Cost Benefit Analysis: Remediation of Trichloroethylene in Groundwater

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Abstract

With the evolution of contaminated sites remediation into a mature industry, the complexity of in-situ remediation or risk management options is now well recognized by environmental scientists and engineers. With the myriad of options available and the numerous interacting inputs and outputs associated with each option, a more structured methodology for remediation decisions has become needed. Cost benefit analysis (CBA) is one such methodology that appears very well suited to remediation projects. The application of this methodology or similar approaches has many advantages and challenges. Advantages lie in its ability to quantitatively evaluate very complex decisions, while the challenges lie in the process of quantification and some of the social or moral implications of that process. Application of the methodology requires knowledge of both applied environmental sciences and economics, as well as recognition of CBA's proper place in the decision process. Financial analysis (a subset of CBA) is often applied by remediation project proponents in their decision analysis, while economic analysis (a more comprehensive CBA incorporating costs and benefits not directly accrued to the project proponent) is not so widely adopted. However, the regulatory perspective more closely resembles the scope of an economic analysis. An example application of CBA to a remediation project illustrates the process, its sensitivities and the differences between its financial and economic scopes. This example also illustrates the need for recognition of the differing perspectives that apply these two scopes, including those of the project proponent, regulators and other stakeholders.

Introduction

Over the past four decades, remediation of contaminated sites has evolved into a mature industry in North America. In the industry's infancy, expectations from remediation efforts on contaminated sites were optimistic – with an expectation that applied efforts, if properly implemented, would result in a clean site within a short time frame and reasonable cost. Installation of a pump-and-treat system and extraction of several dozen pore-volumes from the contaminated area was often anticipated to be sufficient to achieve site closure.

The reality has become much clearer to both industry experts and site owners over the past two decades. Many in-situ remediation methods are now anticipated to be long-term undertakings due to complexity in the subsurface – if they can reach remedial objectives at all. Confronted with this reality, a large sector of the environmental industry has moved to "risk management" to address those sites where remediation is not straightforward (i.e. sites not amenable to dig and dump solutions).

Overall, the decision process in selecting the most practical approach for addressing contamination issues has become much more complex. There are many reasons for this change, including the following: successful full-scale clean-ups have become the exception rather than the rule; an increased understanding of the complexity of contamination (and remediation) in the subsurface; an increased number of available options for remediation due to technological developments; application of risk assessment approaches (to re-examine remediation goals); and, the subsequent addition of risk management options to the decision matrix. The need for a more structured decision methodology in addressing remediation problems has become clear. Indeed, several proposed methodologies have appeared in recent years in technical literature, including: Freeze *et al*'s (1990) hydrogeological decision analysis; Wolka's (1997) application of site-specific benefit-cost analysis to remediation projects; Hansen *et al's* (1998) cost effectiveness or incremental cost analysis approach, Tam and Byer's (2002) decision methodology for contaminated sites remediation based on a maximum net benefit approach; and many others.

Cost benefit analysis (CBA) and similar methodologies are quickly gaining popularity as structured approaches to decision-making regarding environmental protection and remediation issues. Indeed, it could be said that these approaches have been applied in various formal or informal ways over the decades-long course of contaminated sites remediation. The application of CBA is a natural fit, as it was developed to assist in assessing the potential impact of complex projects with many interacting inputs and outputs. With technical, financial, social and ecological considerations in play, environmental projects fit this profile very well.

This paper will discuss the specific application of CBA to decisions in remediation projects. A general presentation of the methodology will be followed by a discussion of the differences between its subsets of financial analysis and economic analysis. The application of CBA to remediation decisions will be presented – supported by an example case applying this methodology to the remediation of a TCE plume in groundwater. The differentiation between financial analysis and economic analysis will be discussed to illustrate the potential conflicts that may occur between contaminated site owners and other stakeholders, particularly regulators, in remediation decisions.

Cost Benefit Analysis Theory

Cost benefit analysis (CBA) has been used to support business decisions since early in the 19th century (Hajkowicz *et al* (2000))**.** Similar approaches under different names were likely applied for centuries before this. The methodology arose out of a need to quantitatively assess whether a person, business or society at large would experience a net benefit or net loss from a given project. This approach was adopted for projects having such varied and intermingling inputs and outputs that the net result of a decision was not readily discernable and a more systematic approach was necessary.

True CBA has its origins in welfare economics. In essence, these studies are applied to determine whether a given project will result in a net benefit (surplus) to society's welfare. Protocols of this analysis have evolved over time and changed in response to different applications. In a recent paper on the fundamentals of CBA, Griffin (1998) presents the following eight principles:

Central Objective

1. "Projects are economically acceptable if the benefits … are in excess of the estimated costs."

Additional Principles

2. "Welfare changes pertain to differences between with or without scenarios.
3. Social opportunity cost is applied to costing.
4. Producer benefits are measured as producer surplus changes.
5. Consumer benefits are measured as consumer surplus changes.
6. Zero sum transfers of benefits or costs are to be ignored.
7. Temporal aggregation employs discounting.
8. Unmonetorized welfare changes are to be disclosed."

