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Decision Methodology for Site Owners for the Remediation of Contaminated Sites

By

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A thesis submitted in conformity with the requirements
for the degree of Doctor of Philosophy
Graduate Department of Civil Engineering
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Decision Methodology for Site Owners for the Remediation of Contaminated Sites

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Doctor of Philosophy
Department of Civil Engineering
University of Toronto
1998

Abstract

An economically-based decision methodology has been developed for helping the owner of a contaminated site select the preferred combination of remedial action and site use. The basic concept behind the methodology is quite simple: identify the preferred combination that maximizes the owner's net benefits, which consists of site use benefits, less the costs of remediation and expected liability. The challenge and contribution of this research was merging existing concepts, techniques and expert opinion from a diverse range of disciplines, such as property appraisal, hydrogeology, health assessment and economics into a coherent, comprehensive and practical methodology.

The need to develop more comprehensive and rational decision methodologies has recently been brought to the forefront as many municipalities grapple with brownfields redevelopment. The research investigates how to assess in economic terms the owner's three main objectives of: 1) maximizing site use benefits; 2) minimizing cleanup costs; and 3) minimizing liability, and these assessments are affected by conflicting interests from different stakeholders, alternative site uses, and uncertainties. Unlike many existing decision approaches, the proposed methodology is not based solely on achieving regulatory compliance or fulfilling a predetermined site use. The research also provides guidance on how to acquire and interpret information needed to estimate the owner's objectives. To facilitate this, new concepts and approaches were developed. For example, "principal liability conditions" are used to identify circumstances in which liability may arise. Liability itself is then defined in terms of contaminant exposure information, health-response data, and other less tangible factors, such as whether or not liability can be legally proven. Many diverse factors are explicitly acknowledged and then integrated into a single framework for decision making in order to identify the preferred site use/remedial action combination.

To demonstrate how the methodology can be applied, the research presents an illustrative example that considers a single hydrocarbon contaminant, several site remediation techniques, such as pump and treat and containment, and several alternative site uses, such as residential and industrial.

Lastly, the research expands on how uncertainty can arise, and demonstrates how it can be incorporated via a two-step process: first, using an extreme case analysis, and second, through a probabilistic analysis that uses probability distributions for the owner's benefits, costs and liability.

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A modern academic thesis, I am convinced, cannot be completed successfully in a vacuum. I would like to thank the following persons for all their efforts:

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My parents taught me the value of learning, of teaching, and of performing my best. The pleasure derived from being "number one" is transitory and shallow at best; the pleasure derived from performing your utmost – whether you succeed or fail – is incomparable. My brother continues to teach me that through diversity comes the strength found in simplicity.

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And finally, to Krista Schneider – the lady who is always there for me – thank you.

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Notation

Symbol	**Explanation**
a	Counter for categories of individuals at a site.
AC'	Arbitrary value of AC.
AC''	Second arbitrary value of AC.
AC_j	Available concentration of the contaminant to which receptors are exposed for RA_j.
$AC_{maxOFFjp}$	Highest, off-site available concentration for RA_j at the p location; uniform distribution.
AC_{maxONj}	Highest, on-site available concentration for RA_j; uniform distribution.
AV	The affected value of a contaminated site; equal to the property value.
b_i	Total number of categories of individuals at SU_i.
b_p	Total number of categories of individuals at the p^{th} location.
$C(RA_j)$	The cost of the j^{th} remedial action.
CC_j	Contaminant concentration at the site for RA_j.
$CC_j(x,y,t)$	Contaminant concentration at coordinates x, y and time t.
C_D	The costs of developing a particular site use; does not include the cost of any remedial activities.
C_{IMj}	The cost of any required interim remedial measure for RA_j.
CL_{La}	Cost of liability required to compensate each individual belonging to the a^{th} category of individuals for long-term health effects.
C_{Lmax}	Maximum financial cost of liability, measured in ($).
CL_{Sa}	Cost of liability required to compensate each individual belonging to the a^{th} category of individuals for short-term health effects.
C_{MONj}	The annual cost of any required monitoring for RA_j.
C_{ONj}	The annual cost of any ongoing activities required for RA_j.
C_{SI}	The cost of the initial site investigation and characterization to determine the approximate type and extent of contamination. Assumed fixed and independent of any RA chosen.
C_{SRj}	The cost of the actual site remediation efforts for RA_j.
f_{b1}	Owner's or community's benefits at existing remediation.
f_{b2}	Owner's or community's benefits if site is remediated to x_{r1} but below x_{r2}.
f_{b3}	Owner's or community's benefits if site is remediated to x_{r2} or above.
$f_{Bc}(x)$	Total community benefits at x level of contamination.
$f_{bc}(x)$	Community's financial benefit function evaluated at x level of contamination.
$f_{bo}(x)$	Owner's benefit function evaluated at x level of contamination.
$f_{cc}(x)$	Community's cost function evaluated at x level of contamination.
$f_{co}(x)$	Owner's cost function evaluated at x level of contamination.

$f_{Lc}(x)$	Community's liability (compensation) function evaluated at x level of contamination.
$f_{Lo}(x)$	Owner's liability function evaluated at x level of contamination.
$f_{ONj}(AC)$	Probability density function defining the fraction of the site space at any AC for RA_j.
$F_R(AC)$	Cumulative dose response function.
$f_{subc}(x)$	Community's benefits from site amenities.
$f_{succ}(x)$	Community costs by not being able to use site amenities.
i	Counter for i possible site uses.
j	Counter for j possible remedial actions.
k	Cost to prevent worsening of current contamination situation.
k	Counter for the k^{th} variation of RA_j.
L_o	Owner liability, measured in ($).
L_{LOFF}	Cost of off-site owner liability due to long-term health effects.
L_{LON}	Cost of on-site owner liability due to long-term health effects.
L_{SOFF}	Cost of off-site owner liability due to short-term health effects.
L_{SON}	Cost of on-site owner liability due to short-term health effects.
m_j	Number of years required for monitoring RA_j.
n_a	Number of persons belonging to the a^{th} category of individuals.
n_j	Number of years required for ongoing activities for RA_j.
NB	Net benefits; measure in dollars ($).
p	Counter for off-site locations.
$P(AC)$	The probability that an estimated AC occurs.
$P(L_{LOFFjp})$	Probability of off-site liability due to long-term considerations given RA_j and p location.
$P(L_{LONij})$	Probability of on-site liability due to long-term considerations given RA_j and SU_i.
$P(L_{SOFFjp})$	Probability of off-site liability due to short-term considerations given RA_j and p location.
$P(L_{SONij})$	Probability of on-site liability due to short-term considerations given RA_j and SU_i.
$P(O)$	The probability that "other" liability factors contribute to owner liability.
$P(O_{LOFFjp})$	Probability of "other" liability factors contributing to off-site liability (long term considerations) at the p location.
$P(O_{LONij})$	Probability of "other" liability factors contributing to on-site liability (long term considerations).
$P(O_{SOFFjp})$	Probability of "other" liability factors contributing to off-site liability (short term considerations) at the p location.
$P(O_{SONij})$	Probability of "other" liability factors contributing to on-site liability (short term considerations).
$P(R)$	The probability that a health response occurs for an estimated AC.
$P(R_{LOFFjp})$	Probability of long-term health impact in off-site individual given RA_j and p location.

$P(R_{LONj})$	Probability of long-term health impact in an on-site individual given RA_j.
$P(R_{SOFFjp})$	Probability of short-term health impact in an off-site individual given RA_j and p location.
$P(R_{SONj})$	Probability of short-term health impact in on-site individual given RA_j.
PLC's	Principal liability conditions.
$P_{ONj}(AC)$	Probability mass function for probability that site is at any AC for RA_j
PV	The property value of a contaminated site.
q	Total number of off-site locations.
r	The annual discount rate.
RA	Remedial action; may encompass remediation techniques and management options.
S	The stigma associated with a site due to contamination.
SB	The financial (site use) benefits received by the owner for a site use after subtracting the cost of development.
S_j	Site space remediated by RA_j to the concentration AC_j; uniform distribution
S_o	Total site space.
SU	Site use after remediation.
t_{BOUND}	The time for the contamination to cross the site boundary.
t_{DIS}	The time when the contamination is discovered and characterized.
t_{HLOFFj}	The time when long-term health effects in an off-site receptor are predicted to occur given RA_j.
t_{HLONj}	The time when long-term health effects in an on-site receptor are predicted to occur given RA_j.
$t_{LITOFFp}$	The time when compensation is awarded to individuals at the p^{th} off-site location (all individuals assumed to receive the award at the same time).
t_{LITON}	The time when compensation is awarded to on-site individuals (all individuals assumed to receive the award at the same time).
t_{MONEj}	The time when any monitoring required for RA_j ends.
t_O	The time the original contamination occurred.
t_{ONEj}	The time when any ongoing activities required for RA_j ends.
t_{RAS}	The time the remedial action starts.
t_{RAZ}	The time the remedial action is finally completed, including all long-term activities such as monitoring.
UV	The unimpaired value of the above site if it was not contaminated.
w_{OFFp}	Number of years between when liability is actually awarded at the p^{th} location and when the remedial action began.
w_{ON}	Number of years between when liability is actually awarded and when the remedial action began.
x_f	Final level of contamination at the site after remedial action.
x_o	Existing or original level of contamination at the site.
x_r	Level of contamination permitted by regulations.
x_r*	Level of contaminant permitted by regulations.

x_{r1}	One level of contamination permitted by regulations.
x_{r2}	Second level of contamination permitted by regulations.

Appendices

Chapter One:
Introduction to Site Remediation

This research develops a decision methodology as a tool for helping to select: 1) the preferred remedial action, and 2) the preferred site use for a contaminated site from the site owner's perspective. Site remediation has recently been in the forefront of environmental concerns as society attempts to balance the need to prevent health risks posed by contaminated sites against the significant economic cost of remediating them. For example, there are concerns about possible relationships between areas of industrial contamination and incidences of cancer (NRTEE,1998). Furthermore, an emerging class of remediation projects, popularly known as *brownfields*, demands a closer look at how decisions are made in such ventures. These are frequently "abandoned" sites located in formerly prosperous industrial or commercial districts with varying degrees of contamination, although usually not to the same degree as, for example, the Superfund sites in the United States (Maldonado,1996). There is considerable interest by current land owners, potential developers, and/or the local and regional governments to return brownfields to productive use (i.e., for profits, taxation income). A recent report issued by the National Round Table on the Environment and the Economy (NRTEE,1998) conservatively estimates that in the City of Toronto alone at least $11 million local tax dollars are foregone because of brownfield sites. Recent developments in regulatory frameworks by some jurisdictions, such as the Ontario Ministry of Environment (1996), have recently implemented more flexible and streamlined regulatory frameworks - based partially on a risk assessment approach - to promote the redevelopment of contaminated sites. The U.S. has also moved towards adopting the *Risk Based Corrective Action* approach for petroleum cleanups, and this same approach will soon be applied to all forms of contaminated cleanups (Begley,1996). These regulatory trends suggest that existing decision methodologies and previous regulatory regimes have proven unsuitable or at least inefficient in addressing the issues important in site remediation. For example, the potential for owner liability is cited frequently as an obstacle to clean up efforts (Maldonado,1996; Boyd and Macauley,1994) but it is often not explored. The owner may face on-site liabilities if there are health impacts after the site is remediated. There may also be off-site liabilities if the contamination migrates beyond the site boundary and impacts the health of adjacent property owners or users. Nevertheless, the owner of a contaminated site must often decide what must be done with the contaminated site, even if it is to not undertake any remediation.

A variety of decision methodologies have been developed to help the owner decide how a site should be remediated, but many are limited in what issues they consider. Chapter Two describes these in greater detail, but the following summarizes some of the major problems.

- Existing methodologies frequently focus on addressing technical matters. However, site cleanups are more complex than simply choosing a particular remediation technique because of the diverse issues involved.
- The owner is assumed frequently to have *already* selected a site use. This site use, however, may not be the "optimal" one given the contamination, the performance of available remediation techniques, and other factors. The suitability of alternate site uses is frequently not examined.
- Existing methodologies are usually developed to operate within an existing regulatory framework. However, regulations have been criticized because they establish cleanup criteria that can be too stringent or too lax, and are not necessarily related to the eventual site use. Regulations are, of course, important for protecting public health, but even with the new initiatives by some government agencies, regulatory compliance does not guarantee that the owner will not encounter problems during or after the cleanup.
- Existing methodologies often do not provide sufficient guidance as to how the information required to use them can be acquired and interpreted.
- Existing methodologies frequently acknowledge that other parties, such as the local community, may have valid concerns about any decisions made regarding site remediation. However, their interests do not appear to be explicitly considered in the methodologies proposed for the owner. Including and examining the effects of such concerns can improve the owner's decision making by demonstrating the implications of certain decisions for others. As a result, the owner may pursue decisions that are more "acceptable" from a social perspective. Potential problems may be avoided, possibly resulting in more timely cleanups.

- Uncertainties are not always considered in existing methodologies. Those that do appear to limit themselves to technical uncertainties related to the performance of specific remediation techniques or physical-chemical processes that may affect remediation. Uncertainties about issues such as liability are often not addressed.

The methodology developed in this thesis adopts a fundamentally different approach when helping the owner identify the preferred remedial action[1] and site use combination. It identifies the combination that maximizes the net economic benefits to the owner based on site use benefits, remedial costs, and liability. The methodology also rationally addresses technical and economic uncertainties which can significantly affect the owner's decision. The methodology attempts to be as comprehensive as possible by using concepts, techniques, and expert judgment from a diverse range of disciplines that can be important to decision making for site remediation. Finally, the methodology should be viewed as a tool to assist the decision maker: it should never be used as a substitute for good judgment. What it can do however, is to capture the interplay between significant factors and demonstrate the effects of issues so that the owner can make an informed decision.

1.1 OUTLINE OF THE DECISION METHODOLOGY

The decision methodology is a structure into which these various issues can be placed in context and assessed. It is divided into two major sections:

- Chapters One through Three present an overview of site remediation issues and how they impact the decision process from both the owner's and the local community's perspectives. In addition to the site owner, the community is frequently an important stakeholder involved in a site remediation project.
- Chapters Four through Six form the core of the methodology. From this point onward, we focus on the owner and how the methodology assists his or her decision making for site remediation.

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[1] The phrase *remedial action* is not synonymous with a *remediation technique*. The former may be envisioned as a "course of action" that should be undertaken, including the "degree" of cleanup and type of remediation technology. Conversely a remediation technique refers only to a specific cleanup method or technology.

This methodology does not assess comprehensively the preferred site use and remedial action from the community's perspective but it does demonstrate that the owner may need to consider other factors specific to the community.

We begin by exploring each of the above issues and why they can impact the decisions made. Chapter Two reviews how current methodologies approach site remediation and their various strengths and weaknesses. We also review two regulatory frameworks because regulations in effect govern what can or cannot be done. Finally, we summarize the findings of two interviews with professionals involved with site remediation. This illustrates some of the differences between the theoretical and realistic aspects of site remediation.

Next, we illustrate the issues of conflicting objectives, alternative site uses, and uncertainties in Chapter Three using a hypothetical, economically based example of decision making for site remediation. It uses simple assumptions to clearly illustrate how the above issues in a practical sense can affect the decisions made by the owner. It also establishes the basic operating premise of our decision methodology: the owner's decision process will be examined through the economic objectives of benefits, costs, and liabilities. There are, of course, problems and controversies with adopting an economic analysis initially, but it serves as a useful starting point.

In Chapter Four we describe in detail the components of the proposed decision methodology. We assume temporarily *certainty* in the information available and for the most part, an *unregulated environment* in order to explain more clearly the components of the methodology. However, a brief discussion will be included on how the decision process may be affected by regulations. We show how information can be incorporated to allow the owner to make preliminary decisions about site remediation. Specifically, this information is used to assess the owner's benefits, costs, and liabilities.

Chapter Five presents an illustrative example of how the methodology as presented in Chapter Four could help the owner decide which remedial action to pursue. In addition, we briefly examine the effect of regulations.

Chapter Six incorporates the effects of uncertainty into the decision methodology by using an extreme case analysis and a probabilistic analysis. For the former, we use an extreme case analysis to demonstrate the "worst case" scenario. (To improve the readability of the chapter, we do not examine the "best case" scenario.) In the probabilistic analysis, we model benefits, costs, and liability as probability functions to examine how the resulting net benefits may vary. We examine how uncertainties can arise, how they can be characterized, and some of the difficulties in doing so. While the decision process becomes more complicated, it also benefits because discrepancies are explicitly acknowledged; current or future problems may be minimized or even possibly avoided.

Chapter Seven discusses the contribution of this research and recommends further research that should be undertaken. In particular, more work is needed to formulate a decision methodology for the community in site remediation situations. The owner's decision methodology limits itself to examining the implications of the community's perspective on the owner's decision. A separate methodology for the community – or public decision making in general - would complement the approach outlined in this research. Merging the two methodologies would provide a more balanced perspective regarding remediation issues.

