Remediation Steps Taken to Date

The work done by the bankruptcy court and the property owner left approximately 890 tons of petroleum products contaminated soils. NJDEP contractors removed these in 1992. A remedial remedy selection report and design were conducted during the first half of 1993. Installation of a groundwater collection and treatment system began late in 1993 and was completed in early 1994.

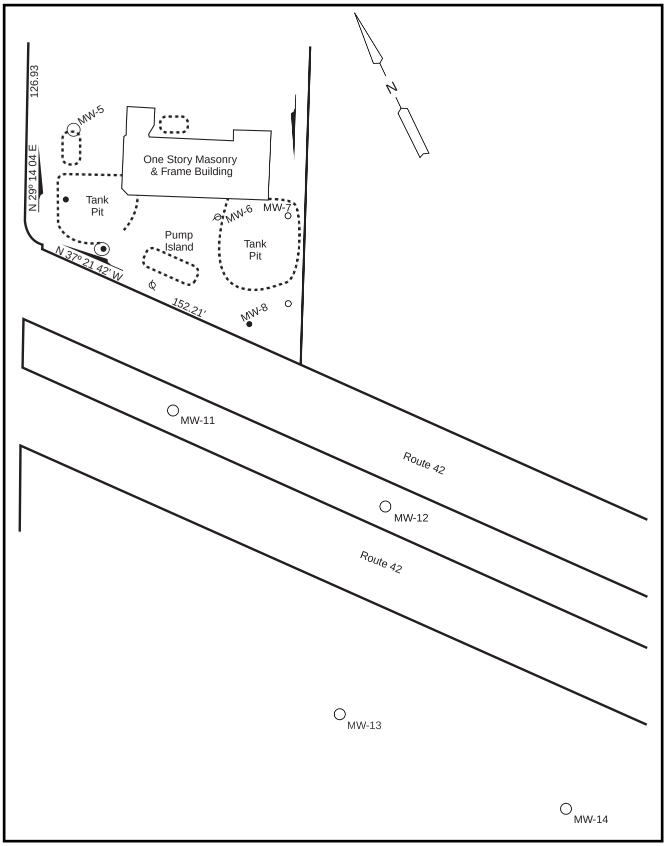

Figure 1. Example 2 Site Plan

The groundwater collection system consists of four recovery wells sited near the location of the former tank pits and pump island. Pneumatically powered and controlled collection pumps deliver water and product to a treatment system in the rear of the property at a rate of 3 to 4 gallons per minute (gpm) (recall the low ground water flow rate). The treatment system consists of a stilling well where product is drained off, and an air stripping system that discharges treated water to the groundwater. Also, NJDEP maintains a discharge to groundwater permits that requires recapture of at least 90% of the discharged water.

The groundwater monitoring system that NJDEP designed and installed, consists of twelve (12) monitoring wells. The well network is a combination of wells installed in 1993 (recovery and monitoring) and 1998 (additional monitoring and sentinel). Sentinel, or clean zone, monitor wells are in place down gradient of the site to monitor plume capture effectiveness. The wells were sampled irregularly, roughly on an annual basis up until recently. Site work was driven by the results of recovery well and treatment plant influent sampling.

A membrane interface probe (MIP) study was conducted in early 2004. This study was conducted to determine the source of the continued relatively high level (882 mg/L) contaminants that were still present treatment plant influent after almost ten (10) years of pumping.

Progress Statement

Initial contact with the site in 1992 found groundwater contaminated with measurable floating NAPL product. Also, start-up of the groundwater collection and treatment system in early 1994, and the intervening monitoring, continued to show measurable but low, less than one (1) inch of product in most on site wells. Some free product, less than fifty-five (55) gallons, was recovered in the early months after start-up. However, the system performed in a classic manner and within the first two years of operation, the recovery of free product and the level of dissolved product followed an asymptotic curve to a relatively low level of dissolved (in hundreds of parts per billion (ppb)) versus the initial free product and thousands of parts per million (ppm) of dissolved. In early 2005, the system influent still sees several hundred ppb BTEX compounds in the influent and occasional heavy sheens of product globules are observed in the recovery wells. By comparison, the clean-up goals for the site include 1 ppb for benzene.