A few of these principles are points of contention between proponents and opponents to CBA application in public decisions. One of the most contentious of these is the use of discounting in aggregating costs over time for comparison. It is often argued that this practice has the tendency to undervalue costs and benefits to be experienced by future generations. Decisions are therefore commonly governed by the present and near future costs and benefits. Options that defer significant benefits to the future are discriminated against, while those that defer significant costs to the future have the advantage. Of course there are other points of contention in these arguments, including: the high uncertainty in monetizing social and ecological inputs and outputs; the sensitivity and moral questions surrounding monetizing human health and human lives; the lack of consideration of whether the distribution of costs and benefits is equitable; the difficulty in determining an appropriate discount rate; and, the appropriate method of integrating unmonetized components into the decision process. Adler and Posner (1999) provide a very detailed examination of the issues surrounding appropriate use of CBA.

Despite the above points of contention, a proper application of CBA – with appropriate sensitivity analyses to evaluate the potential effects of key uncertainties – should still be considered a valuable tool in the decision process on complex issues. It should always be remembered that CBA is simply a tool requiring proper application by the user. Many of the issues above can be addressed to some degree by the decision-makers in their evaluation of the results of the CBA. James *et al* (1996) suggest the following advantages to CBA:

- "It provides a framework that enables managers to see the 'big picture' at complex sites…"
- "It offers a manner of documenting the reasoning behind decisions…" and
- "… it creates a tool for communicating the rationale for decisions to the various stakeholders..."

Financial Analysis versus Economic Analysis

At this time, it is appropriate to define the scope of CBA in its more common incarnations. Specifically, the question is whether the approach being applied is simply a financial analysis or a more comprehensive economic analysis. In their paper on supporting decisions in natural resource management, Hajkowicz *et al* (2000) suggest the following differences between these two scopes, applying the term BCA (benefit-cost analysis) to a full economic analysis in differentiation with financial analysis:

> **Financial Analysis**
>
> "Financial analysis focuses on the interests of individuals directly involved in a project. It … looks at what is the net benefit from a decision to an individual person, firm or organization. It does not consider outside effects of that decision that may occur."
>
> **Economic Analysis**
>
> "BCA considers the wider effects (of a given project decision) on the economy, the environment and society."

In many cases involving application of CBA to remediation project decisions, the analysis centers on those components commonly considered part of a financial analysis, as those are of most direct concern to the proponent. The exclusion of economic analysis components may be due to the difficulties in monetizing these factors as well as the uncertainty that such an effort would add to the analysis. For the large part the considered interests of the project proponent drive this limited application of CBA.

Table 1 illustrates the differences and similarities between financial and economic analysis, as applicable to a remediation project.

Economic analysis does have a history of application to regulatory policy-making. This history, with respect to the U.S. EPA, has been extensively examined in Morgenstern (1997), which reviews the role of CBA in numerous EPA policy decisions. The case of regulatory decisions regarding the use of leaded gasoline is often cited as a supporting argument in the application of CBA to environmental policy generation. However, there is some debate as to whether the application of CBA to environmental regulation better serves business interests than environmental interests. Farrow and Toman (1999) present a proposal for the use of CBA in improving environmental policy regulations that addresses this issue directly.

Regardless of whether CBA should or should not be applied to the drafting of environmental policy, it is clear from their mandate to protect the public's interests that regulatory agencies involvement in specific remediation projects will require application of those aspects of economic analysis (social welfare, ecological welfare) that are neglected to varying degrees in private decisions based on financial analysis. Although it is granted that these regulatory decisions rarely reach the level of a quantitative analysis in site-specific decisions, they do appear to apply a similar (or sometimes identical) list of decision parameters. This factor will be discussed later with respect to how it applies to use of CBA in remediation project decisions.

Table 1: Comparison between Financial analysis and Economic (CBA) analysis

Item	**Financial Analysis**	**Economic Analysis**
Purpose	Indicate net benefit to the individual firm or household	Indicate economic value to society as a whole
Goal	Increase financial welfare to individual(s) or a firm	Increase economic welfare to society as a whole
Concept of improvement	Net benefit to the individual, firm or household	Net benefit to society as a whole
Changes in benefit	Include only those which accrue to individual	Include all, irrespective of how they are distributed
Changes in cost	Include only those borne by the individual	Include all, irrespective of how they are distributed
Government (regulatory) costs	Exclude (except for financial analysis for government)	Include
Externalities	Exclude	Include
Secondary benefits and costs	Exclude	Include when appropriate
Unpriced benefits and costs	Exclude	Include

Source: adapted from Hajkowicz *et al* (2000)
[originally adapted from Sinden and Thampapillai (1995)]

CBA as a Remediation Decision Tool

Earlier in this paper, it was suggested that environmental projects in general and remediation projects in particular lend themselves well to the application of CBA due to their complexity and the need for a structured methodology to assist in decisions. James *et al* (1996) endorse this philosophy as they present the use of CBA in a remediation project decision case study involving remediation options for radioactive waste. Wolka and Austin (1988) provide a procedure for benefit estimation in applying CBA to groundwater contamination. In a later discussion, Wolka (1997) proposes site-specific CBA for environmental remediation and illustrates its application in a case study involving remediation of chlorinated solvents contaminating off-site areas.