1.2 SITE REMEDIATION ISSUES

Figure 1.1 illustrates the major issues that should be included in the planning of site cleanups. The importance of each issue is explained below.

1.2.1 Possible Conflicting Objectives

The objectives of a site cleanup are not always clearly defined nor are they always understood. Before a problem can be solved, the objectives must be properly identified, but improper or inadequate attention to this task can lead to an incorrect solution (Reckhow, 1994). Because many stakeholders are involved, many viewpoints will most likely exist and differing perspectives can obviously delay remediation efforts (Van Horn and Chilik,1988). As a result, what one party may view as desirable objectives may not be considered desirable by another. For example, those wishing to safeguard the environment completely may want a full cleanup (i.e., zero contamination). A government agency, however, may be satisfied with cleaning up the site so that there would be no demonstrable health risk. This does not necessarily imply zero contamination however. There can even be conflicts between objectives that appear similarly aligned. If a soil can retain a high amount of contaminants, less of the contaminants have to be removed to ensure a given level of ground water protection (Belluck and Benjamin,1994). This can save time and money, but there may be future contamination problems if: 1) the soil itself is used in the future; 2) the soil conditions change, resulting in increased chemical mobility; or 3) if the site use changes in the future, resulting in increased contaminant exposure to humans or biota.

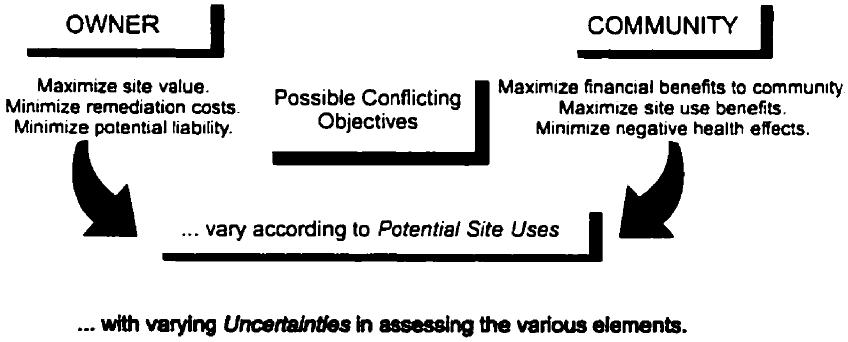

FIGURE 1.1: The issues of site remediation.

Figure 1.1 shows the objectives that each party is likely to consider important. The owner is assumed to be concerned mainly with maximizing the financial value of his or her net economic benefits. This can be accomplished by:

- maximizing the value of the site;
- minimizing the cleanup cost; and
- minimizing the potential liability.

Because it is unlikely that all three objectives can be fulfilled to the same degree of owner satisfaction, tradeoffs must also be made between these objectives to find the best remedial action.

The local community is assumed to have both economic and environmentally oriented objectives. Its objectives are assumed to consist of:

- maximizing the financial benefits to the community;

- maximizing the benefits from local amenities; and
- minimizing any health impacts from the contaminated site.

The community is also expected to make tradeoffs between its objectives. As will be shown in Chapter Three, redeveloping a contaminated site may result in greater financial returns to the community (e.g., tax revenues). However, not all future site uses may be desirable from the community's perspective, and depending on the remedial action pursued by the owner, there may be contamination remaining. There will also likely be different groups within the community, each placing different emphasis on various objectives. For example, business development groups may have objectives similar to the owner's, while environmental groups may emphasize health and ecological goals.

Conflicts will also arise from tradeoffs that must be made between the owner's and the community's objectives. For example, the least expensive cleanup for the owner may be perceived to afford the least health protection to the community. However, the differences between opposing objectives may be better resolved if at least the owner's objectives are rationally defined: the methodology focuses on how these can be described.

As noted previously, we only analyze substantively the owner's perspective in later sections of this methodology. Unlike other decision methodologies (for example, Rosen and LeGrand,1997), we do not suggest that this methodology is necessarily useful for other parties that may be involved, such as the local community. Although the *approach* may be transferable, there are many assumptions and elements pertinent only to the owner. We argue that there are enough differences to warrant a sufficiently different decision methodology for other stakeholders.

1.2.2 Alternative Site Uses

The remediated land may be suitable for a variety of uses depending on the degree of contamination remaining after cleanup. In the past, a site was usually cleaned to meet certain regulated levels in order to facilitate a predetermined use (Janz et al.,1991). However, its intended use may not be the most appropriate given the circumstances; other uses may better satisfy the various objectives of the owner or the community. For example, cleaning a site for a residential development may be prohibitively expensive; instead, a commercial development that requires a less stringent cleanup may be an ideal alternative. Assumptions about future land uses can even be a key source of uncertainty when analyzing the risks posed (Katsumata and Kastenberg,1997). For a proponent, such as a land developer, knowing what must be done given what uses are possible can save time and resources (Bleicher,1990). Furthermore, the site use can change over time, and possibly render the original remediation inadequate. By rationally examining the possible site uses in relation to the objectives, this methodology helps identify the most appropriate use.

1.2.3 Uncertainties

Uncertainty is essentially the lack of needed information, which may or may not be obtainable (Rowe,1994). Determining how to effectively address uncertainties may be the most crucial step to overcoming many of the problems encountered in site remediation cases. For example, from a legal perspective, it may be difficult to judge the adequacy of any remediation effort, or for how long a responsible party is liable. There may be significant differences in the relevant legislation between jurisdictions (NRTEE,1998). Furthermore, the potential risks posed by an ever-increasing variety of chemicals are poorly known. Of those that have been thoroughly studied, the applicability of such data to humans in real situations is often questioned. Finally, even the seemingly "concrete" aspects are rife with uncertainties: have enough site samples been taken for an accurate assessment; how well does this technology perform under these conditions; what is the range in cost? While certain remediation techniques, such as "pump and treat", have been used extensively in the past and their advantages and disadvantages examined in depth, many emerging technologies do not have such well documented histories. The performance of many of these newer techniques is often not known precisely (Freeze and McWhorter,1997). Even well established or proven techniques do not always perform as predicted. Uncertainty thus permeates all facets of the decision methodology; it can potentially paralyze the decision process.

We demonstrate how existing information can be used to better understand the nature of a particular uncertainty, and how it may affect other issues in the decision process. The effects of uncertainty will then be first analyzed using a simple *extreme case analysis*. Johnson and Slovic (1995) found people unfamiliar with risk assessments may recognize risk uncertainty when it is presented simply. This may be advantageous in site cleanups: uncertainty can be communicated quickly to the parties involved. The decision process can thus continue even if the information available is imperfect. Furthermore, an extreme case analysis may be serve as a useful screening device to eliminate unrealistic decisions before conducting more resource-intensive and sophisticated approaches to modeling uncertainty.

Next, we use a stochastic *probabilistic analysis* to demonstrate how the owner's decisions can be affected by a full description of the uncertainties using probability distributions for the owner's benefits, costs, and liabilities. An example illustrates in greater detail some of the potential problems the owner faces in making decisions under uncertainty.

1.3 AN ECONOMIC APPROACH FOR EVALUATION

We adopt an economic approach to evaluate the significance of these issues. In so doing, we determine the owner's preferred remedial action and site use based on the owner's *net benefits*. The combination that produces the greatest net benefits will be selected. In using economics, we can draw upon the literature regarding economic evaluation. An economic approach serves as a useful starting point from which to define the problem and structure the decision methodology. However, we recognize that a standard economic approach can have many limitations.

Economically-based evaluations have been criticized for their inaccuracy in capturing the value of the environment. This is most evident when we consider the owner's objectives against those of an adjacent homeowner. In site remediation cases, one of the most frequent laments is the loss of the homeowners' "peace of mind" after discovering their land may be contaminated. The challenge is to economically quantify this loss, often using a cost-benefit analysis approach, so that it can be evaluated if tradeoffs need to be made - a challenge that has so far been met with only limited success (Portney and Harrington,1995). Despite its efforts at addressing nonmarket situations, environmental economics may be inadequate for matters that are not inherently economic in nature (Evernden,1993).

Although the environment is integral to human existence, it remains largely regarded by many as a material resource. The intrinsic value of land, for example, is overshadowed by the value of what can be extracted from it: the value of nature is only worth what is usable by society (Piasecki and Asmus,1990). Cobb et al.(1995) assert that, "The economic significance of a thing lay not in its nature but simply in its market price."

Using an economic approach to assess the benefits and costs of a site cleanup may be misleading from a fundamental point of view. This can be illustrated by first adopting a much broader environmental perspective. Cobb et al.(1995) argue that the gross domestic product (GDP), a common economic indicator, is misleading in its assessment of economic health.

> By itself, the GDP tells very little. Simply a measure of total output (the dollar value of finished goods and services), it assumes that everything produced is by definition "goods." It does not distinguish between costs and benefits, between productive and destructive activities, or between sustainable and unsustainable ones.(Cobb et al.,1995,p.65)

Thus, if growth is the most important indicator of how society is functioning, then pollution is a positive contribution on a nation's balance sheets because resources are employed – and thus money spent – on remediation. Based on this approach, society should pollute more.

> In fact, pollution shows up twice as a gain: once when the chemical factory, say, produces it as a by-product, and again when the nation spends billions of dollars to clean up the toxic Superfund site that results. Furthermore, the extra costs that come as a consequence of that environmental depletion and degradation – such as medical bills arising from dirty air – also show up as growth in the GDP.
>
> This kind of accounting feeds the notion that ***conserving resources and protecting the natural habitat must come at the expense of the economy*** (emphasis added), because the result can be a lower GDP.(Cobb et al.,1995,p.66)

Using an economic net benefits criterion can be dangerous because it may only perpetuate the status quo: if the site is too costly to remediate, the owner should leave the contamination on-site, or possibly even abandon the site. Even though legal mechanisms exist to prevent or at least discourage such outcomes, the methodology may justify that the owner pursue such options since it only considers explicitly the *owner's* benefits and costs.

Because the methodology adopts an economic approach, issues are translated into dollar terms, raising the controversy of how intangible qualities can be numerically evaluated. For example, liability can arise from the owner's site imposing health impacts on the surrounding community. By including liability as a dollar value in the owner's net benefits, a monetary value is placed on health. This further raises an important question: so long as the owner's net benefits are positive, are health impacts "permissible"?

Despite its imperfections, an economic approach is useful as one mechanism for allocating resources when dealing with environmental matters, and is commonly used in evaluating the merits of both private and public projects. This approach is particularly relevant in the current risk versus cost debate for site remediation. An economic approach may be the only realistic – albeit flawed – tool available from the owner's perspective.

We acknowledge that these issues are significant and should not be diminished by the methodology. Moreover, we do not suggest that it should be used to justify any controversial decisions made by the owner. Instead, we advocate that the decision methodology is a tool for decision making that should be employed judiciously. Because constraints (e.g., regulations, opposition by other stakeholders) have not been explicitly considered, the methodology can demonstrate how the owner may make decisions if unconstrained. It can be used to understand how and why certain site use and remedial action combinations may be favored from the owner's perspective, and why these might differ from decisions made under regulations. This improved understanding should significantly improve the overall decision process for site remediation. However, as mentioned in Section 1.1, a decision methodology focusing on the community would complement the research presented here. Future research could also incorporate real-world constraints directly into an expanded decision methodology.

1.4 ADVANTAGES OF THE DECISION METHODOLOGY

A successful decision methodology should result in improved strategies for planning site remediations. An improved decision process does not automatically result in greater public acceptance in cases where public approval is critical to success (Vittes et al.,1992). This methodology also does not explicitly consider the constraints imposed by regulations or opposition by outside stakeholders. However, there are several significant improvements. Because the decision methodology systematically examines each significant issue, it is rational (Dooley and Byer,1982) and thus should be defensible. The methodology defines the owner's objectives and illustrates how the above issues affect these objectives and the decision process. For example, it clarifies what end uses are suitable for a contaminated site. It also suggests how to interpret existing information for difficult-to-quantify aspects. Finally, the decision methodology helps the site owner identify the most appropriate site use/remedial action combination from his/her perspective. These improvements will benefit the overall decision making process for site remediation.

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Chapter Two: Review of Existing Decision Methodologies and Practices

There are a wide variety of decision methodologies to help select remedial actions. They include regulatory frameworks and guidelines, simple risk-based assessments, and complex multi-faceted frameworks. This chapter reviews the effectiveness of existing methodologies, researches how site remediation specialists actually make decisions, and concludes by discussing what improvements are generally needed.

2.1 THE CURRENT APPROACH TOWARDS SITE REMEDIATION

A decision methodology's primary goal is to determine what is the best remedial action given the site circumstances. Freeze et al. (1990a) state that, "Decision analysis provides the link between the economic framework in which decisions are made and the results of the technical analyses on which decisions are made." However, a decision methodology that successfully provides such a link should also comprehensively address conflicting objectives, alternative site uses, and uncertainties. In general, these issues have been incompletely examined despite their importance. For example, Slater (1987) discusses that remedial alternatives are often evaluated in terms of technical feasibility, environmental impacts, public health effects, regulatory compliance, and cost-effectiveness. Lauer et al. (1991) list the criteria used by the U.S. Environmental Protection Agency (EPA) to select the remedial alternatives. These include: the overall protection of human health and the environment; attaining Applicable or Relevant and Appropriate Requirements (ARARs): long-term effectiveness and permanence; reduce toxicity, mobility and volume; short-term effectiveness; ability to be implemented; cost-effectiveness; state acceptance; community acceptance. In both cases, human health and the environment are to be protected, but the evaluations do not consider issues such as recognizing and incorporating objectives of different stakeholders or alternative site uses. However, this does not suggest that a party has not considered these issues at all. For example, we assume the site owner has some idea of what site use he or she wishes to develop. Instead, we emphasize that this consideration has not been explicitly examined by the owner in combination with alternative remedial actions. Lastly, practically all current methodologies and practices are based on achieving regulatory compliance. Section 2.4, however, discusses how meeting regulations do not necessarily lead to optimal solutions.

2.1.1 Selected Case Studies

Various examples of cleanup projects were found in the literature. In all cases, an evaluation had to be made to select the preferred remedial action. However, most articles focused on the technical merits of various technologies that could be used: few employed some form of comprehensive decision methodology. Furthermore, the governing criterion is based on achieving regulatory compliance. The following examples illustrate some of the issues and methods used to select a remediation action in actual clean up projects.

Van Horn and Chilik (1988) presented the details of the cleanup efforts of the top ranked Superfund toxic dump in the United States. In this case, the U.S. EPA assumed responsibility for the cleanup efforts. To decide which remedial alternatives should be selected, an outside consultant for the EPA, "... examined several cleanup options and evaluated them on several criteria, including safety, implementability, public health, environmental impact, cost, and reliability, as required under Superfund." No details were given as to how this evaluation was carried out. There were also contentious issues regarding the tradeoffs between costs, time for remediation, the dangers that nearby residents would be exposed to, and what level of remediation constituted "clean". Some remedial alternatives decreased potential health risks but at greater costs. In fact, the lack of specific cleanup standards led to an *ad hoc* decision process on the part of EPA officials, a situation that concerned outside government bodies. Predictably, the cleanup efforts were hindered, due partly to the distrust and poor communication between various parties.

Odom and Adams (1990) discussed the selection of a remedial alternative at a Superfund site. The site was a former dye research and production facility. Combinations of various remediation technologies formed the alternatives from which one would be chosen. The analysis considered the following criteria: technical feasibility; legal and regulatory requirements; human health (both present and future exposure); environmental effects; and cost. EPA guidance documents were followed to set remediation objectives, evaluate remediation alternatives, analyze and select the preferred alternative. A staged approach seems to have been generally followed. Alternatives were first evaluated for their technical feasibility, and then whether they satisfied human and environmental criteria.

In general, a regulatory approach was employed. The alternative that best met the criteria and regulations was selected. Apparently no human life resided nearby and thus protection of aquatic life became the principal goal. It is not clear if an intended end use was established for the site after remediation.

Rao, Stachle, and Voss (1991) evaluated the remediation alternatives for an abandoned industrial site contaminated with dense, nonaqueous phase liquid (DNAPL) chemicals. The initial portion of the evaluation focused on comparing the technical advantages and disadvantages of the various alternatives. Technologies that were clearly unsuitable for the site conditions were eliminated. There appeared to be a preference for selecting well-developed, demonstrated technologies. Following this screening, the remaining alternatives were compared against a further set of criteria. Unlike the previous examples, a much more expanded and explicit list of criteria was used. This list included the reliability of the technology, short term and long term effectiveness, the ability to minimize off-site impacts, and legal constraints. The alternatives were then qualitatively evaluated in terms of advantages and disadvantages for each criterion.

While the criteria were certainly more extensive, the accuracy of rating how well each alternative fulfilled certain criteria was unclear. For example, the degree to which the state and the community would accept the alternative was *assumed*. It appears no efforts were made to survey the acceptance of the alternative. Unlike the other two cases in which there were significant discussions about cost/risk tradeoffs, this example focused primarily on comparing the technical merits of the various alternatives. Little emphasis was placed on the issues of cost and the community or state response.