Cost to Date

The following are the actual costs to date for the subject site rounded to the nearest $1,000:

One Time & Capital Costs	
Installation of Collection & Treatment System[1]	$181,000
Disposal of Contaminated Soils[2]	$73,000
Installation of Four Additional Monitor Wells[3]	$30,000
Membrane Interface Probe Study[4]	$30,000
Total of Capital and One Time Costs:	$314,000

Notes:
1992 into 1993; 2. 1993; 3. 1995 (includes initial sampling round); 4. 2004

Annual O&M Costs (historical average)	
Electricity	$4,000
Labor	$18,000
Equipment & Consumables	$5,000
Sampling & Analytical	$9,000
Total Average Annual Expenditures	$36,000

Future Cost Scenarios

Two options will be presented to illustrate life cycle cost analysis for this case: continue with the pump and treat as it exists and in-situ electrical resistance heating. The costs for each scenario, or option, are presented below. The same inflation rate of 4.0% and the discount rate of 6.5%, used in Example 1, are also used in this example.

Starting with the first option the following assumptions will be made, the treatment system that has been operational for the last twelve years will need to continue operating for an additional 10 years. After another 10 years of operation the system will enter a monitoring only phase with a Classification Exemption Area (CEA) in place. The CEA will have to remain in place until the groundwater meets the ground water quality standards for all contaminants, assume another 5 years with annual monitoring costs, in current dollars, of $12,000 for the first two years, $5,000 for the following two years, and $15,000 for the final year. Option one therefore, will require an additional 15 years of operation with a total present value of $361,148, as shown in Table 3. The changes of inflated value and present value from Years 11 thru 15 are noted in Table 3 also.

For the option of in-situ electrical resistance heating, the total operation period is anticipated to be less that six month to achieve the same remediation goals as the P&T system operates for another 10 years. Thus, a total cost of $1,016,000, including both capital and O&M costs, for this option will incur in the first year. However, similar monitoring for another 5 years after in-situ resistance heating treatment is included. The total present value for this option will be $1,061,685, as shown in Table 4. Even though the monitoring costs are the same for both options, the inflated values and present values in this option is different due to the project time frame changes.

From the NPV comparison, the option to continue operation of the existing P&T system seems to be favorable over the in-situ electrical resistance heating option. However, to clean up the site 10 years earlier could have other social-economical impacts to be considered.

Table 3: Example 2 P&T Values

Year	Inflation Value	Net Present Value	Year 1 Investment
1	$36,000	($36,000)	$36,000
2	$37,440	($35,155)	$71,155
3	$38,938	($34,330)	$105,485
4	$40,495	($33,524)	$139,008
5	$42,115	($32,737)	$171,745
6	$43,800	($31,968)	$203,714
7	$45,551	($31,218)	$234,932
8	$47,374	($30,485)	$265,417
9	$49,268	($29,770)	$295,186
10	$51,239	($29,071)	$324,257
11	$17,763	($9,463)	$333,720
12	$18,473	($9,241)	$342,961
13	$8,005	($3,760)	$346,721
14	$8,325	($3,672)	$350,392
15	$25,975	($10,756)	$361,148

Table 4: Example 2 In-Situ Electrical Resistance Heating Values

Year	Inflation Value	Net Present Value	Year 1 Investment
1	$1,016,000	($1,016,000)	$1,016,000
2	$12,480	($11,718)	$1,027,718
3	$12,979	($11,443)	$1,039,162
4	$5,624	($4,656)	$1,043,818
5	$5,849	($4,547)	$1,048,364
6	$18,250	($13,320)	$1,061,685

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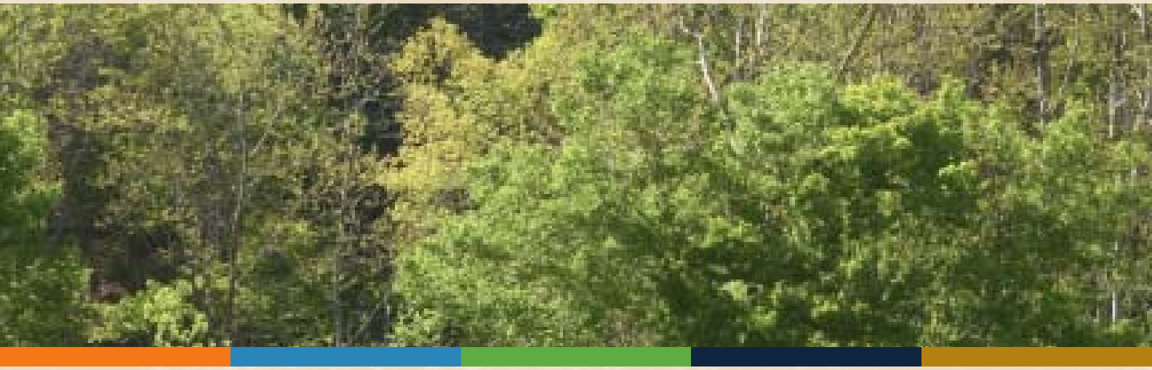

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