The last two references above both use valuation of incremental risk reductions as part of their benefit quantification approach. Indeed, the "willingness to pay" for risk reduction has been used as a means of quantifying the effect of environmental improvements on human health while avoiding the sensitive issue of directly monetizing human life. Applying this willingness to pay over a population large enough that the incremental risk reduction results in one life saved provides a value attached to that reduction. In a recent paper by Farrow and Toman (1999), a value is estimated by determining what a population would be willing to pay for a measure that reduces risk by a finite value.

It is clear in the preceding discussions in general, and application of CBA to remediation projects in particular, that a place exists for this methodology in the remediation of contaminated sites. Some differences of opinion have been noted in application of this approach to public policy, and reservations are widespread regarding blind application of the approach as a "black box." Nevertheless, it is postulated that proper application of CBA to remediation projects can be invaluable, when used as one tool in a decision process that includes application of judgment to address the weaknesses of the methodology (i.e. assessing unmonetized factors, equity in social and temporal distribution of costs and benefits).

It should be acknowledged that though the complexity of environmental remediation problems appears to lend itself to the structured methodology of CBA in decision evaluation, alternatives have been suggested and applied. Tam and Byer (2001) present a decision methodology for remediation of contaminated sites that has many similarities to CBA (albeit in its financial analysis incarnation). Freeze *et al* (1990) present a methodology for hydrogeological decision analysis that offers rigorous examination of a structured approach to these decisions given the complexity of hydrogeological problems. In this paper, CBA is incorporated as one part of a comprehensive methodology spanning scientific and sociological principles. Hansen *et al* (1998) present an alternative financial analysis to CBA involving incremental cost analyses and cost effectiveness evaluation.

It should be emphasized that the discussion of CBA within this paper is related to the *remediation* of contaminated sites. The contamination is taken to be already present in the subsurface, and delineation is assumed to have been accomplished to the point where a remedial action decision is appropriate. Therefore, costs and benefits related to the initial contamination (i.e. potential health claims from past exposure, reduced costs in production) and initial delineation efforts are therefore excluded.

Application of CBA to Remediation

There are generally seven stages for conducting a CBA. Following is a listing of these stages, paraphrased from Hajkowicz *et al* (2000), and related to remediation projects:

- *Stage One:* Define the project – including identification of resources and affected population

  In the case of a remediation project, the resources to be allocated are: the capital and expense dollars of the project proponent; materials, electricity and fuel necessary to implement the remediation; labour of proponent employees, consultants, contractors, lawyers and regulatory agency representatives.

  The population to be affected by the remediation includes the workers at a subject facility, workers, tenants, residents and owners of any adjacent contaminated properties or properties potentially to be impacted by the remediation efforts, and the environment currently being impacted by the contamination and potentially to be impacted by the remediation efforts.

- *Stage Two:* Identify the impacts of the project, including the base case and the proposed action.

  For the purposes of this study, the base case may be one of minimal effort to monitor the contamination and risk management sufficient to accommodate the minimum requirements of the regulatory agency.

- *Stage Three:* Identify economically relevant impacts moving from the base case to the remediation project scenario. Include the distribution of these benefits and costs, and note if they are monetized or unmonetized. Determine what approach will be used for unpriced non-market values.

  As per the principles of CBA, costs or benefits that offset (those present in both the base case and the remediation scenario) will be omitted.

- *Stage Four:* Identify the change in physical quantities of various benefits and costs.

- *Stage Five:* Assign monetary values to the relevant changes in benefits and costs, applying shadow prices – or social opportunity cost – if necessary. Provide some assessment on any unmonetized benefits or costs.

- *Stage Six:* Discount all quantified costs and benefits to net present value. Determine an appropriate discount rate for net present value analysis, develop spreadsheet model, run spreadsheet model (with discounting) and determine base case results.

Selection of the evaluation time period is very important for long-term remediation projects without a definitive closure date. This period should encompass all major expenditures and realized benefits. For example, it may extend to the point when a maintenance mode is reached in the long-term effort.

- *Stage Seven:* Perform sensitivity analysis on any critical assumptions used in the CBA.

  Discount rate is usually included in this analysis. With respect to remediation projects, capital cost overruns due to expanding scope or costs to address system failure may also be applied.

Example Case – Trichloroethylene in Groundwater

In the following case, the principles and stages of CBA presented in the preceding discussion are applied in a simplified example. A decision of whether or not active remediation efforts would result in a net benefit to the project proponent (over and above risk controls that would be required by regulators) is evaluated. The net effect on society as a whole is also examined. In a broader and more rigorous application, the question might be expanded to assess which of several selected options provides the maximum benefits-to-costs ratio.