Brown (1991) detailed how the U.S Air Force selected the preferred method to remediate or dispose a stockpile of petroleum contaminated soil at an Alaskan air force base. The *hierarchical decision process* was used to actually select the alternative once the pertinent information was gathered. Six panel experts, all with vested interests in the case (either members of the U.S. Air Force or federal/state environmental agency), were involved. However, the author made the final decision and not through any multi-party consensus. It was stated that he alone had the responsibility and expertise to decide which remedial alternative was suitable. He acknowledged that in other situations such sole authority might be inappropriate; it is suspected that the decision process in this example was influenced strongly by the prominent role of the military.

This case was clearly an example in which the proponent was striving to find the most expedient method to meet the applicable regulations given various constraints such as cost and technical feasibility. The author states:

> ... the environmental regulations promulgated by the EPA and ADEC ensure protection of the environment. The Air Force is not going to demand any stricter standards on itself than those in the existing environmental regulations. (Brown,1991)

There was little, if any, discussion concerning contentious tradeoff issues. The criteria used to evaluate the options were broadly grouped into economic, regulatory, technical, and perception considerations. Indeed, the criteria and degree of evaluation did not appear as detailed as in the previous three examples. For example, in terms of perception, only two stakeholders were considered - the U.S. Air Force and the U.S. Fish and Wildlife Service. The community did not appear to have been involved at all. Unlike the other three examples however, all factors and their importance were translated into weights to evaluate the alternatives. Furthermore, a sensitivity analysis was performed to determine how the evaluation could be affected.

2.1.2 Summary of Case Studies

A wide range of evaluation techniques were employed, ranging from ad hoc methods to formalized decision models for assessing the suitability of various remediation alternatives given the objectives, constraints, and other site circumstances. More importantly, however, are the differences among the various case studies in terms of establishing both the objectives and information needed to formulate a decision. Objectives and criteria varied widely both in terms of number and detail. Stakeholders, such as concerned environmental groups and the community at large, who normally could be expected to play a significant role, were sometimes considered but in general their presence did not receive significant attention in the owner's decision process. Although not obliged to account for outside interests, the owner may have to consider factors beyond his or her own financial considerations. Lastly, the issue of health risks versus cost in selecting a remedial alternative figured prominently only in the first example. While it is uncertain what health risks may have existed in the other three examples, it appears that the proponent assumes such risks are negligible so long as the applicable regulations are satisfied. Again, this emphasizes how most remediation projects are based on a regulatory approach.

2.2 EXISTING DECISION METHODOLOGIES

We review decision methodologies that deal not only with contaminated site remediation, but also with contaminated ground water remediation. In many site remediation instances, these two cleanup activities are related intimately. Interestingly, few methodologies recognized the role that other stakeholders could play in the decision process. Most were devised for the proponent (e.g., site owner, land developer), although several considered a regulatory or otherwise public agency as the decision-maker.

The existing decision methodologies found in the literature to date can be divided into four main categories as shown in Figure 2.1. This classification system is based on the primary characteristics found in the various decision methodologies. Several methodologies can span several groups and there can be considerable variation in how a methodology approaches site remediation within each group; these categories are intended to divide existing decision methodologies for ease of discussion only. In general, the categories are described in approximate order of increasing comprehensiveness.

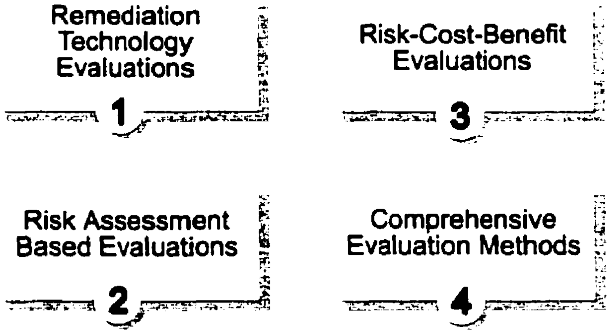

FIGURE 2.1: Classifying existing decision methodologies

2.2.1 Remediation Technology Evaluations

These are primarily evaluations of specific remediation technologies or techniques and detail their advantages and limitations. Prototype technologies were also included in some cases. These can be divided into three general categories: containment, mobilization, and destruction (Hrudey and Pollard,1993). Such evaluations provide the basic technical information needed and frequently use a matrix-type evaluation in order to match possible contaminated site scenarios with technologies that appear to work well under specific circumstances. What is usually not included is a contextual analysis; that is, they do not provide any decision making guidance for issues such as conflicting objectives or alternative site uses. The appropriateness of regulations is usually not questioned and discussion regarding risk assessment is minimal. Because these evaluations are so focused on the technical aspects, they are not reviewed in detail in this research.

2.2.2 Risk Assessment Based Evaluations

These methodologies (Batchelor et al.,1998; Suter II et al.,1995; Elliot,1992; Hwang,1992; Huggins and LaGrega,1991) typically depend on available health data for chemicals and other statistical data to guide the decision maker in making a decision. They can be used to determine cleanup targets, such as the permissible amount of remaining contamination, with respect to physical-chemical interactions and exposure scenarios. As with the first category, most of the methodologies do not address the other important issues, such as competing objectives between the stakeholders, and instead focus on the scientific aspects and issues of risk assessment.

These evaluations, however, can be used to investigate or address variations in risk. For example, Suter et al.(1995) expand their framework to include ecological risk. They balance human health risks against ecological risks in remediation scenarios. Past remediation decisions have often paid less attention to ecological matters and instead focused on human health aspects. Suter et al.(1995) suggest that this problem arises due to the lack of a common scale to evaluate human and ecological concerns. Health risk assessments conclude with the health of an individual human, whereas ecological risk assessments must often deal with many varied populations of species. Cleaning up one arena, be it human or ecological, may impose risks on the other during the remediation process. This, of course, relates to land use conflicts. It makes little sense to remediate a human dominated area in an effort to return it to a "wild" ecological state.

Uncertainty is often considered, but usually only with respect to risk assessment (i.e., uncertainty behind exposure conditions and health impacts). However, a recent article by Batchelor et al. (1998) adopts a stochastic approach to modeling risks at sites contaminated by hazardous wastes. They recognize that many of the factors (e.g., media characteristics, toxic responses) used in risk assessment are variable. Instead of using conservative estimates for the factors, they use distribution functions to describe the various parameters. For the most part, deterministic approaches to modeling risk have dominated. Although the approach proposed by Batchelor et al. (1998) does not examine issues such as liability, it appears to be a more comprehensive procedure for modeling risk.

Risks may also change over time. McBean and Rovers (1995) recognize that not all remediation alternatives (techniques) have the same risk exposure duration. This is expressed as risk-time curves in which, "... the curves indicate the temporal, changing levels in terms of risk, as a function of time, for each of the remediation alternatives." Such curves are useful in determining if there are any peak risk exposure periods. For example, excavation and landfilling results in a brief, initial period of possible high levels of exposure to contaminants from moving operations and the subsequent emissions. This is followed by a much lower, long-term risk due to the absence of the contaminants. Conversely, an alternative such as pump and treat in which contaminants are generally removed at a much slower rate results in a long-term, moderate level of risk. Figure 2.2, adapted from McBean and Rovers (1995), illustrates how they represent the uncertainty of a remediation alternative. The vertical variation for each alternative indicates the range of costs that can be expected for each remediation technique. Similarly, the horizontal variation for each variation indicates the range of possible risks.

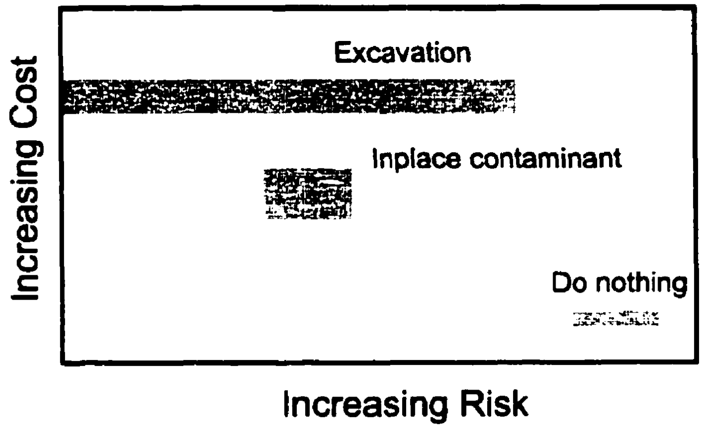

FIGURE 2.2: Societal risk-cost tradeoffs with uncertainty
(after McBean and Rovers, 1995)

2.2.3 Risk-Cost-Benefit Evaluations

These integrate risk assessment, engineering design, economics, and technical uncertainties into a risk–cost–benefit framework, typically from the owner–operator perspective (Katsumata and Kastenberg,1997; Rosen and LeGrand,1997; James et al.,1996; Freeze et al.,1990; Massmann and Freeze,1987). These methods incorporate reasonably sophisticated techniques, emphasize the use of quantitative data, require a significant amount of information, and are much more comprehensive than the first two categories.

Freeze et al. (1990) propose perhaps the most extensive decision methodology in this category. It is based on a risk–based engineering philosophy (i.e., the distribution of the probability of failure) in which, "... the risk of failing to meet design objectives reflects the uncertainty in the technical analysis" instead of the traditional engineering "safety factor" approach. Note that this decision framework uses the concept of risk in terms of design failure and not in the toxicological sense. The framework assesses the suitability of various engineering alternatives given that a particular course of action has been proposed using a combination of:

- field investigation and a data acquisition system;
- a geological uncertainty model;
- a parameter uncertainty model;
- a hydrogeological simulation model; and
- an engineering reliability model.

These are then incorporated into an economically based decision framework.

Issues not strictly of a technical, risk, or economic nature – such as social or community acceptance – are sometimes acknowledged but generally receive little or no consideration. For example, James et al. (1996) mention "negotiating" with other stakeholders but do not discuss how the objectives from other parties have been incorporated. Freeze et al. (1990) indicate that their framework can be used by others than the owner–operator but that there are significant difficulties. Specifically, Massmann and Freeze (1987) acknowledge the problems of economically assessing the value of life, particularly from the public perspective (e.g., willingness-to-pay to avoid a risk) and specifically restrict their risk–cost–benefit analysis to the owner's perspective. Moreover, although Freeze et al. (1990) do question the adequacy of regulations, these evaluations largely use regulatory compliance as their primary means of addressing public objectives (e.g., health and environmental protection).

Katsumata and Kastenberg (1997) present one of the few studies that explicitly consider the effects of future land use assumptions on the risks posed by contaminated sites. As with this methodology, they recognize that different land uses have different populations and behaviors, resulting in different exposure scenarios, and that land planning can be a useful risk management tool. The authors also recognize that there are uncertainties not only in technical aspects (e.g., exposure assessment), but also that they exist in institutional factors and have not received much attention in the past. Their objectives are to: estimate the impact of future site uses assumptions on uncertainty; illustrate how these assumptions affect the selection of a remedy at a selected Superfund site; and demonstrate how the inherent uncertainty can impact the remediation cost. Not surprisingly, they conclude that future residential site uses generally carry larger health risks than current or future industrial site uses.

Katsumata and Kastenberg (1997) operate within a regulatory framework and do not explicitly consider other factors deemed important in the proposed methodology; for example, the owner's benefits[1] and liability are not mentioned. It also appears as if specific remedies were selected for their Superfund case study (i.e., excavation, fixation, on-site disposal for site soils only contaminated with inorganics); costs were estimated for each remedy; and then the site use assumptions were applied to these remedies to determine the residual risks to the corresponding users. The paper does not explicitly investigate how different remedies would have affected the tradeoffs between costs and risks, although it does conclude that there may have been more health- and cost-effective options than those chosen in their case study.

These methodologies can still improve how site cleanups proceed within a regulatory framework. For example, Hwang (1991) suggests that an optimal solution to site remediation can be found by integrating three main aspects: risk assessment, value engineering, and a positive regulatory relationship. Hwang investigates how the feasibility study can be improved within a regulatory framework and suggests that a risk assessment can eliminate or scale down unrealistic or unattainable remediation alternatives, particularly if the risk is shown to be insignificant. However, its applicability to developing a site remediation decision framework is limited to exploring the relationship between risk and cost, and innovative engineering designs.

2.2.4 Comprehensive Evaluations

These methodologies consider explicitly - or can be expanded to include - the widest range of objectives, such as human health, ecological concerns, economic cost, and technological feasibility.

A new approach for assessing site remediation options has been recently developed using a life-cycle framework (Diamond et al.,1997). This framework, which uses life-cycle management and life-cycle assessment methods, recognizes that remediation activities themselves can pose significant human health and environmental risks on site-specific, regional, and global scales. A key strength of this new approach is its promotion of, "... 'life-cycle thinking', and to methodically investigate and highlight potential, often ignored,

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[1] This may be because remediating Superfund sites, unlike brownfields, are usually not viewed as profitable undertakings because of the high costs frequently involved.

or discounted impacts associated with a remediation approach." (Diamond et al.,1997) From the owner's perspective, such an approach could have important advantages over other approaches, especially since life-cycle analysis necessitates examining both short-term and long-term effects.

In its current form, the life-cycle framework appears directed towards selecting site remediation techniques. Issues such as alternative land uses and owner liability are not addressed directly. However, unlike the other methodologies reviewed in the other three classes of existing methodologies, the authors emphasize that such an approach can be used for other applications, such as evaluating a government policy regarding site remediation, and expanded to include other considerations, such as cost and community disturbance. Lastly, the need for expert judgment is recognized. This aspect is discussed further later in this chapter.

The few remaining methods in this category concentrate on how information gathered for site remediation should be "processed" but may not describe how to define this information. For example, Ross and Donald (1995) apply fuzzy logic to model the uncertainties that surrounds the variables - be they social, economic, or political - of site remediation, but do not investigate how these variables can be derived. They concentrate on how to incorporate subjective estimates but do not discuss the issues behind them.

2.3 THE NEED FOR GUIDANCE AND INFORMATION

Complex decision methodologies require an extensive amount of information, especially technical data if sophisticated modeling techniques of physical-chemical characteristics are required. Parties involved with smaller scale remediation projects and having fewer resources may not be able to access or generate the amount of information required. In practice, site owners must make a "sound" decision based on the limited information available. However, existing decision methodologies and frameworks do not usually indicate how to *acquire and/or interpret the information necessary to use the decision methodology.*

This problem can be illustrated by examining the objective of minimizing potential owner liability. For example, Freeze et al. (1990) have developed an engineering oriented methodology for use by an owner/operator of a hydrogeologic project. Equation [2.1] details the components of risk within their overall objective function:

$$R(t) = Pf(t)Cf(t)\gamma(Cf) \qquad [2.1]$$

in which $Pf(t)$ is the probability of failure in year t; $Cf(t)$ are the costs, in dollars, associated with that failure in year t; and $\gamma(Cf)$ is the normalized utility function that allows for possible risk-aversion on the part of some owners. Although risk, as a dollar value to the owner, depends partly on the cost of failure, the above methodology does not clarify the components of this cost. In a follow-up article focusing on groundwater contamination, Massmann et al. (1991) present a specific site scenario and give two arbitrary failure costs. In defining these costs they state, "The owner would develop estimates for these failure costs by considering costs of litigation, fines, additional remedial activities, consultants' fees, and the like." Although they later conclude that efforts to refine these failure costs are not justified within the context of their example, it is still important to provide more detail on how to derive meaningful estimates of variables such as failure cost. These are the very elements - particularly those involving liability - that are frequently difficult to estimate and clouded by uncertainty: there is often no guidance on how they should be evaluated.

Rosen and LeGrand (1997) adopt a similar approach to Freeze et al.(1990) and state in their paper that,

> Economical consequences of contamination includes many items, e.g. remedial costs, loss of value of the resource, loss of property value, costs for finding an alternative water supply, and liability costs. Hydrogeologists often need to cooperate with economists to make appropriate assessment of economic consequences. (Rosen and LeGrand,1997,p.200)

Later in their example they also state that, "The costs of failure were determined to be associated with remediation costs and penalties." Even if it is recognized that outside expertise (e.g., an economist) is needed to provide these estimates, there is little instruction on how to *interpret and incorporate* such results into the decision process.