Scenario

A large industrial site within an urban setting has used TCE as part of its operation at some time in the past. This historic operation has resulted in leakage and spillage of TCE into the ground. The resulting soil contamination has given rise to a groundwater plume of elevated concentrations of this chemical and its degradation products (including 1,1-dichloroethylene and vinyl chloride). The groundwater plume has migrated off-site, extending beneath an adjacent commercial development and subsequently beneath a residential neighbourhood. It is likely that elevated concentrations of the chemicals of concern reach a nearby lake that lies beyond the residential neighbourhood, as it is the discharge environment for the local water table aquifer. Figure 1 illustrates the layout of this hypothetical case.

The dissolved TCE plume is 150 m wide and at least 1.5 kilometers long (measured from the contour of 50 parts per billion (ppb) concentration, which is the generic guideline for TCE in non-potable groundwater in this jurisdiction). The soil is a medium sand unit with an average thickness of 10 m overlying shale bedrock. The water table aquifer is contained within the sand unit with an average saturated thickness of 6 m and an average flow velocity of 0.5 m/day. The commercial area is 300 m wide, measured in the direction of groundwater flow and the residential area is another 1 kilometer wide, ending at the lake. As was noted above, the plume likely reaches the lake at concentrations exceeding the generic guideline for freshwater aquatic life of 21 ppb.

As is often the case in an urban setting, a municipal water supply network provides domestic water in the area. Groundwater is not used for industrial or commercial purposes in this area either.

In this case, a risk analysis problem formulation concludes that the governing exposure pathway is inhalation of indoor air within the buildings overlying the groundwater plume.

TCE in groundwater can volatilize into the soil above the groundwater table and migrate in vapor form up into the air space of overlying buildings or the outdoors. The chemical and some of its breakdown products can cause health problems if inhaled over a long period, even at very low concentrations as it is currently considered to have non-threshold toxicity effects (carcinogenicity). They can also cause more acute health effects over short-term exposure, but not at the concentrations likely to migrate into the buildings in this case.

It has been confirmed through off-site groundwater investigation and indoor air quality monitoring that TCE and its degradation products are present within the commercial buildings and the residential homes. These concentrations are found to be higher in the residential homes, despite the lower groundwater concentrations beneath them, as they are heated with forced-air furnaces that – together with their construction details – causes a "chimney effect" drawing vapors from the soil into the building envelopes. While no commercial buildings exceed the occupational exposure limits, 10 of these commercial properties overlie the area of groundwater contaminated above generic guidelines. In addition, 100 homes overlie the groundwater plume, with 50 of these homes having been identified to have indoor air concentrations consistently above risk-based long-term exposure concentration guidelines for residential scenarios.