2.4 REGULATORY FRAMEWORKS

Many of the decisions concerning what and how to remediate follow federal and/or provincial/state regulations. Regulations, guidelines, and government policies are designed to either dictate or guide what is and is not allowable to protect human health. From this perspective, a regulatory framework can be considered a decision making approach for selecting a remedial action, as well as providing compliance criteria. Regulations, however, have been criticized: they may be too stringent, or else too lax. In the case of the former, resources may be wasted in an attempt to remediate the site to a degree beyond what is required. Generally, the more resources (measured typically in dollars) spent on remediation, the less the risk posed to humans and the environment (Huggins and LaGrega,1991; McBean and Rovers,1995). This *cost versus risk* tradeoff is a central theme in nearly all remediation efforts. On the other hand, there is no assurance that regulations ensure safety (Lauer et al.,1991). While cleanup efforts may achieve the permissible concentrations of chemicals allowed, such levels may be inadequate under specific circumstances. As expressed by Freeze et al. (1990):

> In a regulated environment, protection of the health and safety of the public seems to have been taken over by the regulatory agencies, and most hydrogeologists and engineers would now feel that they have satisfied their ethical requirements if their designs meet the regulatory standards imposed by the regulatory agencies. Many engineers and hydrogeologists are seriously concerned by this development...(Freeze et al.,1990,p.742)

2.4.1 Site-Specific versus Uniform Regulatory Approaches

Currently, site-specific risk-based regulatory approaches are being promoted in some jurisdictions. Such assessments of risks may be preferable (Lauer et al.,1991) because contaminated sites can be remediated to a level that is "clean enough" given the site circumstances, as opposed to restoring contaminated sites to a prescribed, uniform level. Moreover, there may be solutions that prevent exposure instead of reducing the contamination (Begley,1996). This approach is touted as being much more responsive to "real-world" conditions: the cost to clean a site to "no-risk", regulated levels (e.g., non-detection of a substance) may be prohibitively expensive and unnecessary (Stanley,1996).

Does this suggest that site-specific risk assessments are vastly superior? Since they can be adapted to the unique conditions at the site, they can provide greater protection to environmentally sensitive situations that would otherwise suffer from using uniform criteria. Huggins and LaGrega (1991) emphasize that relying on national/state standards does not necessarily provide the same level of protection assurance as risk assessment. However, using risk assessment may also result in more relaxed standards being applied in some situations (Canadian Environmental Law Association,1994) due to the many uncertainties and assumptions inherent in the risk assessment process. Risk assessment can be particularly sensitive to the experience and judgment of the assessors. It also typically involves examining many details - it is possible to lose sight of the objective of risk assessment. The outcome of a risk assessment should not be applied without first verifying the results and considering these results within the context for which they were sought (Hrudey and Pollard,1993). Moreover, more resources must be spent to conduct the individual analyses required. In comparison, uniform regulations can prove to be a less expensive option and further provide a modicum of consistency from one site to another (Labienic et al.,1994). However, there appears to be generally greater support in the engineering related literature for site-specific assessments, and this support can be expected to increase with the anticipated expansion of RBCA (risk based corrective action) guidelines, originally developed for petroleum sites, to all chemical contaminated sites (Schwartz,1997).

2.4.2 Guideline for Use at Contaminated Sites in Ontario

The importance of a regulatory framework can perhaps best be illustrated by examining the *Guideline for Use at Contaminated Sites in Ontario* (MOEE,1996). In particular, its relevance to the three issues of conflicting objectives, alternative site uses, and uncertainties will be highlighted. There are significant developments in this relatively new guideline that parallel the methodology proposed in this research. The Guideline is intended to govern more the assessment and practice of site clean ups to ensure compliance with health and environmental criteria. Specifically, it provides guidance on:

- a process which may used in the assessment of contaminated or potentially contaminated sites;
- three approaches which may be used for site restoration;
- soil, groundwater and sediment criteria which may be used when restoring contaminated sites;
- use of risk assessment and risk management strategies at contaminated sites. (MOEE,1996)

Furthermore, the Guideline specifically states that:

> A proponent may use this guideline to assess, or restore a site for a variety of self-directed or self-initiated purposes. The information provided in this guideline allows proponents to *make decisions* (italics added) about the site assessment and restoration process which may be required at a site. (MOE,1996)

There is indeed some guidance provided on what must be done. However, there is little consideration given to defining the clean up objectives, accounting for uncertainties, and guiding a stakeholder through the actual decision making process. Instead, the Guideline acts more as a procedural "checklist". It is implicitly assumed that the proponent or other decision maker has *already* made important decisions regarding issues, such as which site use should be developed. This contrasts with the proposed decision methodology that focuses on how the preferred remedial action – and site use – can be selected in combination.

Nevertheless, several of the Guideline improvements are pertinent to the three main issues of conflicting objectives, alternative site uses, and uncertainties. These include:

- The use of the *background, generic,* or *site-specific clean up approach* to remediating a contaminated site. It is left to the proponent to decide which is most appropriate. Appendix A provides details on these three approaches.
- The use of three land use designations - *agricultural, residential/park-land,* and *industrial/commercial* - to distinguish between the possible future site uses. The regulations differ depending on the intended site use.
- The possibility of using a *stratified clean up* approach in which subsurface soils are not remediated to the same degree as surface soils. Depending on the current contamination and future site use (e.g., whether or not potable water is needed), a less stringent site clean up may be permitted.
- The emphasis on the need for public communication. However, the guidelines do not provide guidance how the information from any dialogue can be used.
- Providing guidance on land use planning. However, this appears to be directed toward municipalities by concentrating on zoning and land restrictions.

In addition, the Guideline recommends certain goals when proponents design public communication plans. It also discusses land use planning. However, the Guideline is concerned more with the principles and mechanics of establishing these communication or land use plans[2]. For the land use planning, the Guideline outlines how the municipality can use a variety of mechanisms, such as zoning bylaws and land use approvals, to identify and guide/control contaminated lands. Again, the Guideline focuses on the procedures involved and what can be done to regulate land uses, as opposed to examining what are appropriate land uses.

In general, the Guideline allows for alternative cleanup approaches. For example, different criteria are given for a variety of remediation scenarios and different land uses, allowing for variances in cleanup levels within the site. The SSRA allows the proponent or other decision maker to consider options such as capping (i.e., to prevent pathway exposure), and important factors such as the costs of remediation. The Guideline thus addresses, in part, elements of the three identified issues: there is some consideration of alternative land uses and certain objectives (e.g., cost) are acknowledged. However, uncertainties are not explicitly considered.

The MOEE Guideline, as with most regulatory mechanisms, outlines the minimum that must be done to protect human and environmental health, regardless of the actions eventually chosen. In general, they govern the technical aspects of how to remediate a site, but there is minimal discussion regarding:

- how to examine objectives once they have been identified;
- how to assess tradeoffs;
- how to determine if a particular site use out of several is appropriate;
- why one remedial action may be preferred over another; and
- how uncertainties should be handled.

In short, the guideline may influence but does not provide explicit direction to the user in deciding the preferred course of action. Presumably, such guidelines and other regulatory mechanisms could be made significantly more comprehensive and applicable in governing site cleanups if they acknowledge realistic considerations, such as the costs of cleanup

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[2] It is not the goal of the proposed decision methodology to resolve regulatory or procedural issues, such as when and how public consultation should be undertaken. Instead, we examine how any issues raised by the public may affect the owner's decisions.

(Portney and Harrington,1995). The similarities and differences between the Guideline and the proposed decision methodology are discussed in greater detail in Appendix A. It also includes comments from the Advisory Committee on Environmental Standards (ACES,1994), which reviewed the MOEE Guideline when it was in its draft stages.

2.4.3 Risk Based Corrective Action Guidelines

The American Society for Testing of Materials (ASTM) introduced Risk Based Corrective Action (RBCA) guidelines to govern the cleanup of petroleum contaminated sites. This approach is now being extended to include all chemical contaminated sites (EM,1997). In general, it appears to have been widely received in the U.S., in part because of its three tiered approach (Begley,1996).

In Tier 1, the site conditions are compared to generic screening levels. If they are exceeded, the analysis moves to Tier 2, in which site-specific target levels of contamination are determined using relatively simple mathematical models and compared to the site conditions. If Tier 3 is warranted, the complexity and cost increase and a complete risk assessment is undertaken (Stanley,1997).

The redevelopment of petroleum-contaminated brownfields has been attributed (at least in part) to RBCA. It is no longer necessary to clean a site to "pristine" levels, but only to levels sufficient for protecting human and environmental health (Begley,1996). However, RBCA, like its MOEE counterpart, is a procedural approach: it outlines what can be done under particular circumstances, but does not explore the deeper issues underneath. For example, it does not consider explicitly alternative site uses, but rather assumes that the proponent of the remediation has already made such a decision. Because RBCA was introduced fairly recently, it has not yet established a history of aiding successful cleanups. RBCA does, however, appear to offer significant guidance regarding the technical aspects of using its tier system.

2.5 INTERVIEW WITH PRACTITIONERS

Several interviews with professionals actively involved with site remediation[3] were conducted to determine how current decision practices with regards to soil clean–up efforts compare to what is advocated in the literature. Although the following discussion is based largely on anecdotal evidence instead of a rigorous study, it suggests that complex decision methodologies are not used extensively, and that experience plays a significant role in the decision process.

2.5.1 Shell Canada Limited

For several decades, Shell Canada Ltd. (Smith,1995) had previously leased a parcel of industrial land located in a major Southern Ontario centre. The site, being no longer suitable for Shell Canada's current uses, was to be leased to a new tenant. Although the original lease did not contain any environmental clauses, Shell Canada Ltd. undertook the initiative to remediate past contamination that had occurred. Physical and cost restraints prevented Shell Canada from performing a "total" clean–up. Instead, Shell Canada performed a site-specific remediation in which various portions of the site were remediated to differing levels deemed acceptable for future site uses. Clean–up activities were also to be performed at different times.

One of the most important aspects of the remediation effort was to involve all stakeholders: the site owner, the current user (Shell Canada), the next tenant, the provincial government, interested groups (e.g., municipal development groups), and local residents. The need to identify all pertinent objectives, especially conflicting ones, was very important, and a reconciliation of all objectives was apparently reached.

The proponent – Shell Canada – knew in advance the next tenant's intended site use. The issue of potential site uses was therefore not a significant problem. Shell Canada had the advantage of predicting what potential exposures could result to the next site users. The clean up efforts could thus be tailored to meet the specific requirements of the future site use.

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[3] For the purposes of confidentiality, the specifics of the clean–up programs have been omitted.

The greatest hurdle was gaining provincial government approval for Shell's remediation strategy. Uncertainty, primarily in the form of regulatory acceptance and subsequent liability, played a significant role: Shell Canada wanted to ensure that it would not be held liable for obligations it had fulfilled during the clean-up. It also faced other challenges, such as deciding which chemicals would be used in the ensuing extensive technology review and health risk assessment. These were analyzed and interpreted using an acceptable level of risk of 1 in 100,000 as one criterion for deciding which remediation approach was appropriate. Shell stated that selecting such a probability was a value judgment on their part.

The decision process used by Shell Canada to determine the most appropriate remedial action did not match any of the decision methodologies described previously. The decision process was linear in form but with many "parallel tracks". As illustrated in Figure 2.3, each track focused on one specific aspect of site remediation. Note that the aspects considered were not limited to those shown in the figure.

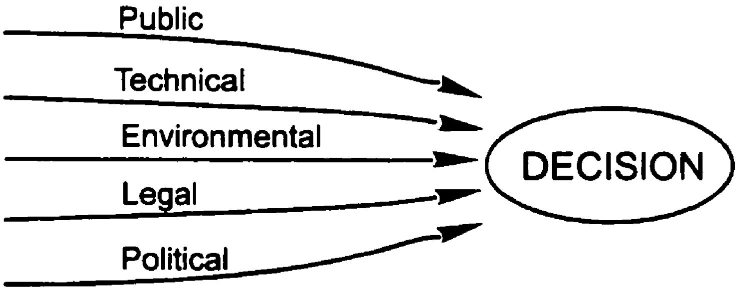

FIGURE 2.3: Parallel tracks of some concerns in decision process for Shell Canada.

The decision to remediate using a site-specific strategy revolved around the health risk assessment[4]. A short list of contaminants that would be targeted in a clean-up effort was eventually formulated. This list was based primarily on potential toxicological and exposure scenarios as well as relevant government guidelines. Achieving a consensus at

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[4] Although environmental concerns did play a role, it is important to note that an *ecological risk assessment* was not undertaken.

this important stage from all relevant stakeholders was very difficult, emphasizing again the conflicting objectives and the tradeoffs that had to be decided. Once a general course of action was determined, the decision process focused on which would be the most suitable remediation technologies. Initially, the various technologies were ranked. However, after a certain point a largely "intuitive", iterative process, based mainly on performance, cost, and environmental criteria, was used to decide which technologies would be appropriate.

2.5.2 Imperial Oil Limited

Imperial Oil Ltd. (Bywater, 1996) adopts a different view than Shell Canada towards its remediation efforts. Risk, regulations, liability, and site management are identified as key issues for Imperial Oil. Because of the public perception of risk, the uncertainties surrounding future site uses, and the uncertainties of the potential health risks, Imperial Oil would rather pursue one of two site management scenarios:

1. Imperial Oil would retain ownership of the site, contain the land, and not remediate it in cases where the financial cost of remediation is nearly equal to the market value of the land. This option would also be favored if a great deal of uncertainty existed regarding the potential benefits of a remediation project.
2. Alternatively, Imperial Oil would undertake to fully remediate the site with the understanding that Imperial Oil would no longer be held responsible for the site. In fact, Imperial Oil would prefer to contract remediation activities to the new site owner (assuming one exists) in order ensure that any clean-up efforts will satisfy the future site uses. Imperial Oil prefers "responsible" new owners that will not dissolve in bankruptcy, thereby leaving Imperial Oil as the financially responsible party.

Clearly, Imperial Oil would prefer to remain the sole owner, and thus controller of the land, or else relinquish responsibility entirely. Any partial remediation strategies, as employed in the Shell Canada case, are not as desirable. Again, the issue of liability through uncertain health risks (i.e., what is defined as "clean") and regulatory approval (i.e., absolving and/or defending Imperial Oil from future actions) is a primary concern, as is the potential use of the remediated site. However, the overall decision process is similar to that used in the Shell Canada situation. Various formalized decision techniques were found useful to help scope the problem. After some point however, the decision process no longer lends itself easily to a quantifiable or engineered approach and an intuitive decision making strategy is adopted.

2.5.3 Conclusions from Interviews

Based on this industry perspective, several interpretations can be made. These conclusions are not universally applicable to all site remediation situations, but they do lend credence to the issues identified in Chapter One.

1. There is a clear need to properly identify and resolve conflicting objectives. Even from the proponent's view alone, the balancing of cost against environmental objectives is apparent.
2. Establishing the next use for a contaminated site would benefit most proponents in the decision process: the clean-up should be appropriate for the next intended use. This approach was seen as the preferred approach to satisfy any health or environmental requirements, reduce the liability of the current proponent, and yet be cost effective. The first case involving Shell is probably atypical: all parties were interested in furthering the use of the site and the next site use was already known. This knowledge undoubtedly aided the decision process. Such certainty is probably not the norm.
3. Both points above relate to the third point – uncertainty. From the proponents' points of view, uncertainty chiefly manifested itself as liability. The greater the uncertainty in such aspects as site use, regulatory requirements, technological performance, and so forth, the greater the potential liability the proponent faces. In turn, the proponent must confront potentially higher costs should a "worst case" scenario occur during a remediation attempt.

A final, intuition-based step played an important role in the decision process. This is apparently not specific to the proponent; financial institutions that lend money for property development appear to behave similarly. When judging whether or not to lend financial aid in contamination scenarios, the decision process is roughly broken into two stages (Bisset,1996). First, quantifiable decision techniques are employed (e.g., site assessments, benefit–cost analysis). However, at some point, the decision is "intuitively" made. This two-stage decision process is similar to that previously described for Shell Canada Ltd. and Imperial Oil Limited. None of the decision methodologies examined previously appear to consider this intuitive factor. The decision methodology should acknowledge that intuition or expert judgment can play a significant role in decision making and explicitly outline how it can be incorporated.

2.6 NEEDED IMPROVEMENTS TO DECISION METHODOLOGIES

Chapter One argued that there are three primary issues in site cleanups: conflicting objectives; alternative site uses; and uncertainties. A review of the literature revealed many of the existing decision methodologies are limited in their ability to handle the three identified issues. Moreover, most do not adequately describe how the information needed to use the methodology can be acquired or interpreted. This is particularly important if data are needed to address a controversial issue, such as potential owner liability. Nevertheless, elements of several of the risk-assessment based and risk-cost-benefit approaches may be useful in constructing a more effective decision methodology. Regulatory frameworks were also examined because they can be loosely considered decision methodologies. Ultimately, regulatory frameworks are guides to the technical aspects of site remediation. It is unlikely that such instruments will assist the owner in understanding the broader issues (e.g., identifying the conflicting objectives and potential site uses). Lastly, in practice, decision makers appear to employ a significant degree of intuition and expert judgment. The need is to incorporate expert judgment in a comprehensive and systematic approach to avoid incomplete, ad-hoc decision making.

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Chapter Three: The Framework for the Decision Methodology

This chapter establishes the basic framework for the decision methodology. The owner's and community's benefits, costs, and liabilities (compensation) are described in economic terms. Illustrative curves for these variables are shown in order to demonstrate the effects of conflicting objectives, alternate site uses, and uncertainty, and to provide an overview of the basis for the proposed decision methodology. Chapters Four and Six describe in detail how the methodology defines and formulates these objectives.