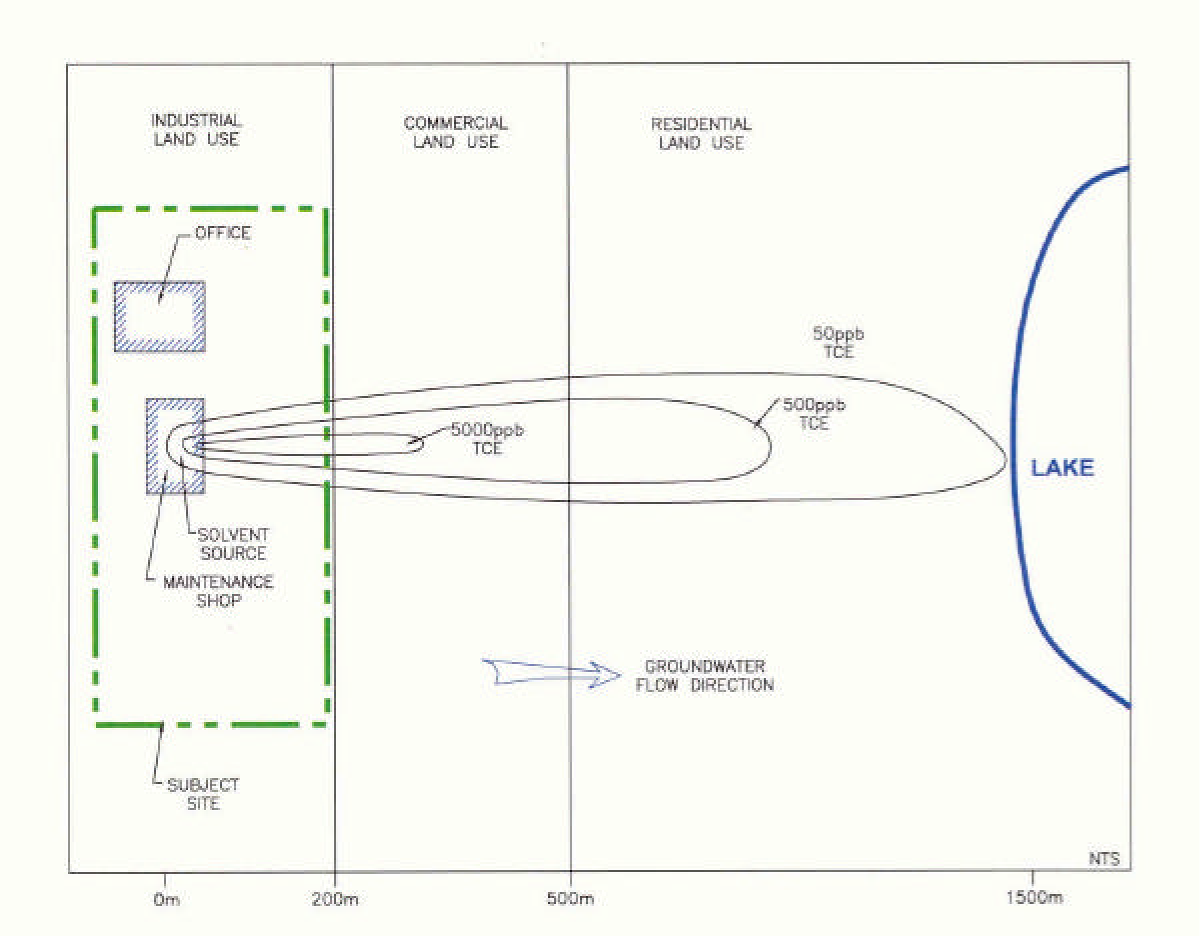

Figure 1: Example Scenario Site Layout

Stage One - Definition of Project: Remediation of Soil and Groundwater Through Air Sparging with Soil Vapour Extraction

Initial assessment of investigation and delineation efforts has already identified that excavation of the source is cost-prohibitive (greater than $30 million) given the difficulties caused by the operations and structures associated with the active facility and the difficult soil conditions for excavation. For simplicity in this example, the remediation approach of in-situ air sparging with soil vapor extraction (IAS-SVE) is analyzed in comparison to a base case of minimal risk management activities.

It is determined that an IAS-SVE wall 200 m in length is required to intercept the plume width, with a safety margin built in to accommodate some plume spreading due to mounding in the sparged zone. Due to constraints on the active industrial site, this system is planned for a distance of 100 m from the source area.

A modelling study predicts that the IAS-SVE system will result in concentrations in the off-site area being reduced to below the action level for TCE (50 ppb) within 10 years of system start-up. The modelling study also predicts that groundwater concentrations reaching the lake will be addressed within this time frame.

Receptor point treatment systems are also required in both the risk management base case and in the remediation approach under assessment, in order to reduce the indoor air concentrations in the residential properties that are above applicable guidelines. This action is considered by the regulators involved in the project to be the minimum acceptable level of effort. In the risk management option, this treatment is required for the entire period of evaluation. However, in the remediation scenario it may be removed from the homes after groundwater and associated vapor concentrations have been lowered sufficiently. This treatment may be accomplished through increased ventilation, indoor treatment (chemical filtering) or sub-slab depressurization systems in the homes. Sub-slab depressurization (SSD) is selected, as it prevents vapors from entering into the homes rather than treating these vapors after entry. It has also been very effective in wide use for similar applications.

The base case in this scenario therefore involves installation of SSD systems to address ongoing human health risks in residences with indoor air concentrations over the applicable guidelines; and, implementation of a risk management program (including monitoring and sampling) to monitor the conditions over time.

Stage Two – Definition of Impacts

Soil and groundwater have been contaminated beneath the industrial facility. Groundwater beneath numerous third-party owned properties has also been contaminated above generic regulatory criteria. Environmental liabilities exist to property owners and financiers who hold these properties as security for loans. Health risks exist for the residents and workers within the contaminated area who are being exposed to these chemicals. The plume is also discharging into the lake above generic guidelines. In addition, emissions into the atmosphere are ongoing, both directly from the ground above the plume and from the impacted buildings through their ventilation systems. Changes to this existing scenario would constitute the impacts of the remediation effort.

Other impacts of remediation would be utilization of resources being applied to this effort, including labor, materials and utilities involved in the remediation as well as legal, communications, regulatory and social costs associated with the project.

Stage Three – Identification of Economically Relevant Impacts

Impacts of the remediation project would include capital and maintenance costs of designing, installing and operating the remediation system. Other costs of remediation would include consumption of resources (i.e. carbon filter material, remediation equipment, operating consumables, and electricity). In addition, the resulting progress in remediation of soil and groundwater would reduce various property liabilities. It is assumed that the health liabilities will be addressed in both the remediation case and the base case, as the SSD systems will effectively remove this liability upon initiation. The remediation effort would also reduce impacts to the environment, including the uncontrolled discharge to atmosphere and exposure of the surface ecology and the aquatic environment (of the lake) to contaminants.

Impacts of the base case of minimal risk management would include maintenance costs of designing and implementing the risk management approach. This approach would include lesser consumption of resources (primarily related to consulting firm and laboratory resources). Impacts to the environment would be largely unchanged.

Some impacts would be unchanged in moving from the base case to the remediation scenario, and the costs and benefits associated with these impacts would therefore offset and be neglected in a CBA. In this example case, and in most remediation projects, some level of internal management costs and most regulatory costs would be common between the two approaches.