We begin by assuming there is a cleanup level - and therefore corresponding level of remaining contamination – that satisfies each stakeholder at a contaminated site. This implies that there is an optimal site use corresponding to that level, and a remedial action to achieve it, from each party's perspective. To find these levels for the owner and the community, we define their objectives in economic terms and then analyze the implications for decision making using a hypothetical, numerical example. Although we will not focus on the community's decision making process in later chapters, including its objectives in this chapter more readily illustrates the potential relationships between and among the owner's and community's various objectives.

3.1 THE OWNER'S NET BENEFIT FUNCTION

We assume the site owner seeks the level of remediation, or conversely the level of remaining contamination, that maximizes his or her net financial benefits. The owner's overall objective is therefore,

$$maximize\ NB = f_{bo}(x_f) - f_{bo}(x_o) - [f_{co}(x_f) + f_{Lo}(x_f, x_r)] \qquad [3.1]$$

in which the maximum net benefits, *NB*, received is the difference between the benefits received, $f_{bo}(x_f)$ from the site at some final level of contamination, x_f, and the costs required, $f_{co}(x_f)$, to achieve this level, and any expected financial liability cost, $f_{Lo}(x_f, x_r)$, that might arise from the final level of contamination. x_r represents a level of contamination that may be permissible by any applicable regulations; whether or not the contaminant is above or below this level could affect the owner's liability. The owner may also be receiving benefits from the site at the current level of contamination, x_o, and these would be subtracted to obtain the marginal benefits. Determining what level, x_f, of remediation maximizes the owner's net benefits requires understanding what comprises these elements. The costs are probably the most straightforward of the three to define. Conversely, liability is presently the most uncertain and difficult issue and will be examined in greater detail.

3.1.1 The Owner's Financial Benefits

A range of site values has been derived for different levels of contamination following remediation. Figure 3.1 depicts the owner's benefits in a *regulated* scenario based on the following assumptions:

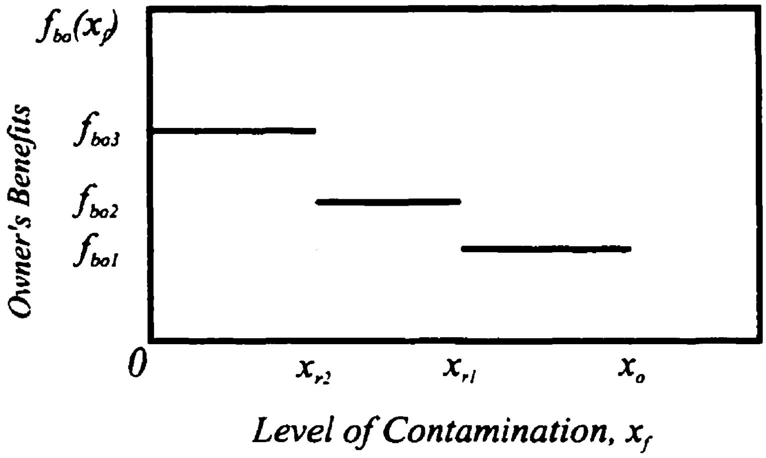

FIGURE 3.1: The owner's benefits vs. contamination

- The benefits, f_{bo1}, (if any) received will remain unchanged until the site is cleaned to some regulated level of contamination, x_{r1}. At lower levels of contamination, the site can be developed for other uses, resulting in greater benefits.
- The benefits are shown as a step function; the lower the final level of contamination, x_f, the more site use options. For example, x_{r1} represents the level of contamination permitted to develop the site for industrial purposes. x_{r2} represents the level of contamination permitted for developing the site into a residential area. Moreover, the benefits, f_{bo2} or f_{bo3} the owner receives are assumed to be relatively uniform within a certain regulatory category.

3.1.2 The Owner's Remediation Costs

The costs of remediation are expected to increase as the site is cleaned to lower levels of contamination as shown in Figure 3.2. In this example, we assume that k represents costs that may be needed to prevent the site from surpassing its current level of contamination, x_o (e.g., a leaking storage tank may need to be plugged). In all likelihood, there is an initial startup cost (e.g., site investigation) before remediation begins. This is shown as a step increase in the cost curve at x_o. For the remainder of the curve, we assume that the marginal cost increases as the level of contamination decreases and that achieving a "virtually clean" site would be prohibitively expensive.

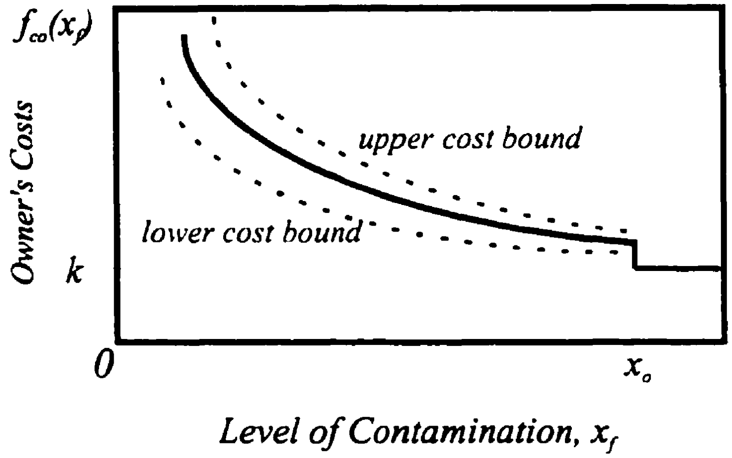

FIGURE 3.2: The owner's costs vs. contamination

Other forms of the owner's cost function are of course possible. For example, a step function with discontinuities, similar to that shown in Figure 3.1, may be more appropriate if different types of remediation techniques are needed to achieve successively lower levels of contamination.

3.1.3 The Owner's Liability

The owner faces both on-site and off-site liabilities. Characterizing them involves evaluating:

1. the situations and circumstances that can lead to liability, or the ***principal liability conditions***;
2. the possible adverse health impacts of the contaminant;

3. the probability of individuals being exposed to the contaminant, and how this probability can be reduced through various engineered and/or management means, such as containment or removal of the contaminant;
4. the probability of an adverse health effect to those exposed;
5. the probability of the owner being actually *found* liable in, for example, a court of law even if the owner is guilty of not meeting regulatory requirements;
6. the financial cost of liability given the above four conditions; and
7. the effect of regulations upon liability.

Chapter Four elaborates upon these issues; a limited discussion of regulations is presented in Chapter Five. For our discussion in this chapter, we assume that points (1) to (5) define the overall probability of the owner being found liable, or P_L. Point (6) involves estimating the maximum financial cost of liability, or C_{LMax}, for specific persons and situations in order to calculate the cost of the owner's liability. The expected value of the owner's liability, L_o, is therefore,

$$L_o = (P_L)(C_{LMax}) \qquad [3.2]$$

Figure 3.3 below shows L_o varying with the final level of contamination, x_f, in a regulated environment. For example, at x_o, the owner's liability is determined by multiplying the probability that the owner is liable - assumed to be P_{L2} in this instance - by the maximum cost of liability, C_{LMax}. At some lower level of contamination, x_{f1}, the probability that the owner is liable has decreased to P_{L1}. At a regulated level, x_r^*, the liability he or she faces may be zero because that level is permitted. Regulations can thus also benefit the owner. x_r^* may be a level of contamination that the regulatory agency no longer considers a health problem, or perhaps a level that poses in their opinion an "acceptable" risk level to the public's health. This acceptable level of risk reflects generally only the health risk (i.e., point (4) above). In reality, Figure 3.3 may take on various forms, such as step functions. There may also be discontinuities or even an increase in owner liability as the level of contamination decreases because regulations may permit site uses with more people who could be affected. Regulations may also change over time, creating the possibility of future liability for the owner.

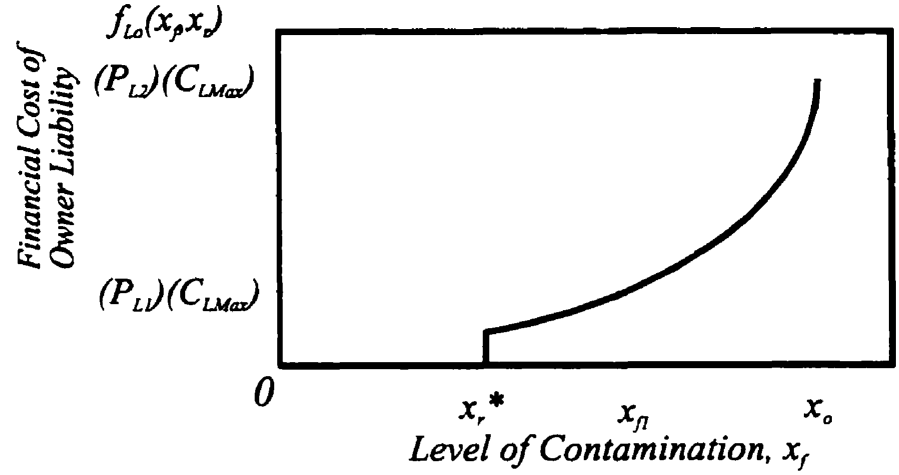

FIGURE 3.3: The owner's financial liability vs. contamination

3.1.4 The Net Benefits to the Owner

Based on Figures 3.1, 3.2, and 3.3, the resulting net benefits function could be as shown in Figure 3.4. For levels of contamination greater than the first regulated level, x_{r1}, the net benefits are negative for the owner due to the high cost of liability; the owner has not met the minimum regulations. Between x_{r1} and x_{r2}, the next regulatory category, the owner's net benefits peak because of an increase in the site value, but then decline as x decreases due to the increasing cleanup costs. A similarly shaped peak appears between x_{r2} and zero. Because the owner is assumed to derive only uniform benefits within each regulatory range, the owner should expend the least amount possible to achieve this category range; thus implying that only the upper contamination limit of any regulatory category should be met. Moreover, a "virtually clean" site produces negative net benefits for the owner due to the high cost of clean up. Based on this analysis, the optimal decision would be to achieve a final level of contamination of x_{r2}, which would allow the owner to pursue a residential site use development.

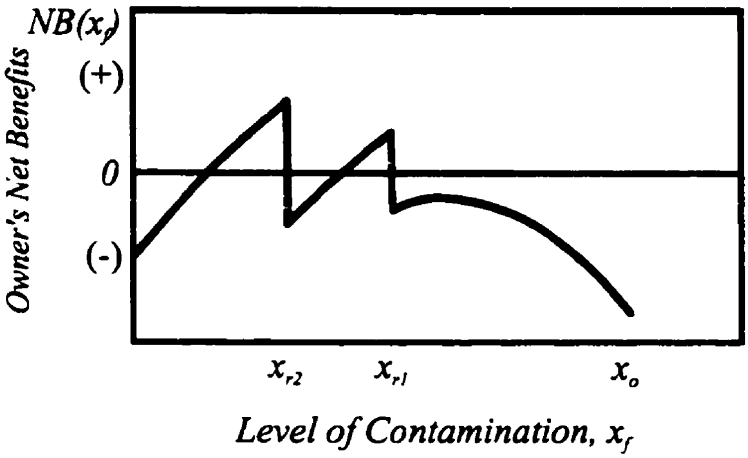

FIGURE 3.4: The owner's net benefits.

3.2 MODELING UNCERTAINTIES

In this chapter, uncertainties will be modeled through a *sensitivity analysis*, resulting in upper and lower bounds for the benefit, cost, and liability functions described above. Figure 3.2, for example, illustrates upper and lower bounds for the owner's remediation costs based on the uncertainties of estimating the costs and performances of remediation technologies. Chapter Six addresses how uncertainties will be incorporated into the methodology.

3.3 THE COMMUNITY'S NET BENEFITS FUNCTION

A similar decision making analysis and notation can be developed for the local community. For the purposes of illustration, all members of the community are assumed to have similar preferences[1]. The community is assumed to also want to maximize its net benefits function as shown in Equation 3.3. Since not all of the costs and benefits can be as easily represented in economic terms as in the owner's case, this approach is less satisfactory. However, it serves as a useful starting point.

$$\text{maximize } NB = \Sigma f_{Bc}(x_f) - \Sigma f_{Bc}(x_o) - f_{cc}(x_f) + f_{Lc}(x_f) \qquad [3.3]$$

The benefits realized by the community are the difference between the total benefits of the

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[1] In reality however, there may be different groups within the community. Each group may emphasize different objectives and prefer a different alternative.

site after remediation, $f_{Bc}(x_f)$, and of any benefits $f_{Bc}(x_o)$ received from the site at its original level of contamination. The costs, $f_{cc}(x_f)$, to the community are due to negative health impacts, if any, from the final level of contamination remaining. However, these costs to the community may be offset by any compensation, $f_{Lc}(x_f)$, received from the owner, assuming he or she has been found liable and ordered to make reparations.

3.3.1 The Community's Benefits

The local community's benefits, $f_{Bc}(x_f)$, can be divided into components if the site is remediated:

1. financial benefits (as represented by $f_{bc}(x_f)$), and
2. benefits from using the site itself (as represented by $f_{subc}(x_f)$).

The financial benefits are shown in Figure 3.5. These include an increased tax base if the site is developed into, for example, a shopping complex. As with the owner, Figure 3.5 assumes that regulations have restricted the site uses and thus the financial benefits to the community are uniform within a regulatory range. From the community's view, however, no or few financial benefits would be realized between x_{r1} and x_o if the site is too contaminated for uses that would actually benefit the community. The community may receive significant financial benefits between x_{r2} and x_{r1}. This range is assumed suitable for industrial or commercial purposes. If remediation continues and the level of contamination decreases to below x_{r2}, financial benefits may again increase; the site may now be suitable for housing, as an example. However, a decrease in financial benefits to f_{bc3a} is also shown to illustrate that further remediation does not always result in increasing financial benefits to the community and depends on the exact site use.

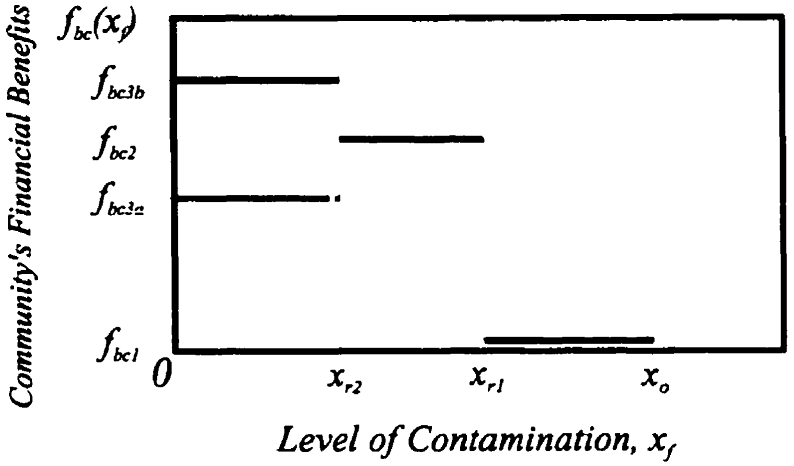

FIGURE 3.5: The community's financially related benefits versus contamination.

The "site use" benefits include the amenities (e.g., aesthetics) of the site and its surroundings and its contribution to the community image and reputation. These benefits are shown in Figure 3.6. At the current level of contamination, x_o, there are few or no site use benefits to the local community (i.e., f_{subc1} is approximately zero). As the level of contamination decreases, the benefits increase but at a much slower rate as the contamination approaches zero.

Alternatively, these benefits may be shown as costs (e.g., f_{succ1} at x_0) to the community: it may be difficult to evaluate the community's site use benefits from a pristine environment. As explained in Section 1.2.4, there are limitations to using an economic approach. Nevertheless, for the purposes of illustrating the decision framework it may be easier to view these increased site use benefits as decreased site use *costs* from the community perspective. A site with no contamination implies the community is not deprived of any site use nor is its reputation stigmatized; there is no cost.

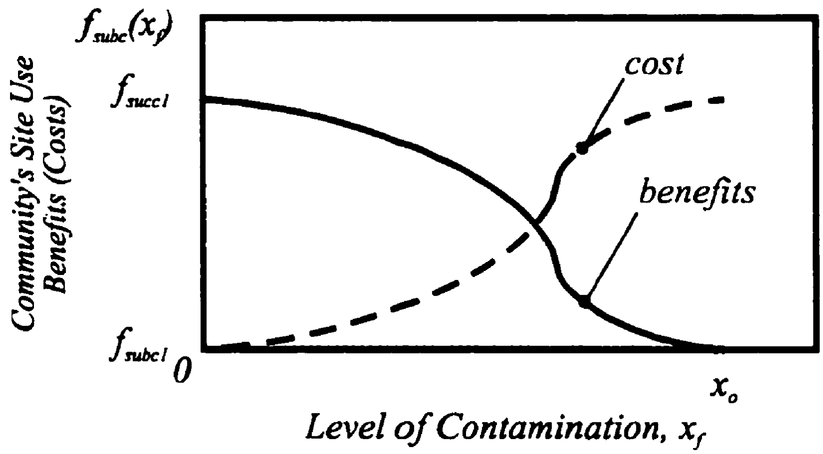

FIGURE 3.6: The community's benefits (costs) of amenities versus contamination

As the site is remediated for more sensitive uses, the site amenities are assumed to correspondingly increase. This may not always be true. For example, remediating a heavily contaminated site to permit a large commercial warehouse would reduce the possibility of environmental impacts from the contaminant, but may also introduce other nuisances and dangers, such as noise and traffic. Further separation of these site use benefits/costs may be necessary.

3.3.2 The Community's Costs

Figure 3.7 shows the negative health impacts, measured as a financial cost, upon the local community. In general, the cost of the health impacts is expected to decrease as the level of contamination decreases. In this example, we have also assumed that the owner compensates the community directly for health impacts, resulting in the net cost curve. Although the amount received as compensation should equal in magnitude the costs borne by the local community, this is not necessarily the case because of uncertainties in determining liability. There may be situations in which there may be no compensation forthcoming, such as if the owner abandons the site.

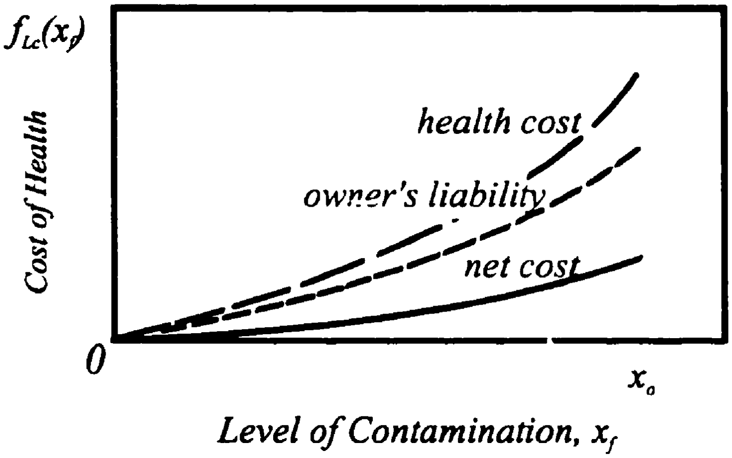

FIGURE 3.7: Cost of health effects upon the community.

3.3.3 The Net Benefits to the Community

The net benefits to the local community are shown in Figure 3.8. The community receives negative net benefits when the contaminant level exceeds the minimum existing regulation, x_{r1}. The net benefits are largely uniform throughout the two regulated ranges, from x_{r1} to x_{r2} and from x_{r2} to 0. Unlike the owner, the community does not have to pay increasing remediation costs as the level of contamination decreases. For the community, the optimal decision is to completely cleanup the site (i.e., $x_f=0$). Remediating to x_{r2} would result in slightly lower net benefits. However, like the owner, uncertainty is also present in all three objectives of the local community. This is modeled through a sensitivity analysis and is explained in the following example.

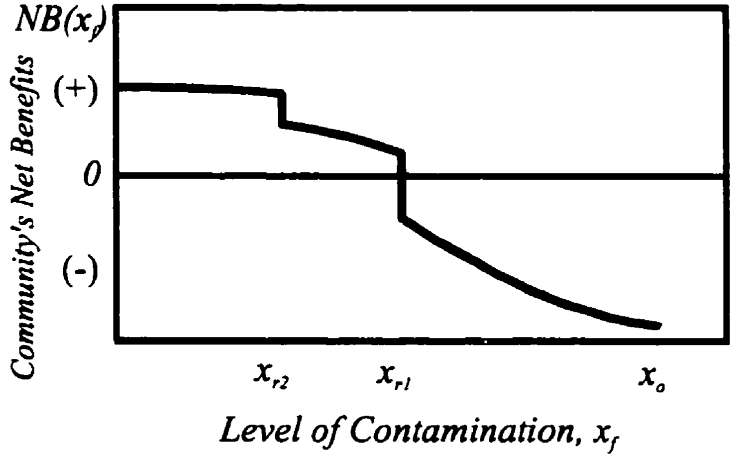

FIGURE 3.8: Net benefits for the local community

3.4 HYPOTHETICAL EXAMPLE

A hypothetical numerical example using the owner's and community's net benefit functions demonstrates the difficulties in deciding how much to clean up a contaminated site. These functions are shown in Figures 3.9 and 3.10 below and were derived from functions that were deliberately created to mimic the various shapes seen in Figures 3.1 to 3.8. We assume that the current level of contamination at the site is 150 mg of the contaminant per kilogram of the soil matrix, and specify two regulatory levels of 30 mg/kg and 60 mg/kg that would have to be met for different site uses. Figures 3.9 and 3.10 also show the range of resulting net benefits functions if each party's benefits, costs, liability/compensation functions, and the regulatory levels were varied arbitrarily by ± 10% in order to model the effects of uncertainty.

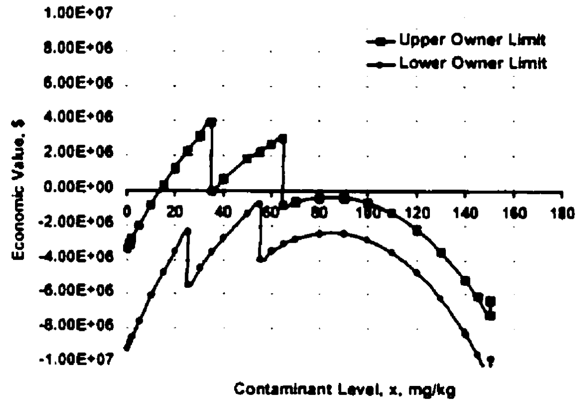

FIGURE 3.9: Net benefits for the owner under uncertainty.

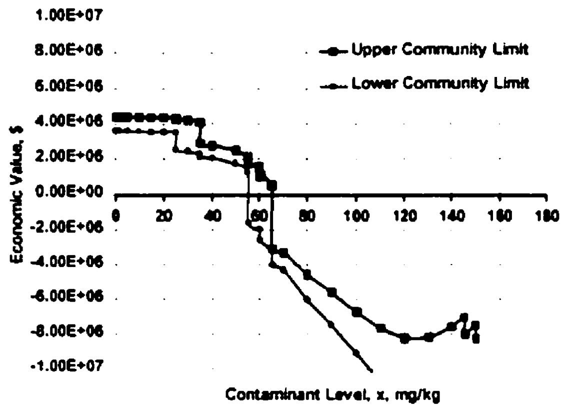

FIGURE 3.10: Net benefits for the community under uncertainty.

In Figure 3.9, the owner realizes the most net benefits if uncertainty works in his or her favor (e.g., the benefits predicted are actually 10% greater, costs are actually 10% lower, etc.). According to the "upper owner limit" curve, the site should be remediated to 35 mg/kg. However, in a "worst case" scenario, the owner's lower net benefits curve remains negative for all values of x_f and the owner may remediate to a level of 55 mg/kg in order to derive the greatest, albeit negative, net benefits; the owner may even consider abandoning the site. Understanding the effects of uncertainty should lead to a better understanding of the decisions that might be expected under specific scenarios. In this case, the decision to remediate to 35 mg/kg, 55 mg/kg, or some other level should depend on factors such as the owner's risk aversion, the likelihood of various scenarios, and the view of other stakeholders.

However, the owner is also unlikely to consider remediating a site to *very low* concentrations because of the high costs involved. Even for the upper curve shown in Figure 3.9, the owner's net benefits are negative at contaminant concentrations below 15 mg/kg. At the other extreme, the owner is unlikely to remain at a high contaminant concentration (i.e., > 60 mg/kg) because the of high liability cost incurred.

Like the owner, the community (Figure 3.10) also does not receive significantly more benefits from a site remediated to very low concentrations because the difference in benefits between a "zero contamination" site and a "low contamination" site is assumed insignificant. However, the community, unlike the owner, receives positive net benefits at the low concentrations. This illustrates again the potential for conflicting objectives. Different stakeholders may view different contamination levels - and thus site uses - quite differently. Predicting in advance what and how potential conflicts may arise may allow opposing parties to negotiate alternative remedial actions or site uses.

3.5 CONTINUING DEVELOPMENT

This chapter established the basic framework for the proposed methodology and illustrated the potential effects of site remediation issues on decision making using a simple, hypothetical example. Chapter Four describes how the owner can establish estimates for his or her benefits, costs, and liability for any combination of remedial action and site use. Since only a limited number of combinations are considered, the full curves for benefits, costs, and liability (as shown in this chapter) are not needed. Only a decision methodology specific to the owner will be pursued for the remainder of this research. While a methodology for the community would also be useful, it will not be pursued here. However, the explicit nature of the owner's methodology should help to facilitate discussions between the owner and the community.

Chapter Four: The Decision Methodology for the Owner Under Certainty

Chapter Three presented the basic structure of the decision methodology. Using an economic perspective, it illustrated how the three important issues of conflicting objectives, alternative site uses, and uncertainty could affect the respective net benefits of the owner and the community. Although the concept is simple, the challenge is to develop a methodology that brings together the diverse information required to define the specific objectives of the owner[1]. This chapter develops such a methodology.

We begin by redefining the contaminant concentration to which a receptor is exposed. Next, we examine how to characterize and measure the owner's benefits, costs, and liability in order to derive his or her net benefits. The effects of uncertainty illustrated in Chapter Three will not be considered until Chapter Six.

The flow chart in Figure 4.1 illustrates the basic steps of the decision methodology. We stress that stepping through the methodology is an *iterative process* as new information or outcomes from evaluating individual components may affect how other steps are carried out[2]. Although the steps are shown as distinct from one another, there may be elements or required actions common to two or more steps. The precise grouping of elements under each step is not as important as its objective.

In each step, the methodology expects the owner will consult with experts of various fields, such as property appraisers, vendors, consultants, and lawyers. We assume that they can predict with certainty the factors contributing to: the performance of remedial actions, the cost of such actions, the benefits the owner receives, and the liability the owner faces.

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[1] The owner obviously includes the party that owns the site and may wish to sell or develop it, but it may also include those on the owner's "team", such as the site developer or consultants.

[2] For example, the owner may realize after the initial use of the methodology that investing more resources in site characterization could result in more accurate information about the contamination, and therefore lead to a more cost-effective remedial approach.

Furthermore, such estimates are assumed to be mostly point values describing "normal" values, instead of a range of values (e.g., minimum and maximum values).

Step 1: A site investigation is performed. The type and extent of contamination and site features are characterized. Potential *principal liability conditions* are also identified by considering what circumstances may lead to owner liability which is examined in Step 4.

Step 2: The possible remedial actions (*RA*) are analyzed for their performance, required time for implementation, and costs. We assume that all possible remedies are screened, possibly using some of the *remediation technology evaluations* described in Chapter Two, and that those deemed most appropriate are considered in the decision methodology. The "do nothing" scenario should always be considered – even if it at first seems inappropriate - since it represents the current state of the site and because it is needed as a basis of comparison for the other remedial actions. Furthermore, we focus on finding the *preferred long-term site use and remedial action,* but acknowledge that *interim remedial measures* may be needed.

Step 3: The possible site uses (*SU*) and corresponding benefits of each *SU* are determined. We do not advocate the owner restrict prematurely the options he or she may pursue. Although there may be site uses that appear "unsuitable" initially, when combined with certain remedial actions, such combinations may produce significant net benefits.

Step 4: The owner's liability is characterized. This involves:

- determining the possible on-site exposure, health impacts, and other liability factors;
- assessing the possibility of off-site liability;
- estimating the financial value of liability for specific situations and parties involved; and
- combining the above to evaluate the owner's liability for the short-listed site use and remedial action combinations.

Step 5: The net benefits to the owner are calculated by analyzing the benefits minus the costs and liabilities for each site use and remedial action combination. The preferred combination produces the highest net benefits to the owner.

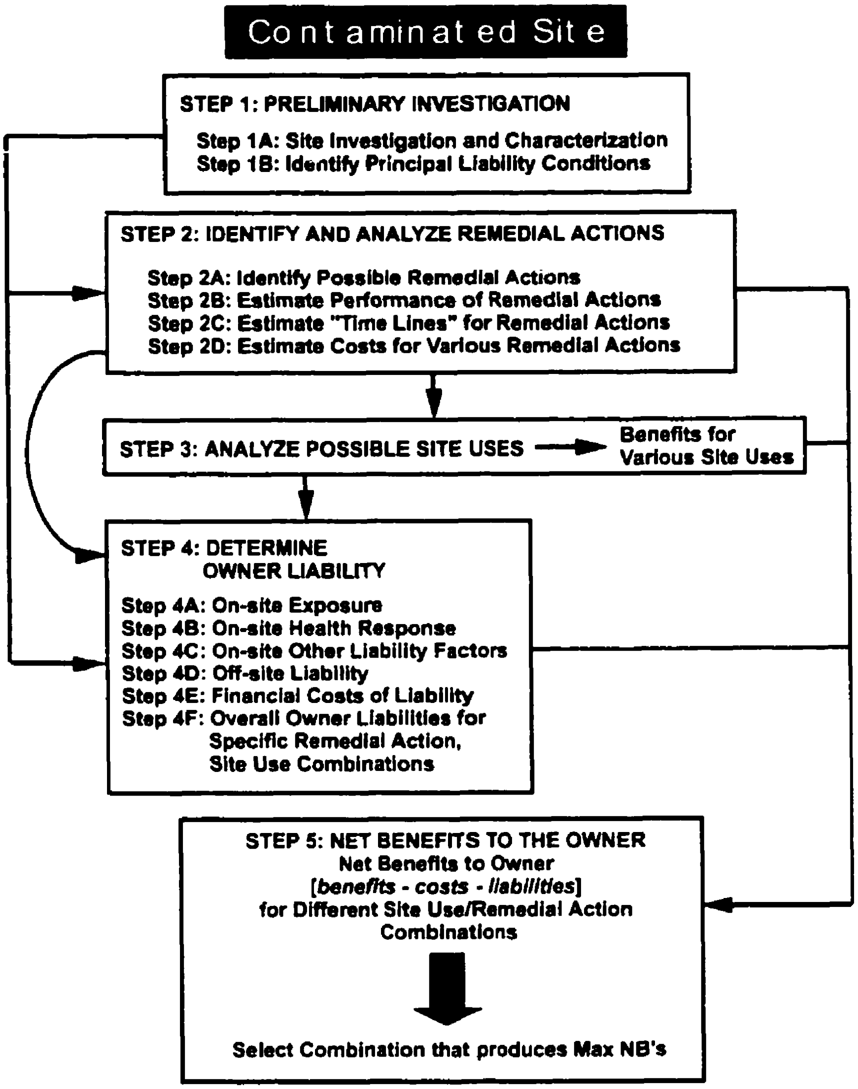

FIGURE 4.1: Flowchart of basic components in the decision methodology.

4.1 DEFINING THE EXPOSURE CONCENTRATION

The owner's objectives were previously shown as a function of the final level of contamination remaining, x_f, after applying remedial actions (e.g., pump and treat) that reduce the amount of contaminant physically present at a contaminated site. However, this earlier approach does not allow for remedial actions such as containment that reduce exposure, but do not necessarily reduce the level of contamination. Therefore, if the j^{th} remedial action, RA_j, is undertaken, the resulting concentration to which a person may be exposed[3] will be called the *available concentration, or* AC_j, while the concentration of the contaminant remaining will be termed the *contaminant concentration, or* CC_j. Determining AC_j from CC_j will involve a pathway analysis to examine the movement of the contaminant from its source through various media to the receptor. These concentrations are illustrated in Figure 4.2.

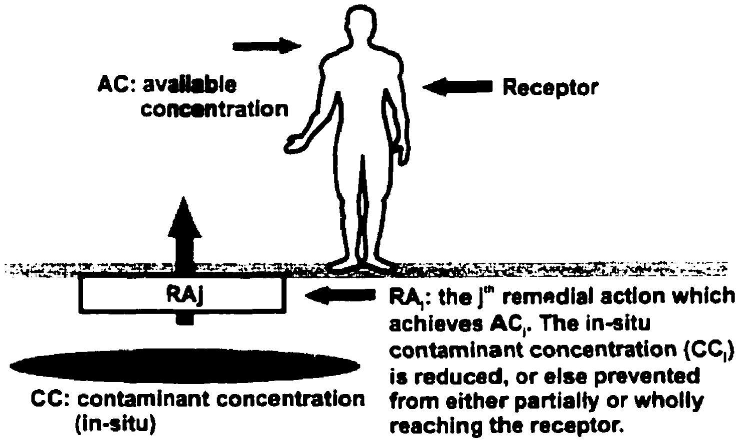

FIGURE 4.2: Distinguishing between the in-situ concentration and the available concentration of a contaminant.

4.2 STEP 1: PRELIMINARY INVESTIGATION

The preliminary investigation is divided into two separate but related steps: 1) a site investigation, and 2) identifying potential liability conditions based on the investigation.