Stage Four – Identification of changes in costs and benefits

Following is a detailed listing of the anticipated costs and benefits associated with the remediation effort and the base case approach.

Remediation Costs

Costs associated with the remediation project include the following:

Direct financial costs:

- Environmental consulting costs – costs to scope, pilot test, design and apply the remediation effort and post remediation monitoring, or to scope, design and apply the risk management effort (base case);
- Remediation contractor costs – costs associated with construction and installation of remediation system, operation and maintenance on the system, and periodic upgrades over the remediation project life cycle. In addition, there are costs associated with the design and installation of the SSD systems, though the operating costs would be for the full 25 year evaluation period in the base case and limited to a 10 year period in the remediation case;
- Waste disposal costs – costs associated with disposal (or recycling) of spent carbon filter material (used to capture the TCE drawn from the soil and groundwater), contaminated soil and groundwater brought to the surface during installation actions, or waste disposal costs associated with any sampling program;
- Laboratory analysis costs - costs to analyze soil, groundwater, and air samples to evaluate the operation of the remediation system, or to evaluate levels during a risk management approach;
- System operating costs – costs to provide electricity for the remediation system, consumables such as carbon filter recharges, etc;
- Permitting costs and regulatory approval fees;

Other financial costs:

- Internal (management) costs to the company – project management of the remediation project or risk management approach, senior management briefing and assessment costs, internal communications costs, administrative costs, internal legal costs, etc;
- External legal costs – legal costs associated with assessing legal position, evaluating options, and addressing claims associated with the remediation efforts;
- Communications costs – costs associated with the communications program related to affected stakeholders (i.e. residents, tenants, owners, regulators, etc);
- Third party costs – costs for compensation to commercial and residential land owners and tenants for disruption from investigation (well installations, indoor air quality testing) and SSD installation (if applicable), as well as compensation for the operating costs of the SSD systems. Potential compensation for stigma - though it may be argued that this stigma will be there in either case (both before and after the remediation) and therefore may cancel out.

Economic costs (non-financial):

- Environmental cost of the fugitive emissions of the remediation system to the atmosphere and the addition of wastes from the remediation to the landfill. In addition, the SSD systems may cause some additional loading of contaminants into the atmosphere;
- Economic cost of the non-renewable resources consumed by the remediation effort, though it may be argued that these costs are built into the financial costs of these resources; and,
- Economic cost to society if the corporation goes bankrupt or requires layoffs to fund costly remediation efforts.

Remediation Benefits

Benefits that may be associated with remediation of contaminated sites are primarily a reduction in the various liabilities that result from environmental contamination. Remediation benefits for this example case are as follows:

Financial benefits

- Recovery of lowered property value of the subject industrial site. However, as the remedial option under study does not propose to address on-site contamination, this factor can be neglected as offsetting in both the remediation and risk management (base case) scenarios;
- Recovery of lowered off-site property values due to stigma associated with the contamination;
- Reduction in public liability related to costs incurred by financing problems of the off-site owners of contaminated property;
- Reduction in public liability related to settlement of civil claims of impacted third-parties;
- Limit the probability of costs related to regulatory prosecution or Orders for off-site contamination;

Economic benefits

- Recover or enhance public goodwill for the company, lost with the discovery and revelation of contamination;
- Improved quality of life of residents/tenants who live/work in the contaminated area, recovery of a thriving and desirable community;
- Improved environmental quality of receiving environments (soil, atmospheric and aquatic); and,
- Enhancement of groundwater resource for potential future water supply purposes.

A base case for definition of net costs involves the risk management and receptor point mitigation efforts that will be required by the regulators. In this case, there will be some liability reduction benefits and significantly reduced cost (as risk management measures will be significantly less costly than the full remediation option).

One of the more difficult financial liabilities to quantify is impaired property value; that is, quantifying what the impairment to the property value is from the contamination and subsequently quantifying the lessening of this impairment as remediation progresses. Dotzour (1997) gives the following equation for calculation of impaired value of property:

Contaminated value = Uncontaminated value – clean-up costs – public liability – stigma

In this reference, the component of stigma is further broken down into factors such as: hidden cost, trouble factor, mortgage ability, disruption, concealability, aesthetic effect, responsibility, prognosis, degree of peril and level of fear.

In the example case, it is assumed for simplicity that the party responsible for the contamination is clear and the company has made a business decision not to contest its responsibility in the cost of addressing the contamination problem (within reasonable limits). In providing this assurance to adjacent land-owners, and assuming all costs of remediation, the reduction in value due to clean-up costs (in the above equation) can be largely neglected, as they have become part of the Responsible Party's financial equation. However, public liability (cost of settling public claims) and stigma liabilities still persist. The following cost analysis has therefore incorporated these liabilities into its calculations.