4.2.1 Step 1A: Site Investigation and Characterization

The owner should first perform a site investigation to characterize the type and extent of contamination and identify any significant on-site and off-site features. These include subsurface features, such as highly permeable strata that would promote the migration of the contamination. There are established procedures that the owner can use to conduct the assessment, such as the *Phase I Environmental Site Assessment Process* issued by the ASTM (Marsh et al.,1996). The following list gives examples of the type of information that would be helpful in site characterization.

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[3] Adapted from : Health and the Environment: A Handbook for Health Professionals (Draft). Health Protection Branch, Health Canada, and Public Health Branch, Ontario Ministry of Health. March 1995.

- Site history.
- Audits and other documentation of previous chemical use or storage on site.
- The type and source of contamination, and whether it continues to leak into the environment or if the problem was due to a one-time discharge.
- Preliminary fields testing to either determine or verify the extent of contamination.
- Hydrogeological parameters, such as ground water velocity, soil density, soil permeability, etc. These would also help identify the most likely pathway(s) for the contamination to travel.
- The proximity, nature, and demographics of surrounding land uses. Combining these with the pathway analysis later on would indicate probable locations at which exposure could occur. Furthermore, knowledge about the local community would provide the owner with an indication of the possible site uses and benefits, although we expect that this analysis would have already been performed through a market analysis.

The contaminated site may appear as shown in Figure 4.3 at this *time of discovery or characterization* (t_{DIS}). Concentrations are expressed as $CC(x,y,t)$; that is, in terms of the location along the x-axis, the location along the y-axis, and time.

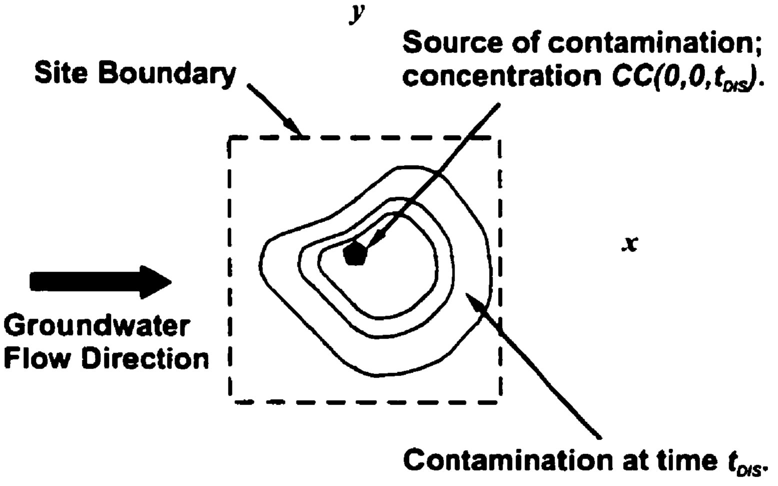

FIGURE 4.3: Possible results of the initial site investigation.

Figure 4.3 depicts the contamination within the site boundaries, and identifies the location of the contamination source and its concentration, $CC(0,0,t_{DIS})$. Other scenarios are also possible. For example, at the time of the investigation, the contamination may have already spread beyond the boundaries and the location of the contamination source may be unknown.

4.2.2 Step 1B: Identify Principal Liability Conditions

Based on the initial information established in Step 1A, the owner should begin identifying potential *principal liability conditions* (PLCs). These are circumstances or scenarios that should be examined because they are likely to lead to owner liability. One of the criteria the owner may use to select PLCs are if the circumstances represent a "reasonable" worst case analysis. For example, we ask in later sections for the owner to select the highest *AC* value that would occur for determining liability if there is a range of *AC* values to choose from. This value, however, would be the highest *AC* level predicted to occur given that all conditions leading up to this estimate are known with certainty under normal - as opposed to extreme - circumstances. PLCs also help direct the efforts of any required analysis if: 1) decision-making and information resources are limited, or conversely 2) there is an overwhelming amount of data available. The following are examples of such conditions.

- Selecting the most hazardous compound for analysis out of a complex mixture of contaminants. This substance could reasonably be expected to produce the most severe health response and hence greatest liability. It may also be unrealistic to analyze every component that could possibly result in health impacts.
- Selecting the preferred pathway of contaminant movement to determine the probable exposure scenarios. This involves examining the source of the contamination, the environmental media, the route of exposure, and the receptor person or population (Health Protection Branch,1995), and predicting the contaminant concentrations to which receptors may be exposed. There may be several possible pathways for the contaminant to reach the receptor. If there are no "insignificant" pathways that can be disregarded, the owner should:
    1. Select the one that would likely result in the greatest potential liability, or
    2. If it is not possible to judge which pathway is the most significant, the owner should examine each pathway and then combine the results. For example, if both inhalation and ingestion are considered the means of contaminant intake, a pathway analysis for both situations would need to be examined. The owner's liability would then be

based on receptors who both inhale and/or ingest the contaminant. This methodology does not explicitly address multiple pathway scenarios: future research could improve this aspect.

- Selecting the highest concentration of a contaminant when looking for possible health effects during the time periods that individuals would be exposed to the contaminant at both on-site and off-site locations. This conservative approach is not unreasonable if the placement and/or movement of receptors over the site is highly variable.
- Selecting the most sensitive receptor (e.g., a child) when determining the possible health effects from a contaminant.
- Selecting conditions or areas where there is likely to be a high density of individuals (e.g., hospital, school).

Although it appears out of sequence to address an aspect of liability at this point, certain assumptions have to be made prior to further analysis. For example, the contaminant of concern must be chosen for analysis when estimating the performance of remedial actions. As the owner proceeds through the methodology, he or she should be able to refine what constitutes a PLC. For example, the owner may suspect a nearby school is a possible cause of off-site liability. He or she may not be able to declare it as a likely source of liability until the models used to predict the spread of the contaminant indicate if the school is in the probable path of contaminant travel.

4.3 STEP 2: IDENTIFYING AND ANALYZING REMEDIAL ACTIONS

Step 2 can be divided into four major components:

1. Identifying the possible remedial actions.
2. Estimating the performance of the remedial actions considered.
3. Estimating the times important events occur with regards to these remedial actions.
4. Estimating the costs of the remedial actions.

4.3.1 Step 2A: Identify Possible Remedial Actions

In general, there are three main remediation strategies that can be used either separately or in combination for the cleanup of contaminated sites:

1. destruction or alteration of the contaminants;

2. extraction or separation of contaminants from the media; and
3. in-situ containment of the contaminants (Vogel et al.,1994).

The appropriateness of any remedial action may depend on, but is not limited to:

- the physical and chemical properties of the contaminants involved (e.g., density, Henry's law constant, biodegradability, contaminant phase, contaminant mobility, etc.);
- the concentration at the time of discovery;
- the physical extent of the contamination;
- the site's hydrogeological characteristics (e.g., permeability, temperature, moisture content, organic fraction, groundwater velocity, etc.); and
- the PLCs that must be examined.

Much of the literature on remediation techniques suggests that a combination of several remediation techniques can offer distinct advantages over a single technique (Hrudey and Pollard,1993). Choosing which remedial solutions are suitable for the owner's site-specific requirements is itself a technically oriented - multiobjective decision. There are several publications and reports that detail the advantages and limitations of different remedial approaches (e.g., Environmental Protection Office,1991a; Fan and Tafuri,1993). The proposed decision methodology does not provide technical guidance on how to select suitable approaches or how to model the performance of any particular remedial action. The owner will require experts, such as remediation specialists to assess which remedial actions deserve serious consideration.

The owner should use existing analytical and modeling methods to estimate the *extent and degree of contamination over time (AC and CC values)* for each of the possible remedial actions, including the option of "no remedial action", $RA_{\emptyset}$, (i.e., leaving the site "as is"). This output is needed to estimate the costs and liabilities of each remedial action and site use combination. For example, the owner should consider off-site liability if a remedial action would not contain the contamination within the site boundaries. The same remedial technique may also be implemented differently or to different degrees (e.g., two different pump and treat scenarios, each achieving different CC and AC levels); for the j^{th} type of remedial action, RA_j, there may be a k^{th} subalternative, RA_{jk}. Thus, RA_{j1} and RA_{j2} would be two separate remedial actions.

This decision methodology focuses on *long-term or permanent* remedial actions but does not address *interim* remedial actions that may be warranted[4]. For example, if the predictions indicate the contamination is spreading quickly, excessive liability may result if the owner does not immediately pursue a temporary remedy to prevent off-site contamination. This intermediate remedy will likely increase the cost, but this additional cost may be less than that of a significantly more extensive remedial action that would otherwise be required.

The following sections explain what data regarding the performance of the possible remedial actions are needed for the decision methodology.

4.3.2 Step 2B: Estimates of the Extent and Degree of Contamination

Figure 4.4 illustrates the contaminated site shown previously in Figure 4.3 and the resulting plume of contamination at some future point in time, t_F, if no remedial action, RA_O, is pursued. The concentration of the contaminant, *CC*, and the available concentration, *AC*, decrease as the plume disperses in the x and y directions away from the source over time. For illustrative purposes, we show the concentrations of the contaminant along the x-axis. For example, the CC value at distance x_3 from the source is $CC_O(x_3,0,t_F)$. These concentrations would be predicted using models or other methods appropriate to the site[5]. Such modeling is necessary to not only establish a basis for comparing the effectiveness of other remedial actions, but to also identify which possible on-site and off-site areas might be impacted and thus represent a PLC.

As mentioned previously, calculating the *AC* values from the CC values involves analyzing the exposure pathway. However, choosing the appropriate means of analysis depends on

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[4] The methodology acknowledges the possible cost of an interim remedial action when determining costs.

[5] As an example of what basic modeling and estimation techniques are available, we refer the reader to *Physical and Chemical Hydrogeology* by Domenico and Schwartz (1990).

the site circumstances and the PLCs. For example, if a buried contaminant poses the greatest danger if inhaled, the analysis of how well a remedial action performs should consider the flux of the contaminant through the ground surface, the amount of atmospheric mixing, whether or not the receptor is in an open or enclosed space, and other factors. Examples of factors to consider and possible means of analysis can be found in works by Health Protection Branch (1995) and Johnson et al.(1993).

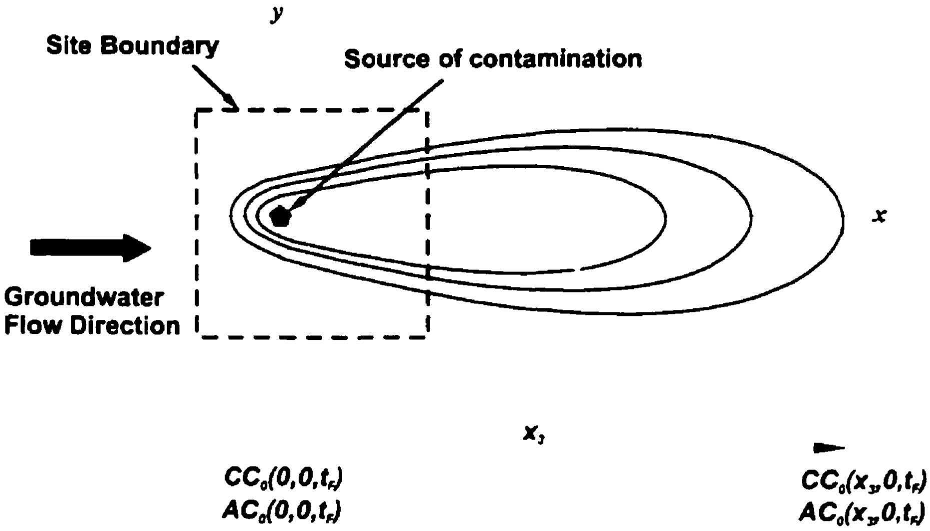

FIGURE 4.4: Future contamination – no remediation ($RA_\emptyset$).

Figure 4.5 shows as an example how the contamination might appear at this same time, t_f, if different remedial actions, designated RA_1 and RA_2, are implemented. To highlight the differences, we assume that RA_1 adopts a containment approach, while RA_2 actually removes the contaminant. This reinforces the need to distinguish between CC, the contaminant concentration in-situ, and AC, the available concentration for exposure. RA_1 contains the contaminant within the site boundary, preventing any off-site migration, and effectively interrupts the exposure pathway. However, because no contamination was actually removed, the site remains essentially contaminated as it did at the time of discovery (i.e., Figure 4.3). Conversely, because the contaminant is actually removed in RA_2, the concentration at the original source of contamination, $CC_2(0,0,t_f)$ is less than $CC_\emptyset(0,0,t_f)$ or $CC_1(0,0,t_f)$ in the respective $RA_\emptyset$ and RA_1 scenarios. In general, we expect a remedial action in which the contaminant is actively removed to produce lower, *on-site* concentrations than either containment or no remedial action. We also expect that actively removing the contaminant would prevent it from migrating as far off-site than if no remedial action was pursued. For example, $CC_2(x_2,0,t_F)$ in Figure 4.5 could represent the same concentration as $CC_\emptyset(x_1,0,t_F)$ in Figure 4.4: it has spread only as far as distance x_2 compared with distance x_1.

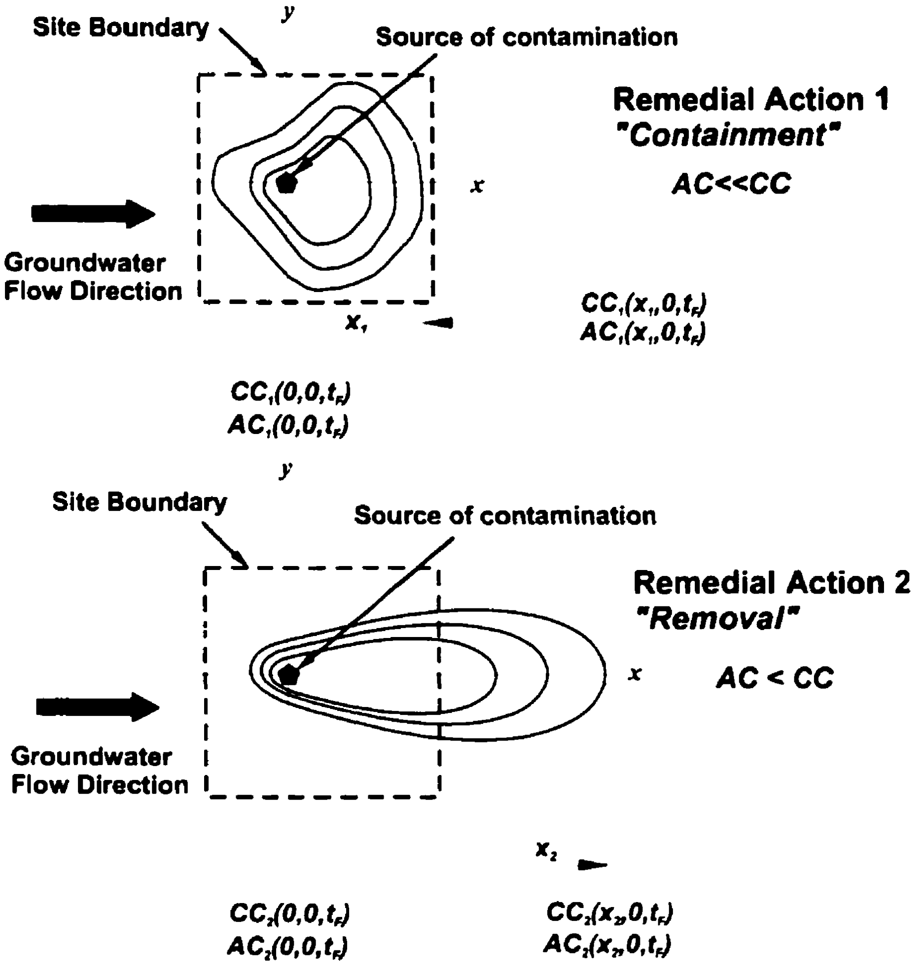

FIGURE 4.5: Future contamination scenarios for two remedial actions, RA_1 and RA_2.

Because regulatory constraints have not been introduced into the methodology, there is no "formal" guidance on which predicted concentrations should be used to judge the extent of contamination for each remedial. Instead of using a pre-selected, regulated concentration value, the consultant should estimate concentrations at the following locations and times for each remedial action: 1) sites represent principal liability conditions; 2) and the estimated time needed to attain maximum effectiveness.

4.3.3 Step 2C: Determine Time Line of Contamination/Remediation

The decision methodology requires that the models or other predictive methods used also predict a *time line of events* for each remedial action considered. These are also important for characterizing the owner's costs and liabilities. Much of the literature focuses typically on the time required for the contaminant to reach a regulated level at a specified compliance point, such as the site boundary, given various remediation scenarios (for example, as shown by Freeze and McWhorter,1997). As mentioned earlier, we do not constrain our analysis with regulations. Instead, we investigate the impacts of attaining various concentrations on the owner's costs. Thus, for our decision methodology we want to know for every remedial action considered the relationship between the contamination levels and when various important events may occur. This is necessary for further refining the PLCs.