It is noteworthy that in a recent court case in Canada (Tridan v. Shell (2000)) it has been ruled that stigma can exist with any level of contamination above "pristine" concentrations (assumed to be background). This appears to apply even if contaminant concentrations are below the applicable generic criteria for the intended land use and as per the zoning designation (i.e. remediation of a commercially zoned property to commercial land use criteria). Though this ruling has yet to be widely tested, it may have future implications on the liability portion of cost benefit analyses in the future.

Stages Five and Six – Quantify and discount applicable costs and benefits

For the purposes of this example case, an evaluation period of 25 years is assumed and a discount rate of 8% per annum has been selected. The following tables present summaries of the costs and benefits associated with both the remediation example case and the base case of risk management, all discounted to present value:

Table 2a: Summary of Costs for Example Case

	Remediation	**Base Case**	**Net Present Value** *
Consulting	$1,000,000	$800,000	$200,000
Remediation system costs (contractor)	$750,000	$350,000	$400,000
Laboratory costs	$1,100,000	$850,000	$250,000
Operating costs (including waste disposal)	$1,550,000	$200,000	$1,350,000
Internal (management) costs	$650,000	$600,000	$50,000
External legal costs	$1,300,000	$1,300,000	$0
Communications costs	$550,000	$650,000	($100,000)
Third party costs	$1,100,000	$1,500,000	($400,000)
TOTAL			**$1,750,000**

Table 2b: Summary of Benefits for Example Case

	Remediation	**Base Case**	**Net Present Value** *
Reduction in stigma to property values	$10,600,000	$6,400,000	$4,200,000
Reduction in public liability due to financing issues and civil claims	$1,600,000	$950,000	$650,000
Reduction in liability for regulatory fines	$23,000,000	$22,000,000	$1,000,000
TOTAL			**$5,850,000**

* Net present value equals remediation present value minus base case present value.

Important assumptions used in calculating the above example case costs and benefits are as follows:

- Estimated annual costs and benefits are discounted to present value using a discount rate of 8% per annum.
- Evaluation period is 25 years, with off-site remediation to generic guidelines achieved after 10 years.
- Assumed average value of properties: residential = $150,000; commercial = $3,000,000.
- 10 commercial properties overlying contaminated groundwater (above guidelines); 50 residential properties with indoor air contaminated above guidelines; and 50 residential properties overlying the contaminated groundwater that are not contaminated with respect to indoor air.
- Property values are initially depressed by 25% for residential and 30% for commercial properties due to contamination. These property value impacts are gradually reduced to 5% with achievement of remediation to generic guidelines beneath properties. Risk management reduces the property value impacts

to: a 15% reduction for residential properties with SSD, a 5% reduction for those residences where SSD is proven not to be required and a 20% reduction for commercial properties.
- Property value reduction is realized upon sale of properties, with a cycle of 5 years for residential property sales and 10 years for commercial property sales. Repeated sale of these properties are subsequently impacted by limited appreciation (over the ownership period) due to the contamination.
- Public liability (cost of legal actions) is assumed to be 15% of property value claims.
- Potential regulatory actions are assumed to be an environmental protection order for immediate remediation of the site at a cost of $30,000,000. It is assumed that this action would have been made within the first 10 years if no action was undertaken, will not be made if off-site remediation is undertaken, and has a remaining 5% possibility of occurrence if only risk management actions are taken.

Unmonetized costs and benefits

Unmonetized costs and benefits in this study include the following:

- Environmental loading of the TCE (and degradation products) to the environment would be significantly reduced by the application of a remediation system where these chemicals are captured for disposal. This would result in a significant net environmental benefit.

- The consumption of resources in remediation efforts would result in a small net environmental cost; though it may be argued that these costs are incorporated into the financial costs.

- Public goodwill toward the company would experience a net increase for the larger and more proactive efforts of active remediation.

- Improved quality of life for residents/tenants, improved quality of the receiving environments, and improvements to the groundwater resource would result in a significant net benefit from the implementation of active remediation and the subsequent reduction in groundwater and air contamination.

It is clear from the above analysis that with a benefits-to-costs ratio of 3.3 remediation of the contaminated groundwater is warranted from the financial analysis perspective. In addition, the unmonetized costs and benefits appear to generally increase this preference for remediation over the base case. However, it is also clear from these results that the benefits are strongly dominated by the assumptions in property value impacts (and the potential benefits in reducing these liabilities) and the assumed regulatory liability. Given the large uncertainty in the impact of contamination on property values, and market influences on these factors, the sensitivity of the results to these factors should be examined. The significant net value of the regulatory liability should also be assessed. Finally, as noted earlier, the influences of discounting rate and evaluation period should also be examined.

Stage Seven – Sensitivity analysis

Dotzour (1997) presents data indicating that in certain market conditions and/or when responsible parties respond proactively in addressing environmental contamination there may be minimal impacts on property values by environmental contamination. In the above case, the proactive measures of the responsible party and the controls put into place to minimize contamination in the short term may be conducive to this result. It is therefore advisable to examine the effect of significantly reduced property value impacts (and the benefits that subsequently arise from remediation) on this case.

Assuming depressed property values are impacted to a lesser degree initially, 10% for residential and 15% for commercial properties, and assuming that all but 2% of these property value impacts can be regained from remediation, the net benefit for this case is reduced to $2,000,000. This brings the benefits-to-costs ratio to 1.1 (or one third of the previous assessment). Though this still indicates that there is a net benefit to the remediation effort, the significant change in the margin is noteworthy.

It is also noteworthy that removal of the regulatory liability from the equation would then reduce the ratio of benefits to roughly 0.6, indicating that active remediation is not recommended on the basis of financial analysis. If the base case were able to ensure a complete removal of the potential for regulatory actions, through strong regulatory consultation and approvals, then this scenario may be applicable. The unmonetized costs and benefits might then play a key role in assessing the case for remediation.

A change in discount rate in the initial scenario above from the higher value of 8% to a much lower rate of 3% results in the benefits-to-costs ratio increasing to roughly 6.9. A lesser increase is noted in a scenario with both reduced property value benefits and a 3% discount rate (increased from 1.1 to 1.9).

Finally, to further evaluate the time sensitivity of the decision, a 50 year evaluation period was examined for the three scenarios listed above. The results of these calculations are summarized in Table 3 along with the preceding sensitivity analysis results.

Table 3: Summary of Sensitivity Analyses Results

	25 Year Evaluation Period	50 Year Evaluation Period
Initial scenario (as per Table 2a and 2b)	3.3	3.9
Reduced property value impacts from contamination:		
- with potential regulatory impacts	1.1	1.2
- without potential regulatory impacts	0.6	0.6
Reduced discount rate to 3%	6.9	12.5
Reduced property value impacts from contamination and reduced discount rate (3%):		
- with potential regulatory impacts	1.9	3.2
- without potential regulatory impacts	1.2	2.4

It is apparent from the above summary that the initial scenario will produce a net benefit to the project proponent. An assessment of the unmonetized parameters in this decision indicates that these costs and benefits would likely increase the benefits-to-costs ratio and support a remediation decision from both the project proponent and regulatory perspectives. However, the sensitivity analysis underscores the need to understand the potential impacts on property values and the nature of relations with the regulators.

It is also clear from the above analysis that the time distribution of costs and discounting of those costs for comparison can also have a significant influence on the decision. In application of the CBA methodology to a full remediation decision, these sensitivities would likely be highlighted in comparing remediation approaches with significantly differing temporal distribution of costs and benefits. For example, a high capital cost / low maintenance cost option such as a passive reactive barrier would likely have significantly different sensitivities than the above approach.

Discussion

The preceding discussion of cost benefit analysis applied to remediation decisions highlights several issues:

- Technically, the CBA approach appears very applicable to the complex decisions involved in environmental issues. However, there is some controversy over the application of this methodology to environmental problems, including questions of social equity, the moral appropriateness of quantifying human health issues and temporal equity related to discounting practices.

- Even with the existing differences of opinion in the appropriateness of applying CBA to environmental issues, it is clear that proper application of this methodology as a decision-making tool can be very useful in evaluating business or policy decisions.

- The differences between a financial analysis and an economic analysis should be remembered. Business decisions primarily follow the scope of a financial analysis, while regulatory decisions may be based on the economic perspective (whether or not quantitative analysis is applied). When evaluating alternative courses of action, this knowledge of the differing perspectives may be a useful tool in anticipating the needs of regulators, or even in justifying courses of action to them in negotiations.

- Similarly, regulators need to understand and appreciate the financial aspects of CBA and how remediation costs can impact not only the "bottom line" of a Responsible Party, but also how this impact leads to a rippling effect within society as a whole. For the most part, this understanding has been incorporated into the generation of regulatory policies. Continuing to recognize it in the application of these policies is therefore very important.

- The example case provides a quantitative analysis that indicates what may be intuitively felt, that proactive remediation will likely provide a net benefit when significant off-site liabilities exist. In addition, this net benefit will likely extend to society as a whole and thus agree with the regulatory perspective on the issue. The identified sensitivity of the example case to property value impacts, regulatory impacts and temporal parameters (discount rate and evaluation period) underscore the importance of understanding these aspects of a problem in making the appropriate business or regulatory decisions.

- Further application of CBA in evaluating various remedial approaches to a contaminated site would be informative in identifying the preferred approach. Of particular interest would be a comparison of those remedial approaches with significantly different cash flow and benefit realization patterns, given the demonstrated sensitivity of analysis on the time-distribution of costs and benefits.

- Further exploration of the influence of unmonetized (economic) parameters on the relative perspectives of Responsible Parties, regulators and other stakeholders should be undertaken.

The preceding discussion has been a very broad examination of a subject with a wide range of interacting theories and avenues to explore. Space limitations have resulted in barely touching on most of these issues. However, it is the author's hope that this discussion has provoked thought on these issues and the potential of the CBA methodology within the field of contaminated sites remediation. When the total costs and potential benefits of such decisions are large, as they are in major remediation projects, the effort necessary for this type of rigorous analysis can be easily justified.

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