Figure 4.6 presents a time-line of *possible* significant events during the course of site remediation. All events need not necessarily occur, nor need they occur in the order illustrated. We also stress that this is a rudimentary treatment of temporal aspects: clearly more research is needed. However, including time adds to the robustness of the decision methodology and contributes to our understanding of the owner's decision process.

FIGURE 4.6: Time-line of possible events.

These time elements are:

t_O	When contamination occurred; may or may not be known.
t_{DIS}	When the contamination is discovered and characterized.
t_{BOUND}	The time for contamination to cross the site boundary, thus creating the possibility for off-site liability. Estimated through modeling, etc. (assuming it has not spread this far already).
t_{RASj} ✔	When the j^{th} remedial action (*RA*) starts.

t_{ONE_j}	✔	When any ongoing activities required for RA_j end.
t_{MONE_j}	✔	When any monitoring required for RA_j ends.
t_{HLON_j}		When long-term health effects in the on-site receptor are predicted to occur for RA_j; there may be a significant delay before they manifest. This latency period may not be easily identifiable however.
t_{HLOFF_j}		When long-term health effects in the off-site receptor are predicted to occur for RA_j; there may be a significant delay before they manifest. This latency period may not be easily identifiable however.

Time elements highlighted with a (✔) will be later used in calculations to determine the owner's costs and liabilities. Analyzing the time-line may also prompt the owner to pursue interim remedial measures. In general, the greater the t_{RAS} value, the more likely the contamination has migrated outward. A more extensive or prolonged remedial action may be required, possibly increasing the owner's cost significantly when compared to the cost of an interim measure.

4.3.4 Step 2D: Estimating the Owner's Costs

The owner's costs will depend on the remedial action. In Chapter Three, the cost depended on the level of contamination remaining, x_f. This however is too simplistic: clearly more information is required (Penmetsa and Grenney,1993). Instead, cost is a function of the remedial action[6] selected. To estimate the cost, we can define certain components that would likely always be present and hence contribute to the total cost to the owner (Ross,

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[6] There are two situations in which cost could be argued to depend on the site use as well as the remedial action.

1. In a regulated environment, there is some level of performance that must be obtained by the remedial action to facilitate a particular site use. For example, contaminant A must be at B concentration before houses can be built. We are not examining the effects of regulations in this chapter in order to examine how the owner's net benefits vary without any constraints.
2. Monitoring may depend on the site use. In general, the more aggressive a remedial action, the less monitoring needed based on the assumption that the contamination is removed more quickly (Markotich, July 7, 1998). However, even if an aggressive cleanup is pursued, future site users or the community may still demand extensive monitoring. Who uses the site depends on the site use. We acknowledge that the owner may have to consider the site use when estimating

required (Ross,1997;Penmetsa and Grenney,1993). The owner would need estimates from the remediation specialists (e.g., consultants, vendors) for the following costs:

1. initial startup remediation cost;
2. actual cleanup cost for the specific remediation technique to be used; and
3. ongoing costs, even after the remediation is finished (e.g., monitoring, equipment maintenance, upgrading of equipment, etc.).

The cost of RA_j can be expressed as,

$$C(RA_j) = C_{SI} + C_{IMj} + C_{SRj} + \frac{C_{MONj}\left[(1+r)^{mj} - 1\right]}{i(1+r)^{mj}} + \frac{C_{ONj}\left[(1+r)^{nj} - 1\right]}{r(1+r)^{nj}} \qquad [4.1]$$

in which,

$C(RA_j)$	is the present value cost of the j^{th} remedial action. The start time for any remedial action, t_{RASj}, is assumed to be the same.
C_{SI}	is the cost of the initial site investigation and characterization to determine the approximate type and extent of contamination. Because this occurs prior to any remedial action, it is fixed and independent of any *RA* chosen. Future characterization efforts that might be needed for specific *RA's* can be captured in the C_{ONj} term.
C_{IMj}	is the cost of any required interim remedial measure for RA_j.
C_{SRj}	is the cost of the actual site remediation efforts for RA_j.
C_{MONj}	is the annual cost of any required monitoring for RA_j.
C_{ONj}	is the annual cost of any ongoing activities required for RA_j.
r	is the annual discount rate.
m_j	is the number of years required for monitoring RA_j (i.e., $t_{MONEj} - t_{RASj}$).
n_j	is the number of years required for ongoing activities for RA_j (i.e., $t_{ONEj} - t_{RASj}$).

For simplicity, we have assumed that the first three activities of investigation, implementing interim measures, and implementing the preferred remedial action occur

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certain situations. (The demands of the community are not examined in detail in this methodology.)

over a relatively short period of time and therefore do not require discounting. This need not be the case depending on the specific site circumstances.

Vendors and consultants may specify additional costs or group certain cost elements depending on the specific circumstances. Cost data may be also reported in the site remediation literature for more established technologies (Lauer et al.,1991).

4.4 STEP 3: ESTIMATING THE OWNER'S SITE USE BENEFITS

In Chapter Three, we assumed three broad site use classifications for illustration: residential, commercial, and "as is" (i.e., unremediated). We will continue to use these classifications for the remainder of the methodology to maintain clarity because of the differences between such site uses. In reality, there are variations within each site use (e.g., different types of housing and even mixed site uses) and different means of constructing any particular site use, some of which may be more appropriate than others for the site-specific circumstances or remedial actions chosen. Regulations would most likely restrict which site uses are permissible under any specific conditions. For the moment, we ignore any limitations regulations may impose, but show in Chapter Five how regulations could limit the choice of combinations.

The owner's net benefits function was originally given in Chapter Three as

$$\text{maximize } NB = f_{bo}(x_f) - f_{bo}(x_o) - [f_{co}(x_f) + f_{Lo}(x_f, x_r)] \qquad [3.1]$$

The first term, $f_{bo}(x_f)$, represents the economic benefits the owner receives from the site after it is remediated, while the second term, $f_{bo}(x_o)$, represents the benefits - if any - that the owner is currently receiving. In the proposed decision methodology, the site's property value for a particular remedial action (*RA*) and subsequent site use (*SU*) combination will be used in determining the owner's benefits.

The following sections discuss how appraisers may approach contaminated site evaluation and how this approach can be used in the proposed methodology. Chapter Six examines some of the uncertainties behind property value estimation.

4.4.1 Appraising Properties

In general, the value of a property depends on its expected yields of either profit or pleasure (Knetsch,1983). The owner relies on the expert opinion of a real estate appraiser to determine the value of the site after remediation. In real estate appraisal, the value of a parcel of land is estimated using the *highest and best use* principle, which is defined as (Lennhoff and Eigle III,1995):

> The reasonably probable and legal use of vacant land or an improved property, which is physically possible, appropriately supported, financially feasible, and that results in the highest value. The four criteria the highest and best use must meet are legal permissibility, physical possibility, financial feasibility, and maximum profitability.

The value of a site is also a function of the local market demand, the available services and utilities, the taxes on the site, the amenities it offers, and other similar factors. However, because the site is contaminated, the value of the site is not as clearly determined. Applying highest and best use principle may be difficult for contaminated sites, depending on the circumstances. Certain remediation costs may be partially dependent on the highest and best use because the level of cleanliness required in a regulatory environment depends on the eventual site use, but an environmental risk may change this use because of the increased cost to achieve it (Wilson,1996). Even though his discussion is framed in a regulatory context, Wilson (1996) recognizes the relationship between site use (*SU*) and remedial action (*RA*)[7].

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[7] Much of the appraisal literature does not explicitly tie site use to the remedial action. For example, Chalmers and Jackson (1996) state:

> Certainly, until the contamination is characterized and the cost of required remediation is determined, an appraiser cannot begin to develop an opinion on the implications of the contamination for the value of the property.
>
> Once a cleanup strategy is approved and the responsibility for implementing the strategy assigned, an appraiser can address the question of value diminution.

There may be several property uses that are "physically possible" depending on the remedial action chosen. Although Chalmers and Jackson (1996) recognize the costs of remediation, they do not consider how these costs might vary given different site use/remedial action combinations. It appears as if they assume there is a unique cost of remediation and unique site use, and that each is largely independent of each other. Even if regulations were considered and permitted a specific site use, In this decision methodology, the appraiser is asked to estimate the site value – and hence the owner's benefits – for different *SU/RA* scenarios, rather than one estimate of what is, in their best opinion, the highest and best site use. Although less common, appraisers are asked in practice to "forecast" such situations (Greenburg, July 7,1998).

4.4.2 Estimating the Owner's Site Use Benefits Under Certainty

In real estate appraisal, the value of a contaminated property is generally given by

$$IV = UV - RC - S \qquad [4.2]$$

in which *IV* is the impaired value of the site due to contamination, *UV* is the unimpaired value of the site (i.e., if there was no contamination), *RC* is the cost of remediation, and *S* is the "stigma" associated with the site circumstances (Wilson,1996) due to its contamination. According to Roddewig (1997), stigma can be defined as the adverse public perception about a property because of the environmental risks associated with it. It results from the uncertainties (e.g., uncertain cleanup costs, uncertain regulatory protection) and risks (e.g., risk of litigation) associated with the site, and can reduce the owner's benefits because of the reduction in the site value if the owner plans to sell it. Stigma is often intangible or not directly quantifiable, possibly rendering appraisal difficult. Nevertheless, real estate appraisers can still attempt to evaluate stigma through indirect means. For example, these include (Mundy,1992a):

- *Rent:* properties that suffer from stigma may rent for less than those that do not.
- *Occupancy:* stigmatized properties may have reduced occupancy.
- *Expenses:* more costs may be required to advertise and promote the site to potential buyers.

The principles of equation [4.2] can be modified as follows for the methodology.

- The cost of remediation, *RC*, is treated separately and has already been discussed in Section 4.3.

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liability could still arise (as discussed in Chapter Three). This could result in a situation in which a particular site use is legally permissible, but financially unfavorable.

- In the real estate literature, stigma appears to be a "catch all" and includes uncertainties, risks, health concerns, and "... the simple fear of the unknown". (Patchin,1991). In this methodology, stigma specifically does not include liability due to health impacts nor uncertainties: both are addressed separately. Instead, stigma represents the appraiser's estimate of how much the site's value to the owner is negatively affected because of the buyer's concerns and perceptions about contamination and remediation. Patchin (1991) notes that previously contaminated properties may not sell even if they are cleaned "as much as technically possible" and carry an indemnity to protect future owners from additional remediation costs.

If there were no contamination, the site would have an unaffected site value, *UV*, which is a function of the site use, *SU*. Any contamination remaining after remediation can be expected to affect the value of the site because potential site buyers would be concerned with possible health or financial risks; the value may increase as the contamination is removed or remediated (Mundy,1992b). Thus, even if *AC* is essentially zero because of a remedial action such as containment, the *knowledge* that contamination still exists on-site (i.e., CC) may be sufficient to affect the site value. Consequently, both *CC* and *AC* contribute to the stigma, *S*, associated with the site. Under certainty, we assume that the greater these two concentrations, the greater the stigma. Site use should also be considered. For example, prospective homeowners may be more concerned with any remaining contamination because the site is to be their home. Commercial owners may not have the same degree of concern. The property value, *PV*, is thus the difference between *UV* and *S*[8].

Realistically, the appraiser may not be able to effectively use the numerical values of *CC* and *AC* when estimating stigma. The literature does not give, for example, numerical correlations between the concentration values for various contaminants and the financial value of stigma. However, through experience and comparison with other similarly affected

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[8] If the owner does not sell the site, there may still be ongoing costs (e.g., taxes) associated with the site. This can be included in: 1) the property value, PV; or 2) the cost of development, C_D, which is discussed later.

and unaffected areas, we expect that an appraiser would be able to assign "high", "moderate", and "low" estimates to the contaminant in order to estimate the stigma for each *RA/SU* combination. Thus, for the i^{th} site use and the j^{th} remedial action, the property value is,

$$PV(SU_i, RA_j) = UV(SU_i) - S(CC_j, AC_j, SU_i) \qquad [4.3]$$

As the previous section on remedial actions already indicated, *AC* values could vary over the site – what *AC* value should therefore be used to determine property values? Two possible approaches can be used:

1. Depending on the variation of contamination and the physical extent of the site use after development, the maximum *AC* resulting from the remedial action, AC_{maxj} can be used. This approach assumes AC_{maxj} occurs uniformly throughout the site.
2. If the site use is restricted to only portions of the site area, specific property values can be estimated from ACs for those localized areas.

From a practical perspective, for any specific site use, the real estate appraiser needs to have some idea of the site value as if there was no contamination. He or she then estimates the affected site value for each use considered in combination with the amount of *CC* and/or *AC* remaining. The literature for appraising contaminated sites is extensive and there are several methods to choose from (Wilson,1996; Chalmers and Jackson,1996). This decision methodology is not intended to be a critique of the many appraisal procedures available. Instead, the input of an experienced real estate appraiser is clearly part of the appraisal process (Knetsch,1983). However, there appears to be general agreement in the literature that in most cases, the site must be first appraised as if there was no contamination and then "adjusted" to reflect the contamination present. Although stigma can arise in part from uncertainties, we assume momentarily that stigma itself can be estimated with certainty.

Lastly, we must include the *cost of development*, C_D, that would be paid by the owner for each proposed *SU* (e.g., the cost of constructing houses). C_D does not include the cost of remediation that was discussed previously in Section 4.3. Subtracting these costs from the property value would result in the *net (or actual)* site use benefits, *SB*, to the owner. The issues surrounding these costs of development are beyond this decision methodology and will not be explored in detail. Thus, for RA_j and SU_i, the owner's site use benefits are,

$$SB(SU_i,RA_j) = PV(SU_i,RA_j) - C_D(SU_i) \tag{4.4}$$

4.5 STEP 4: ESTIMATING THE OWNER'S LIABILITY

The owner may ignore or engage in remediation activities that may ultimately harm another party, giving it reasons to seek compensation from the owner. In the proposed decision methodology, the consideration of liability is divided into several key components:

1. The contaminant available concentration (*AC*) to which receptors are actually exposed;
2. The "ability" of the contaminant to produce an adverse health response;
3. "Other" aspects that contribute to the owner being found liable in a court of law; and
4. The financial cost of liability.

We acknowledge the probabilistic nature of liability, but assume the above factors that constitute liability are known with certainty. The owner's liability is thus estimated using expected values, which appears in keeping with the actions of a risk neutral decision maker (de Neufville,1990). However, elements of the decision methodology dealing with liability are conservative in nature (e.g., the use of principal liability conditions); the methodology's treatment of liability is thus comparable with a risk averse decision maker. The methodology also only addresses the owner's liability as related to health impacts in the decision methodology. It could be expanded in future research to include other forms of liability, such as financial liability if the contaminant renders an off-site location unusable (e.g., inability to operate a business due to contamination).

The first two components are similar to those of a typical risk assessment model (Covello and Merkhofer,1993) shown in Figure 4.7. *Step 4A: On-site Exposure to the Available Concentration, AC* is analogous to the exposure assessment step of the Covello-Merkhofer model, which consists of quantifying the circumstances of human and environmental exposure to risk agents released by the risk source. This typically involves a pathway analysis describing the exposure intensity, frequency, and duration through various media; exposure routes (e.g., inhalation, ingestion); and characteristics of the receptors (e.g., number of receptors, ages, etc.) Step 4B: On-site Adverse Health Response is similar to the consequence assessment of the Covello-Merkhofer model, which consists of quantifying the relationship between the above exposure and the health and environmental effects that may arise. This typically involves specifying either adverse human or environmental responses given the exposure scenarios. There is no parallel component in the methodology to the release assessment step of their model since the contaminants have already been released[9]. We also have a different objective with regards to the last step of risk estimation: the first three components of liability (i.e., exposure, health response, and "other") are evaluated to determine how they specifically affect the owner's liability (as opposed to estimating risk in general). The following sections elaborate on evaluating liability.

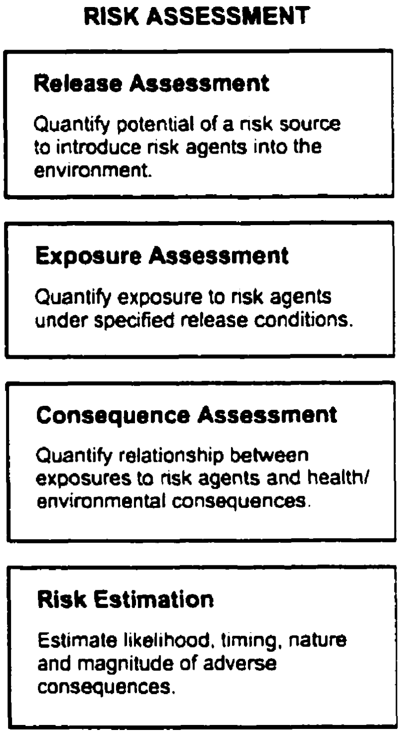

FIGURE 4.7: Covello-Merkhofer model of risk assessment.
(from Covello and Merkhofer, 1993)

4.5.1 Step 4A: On-Site Exposure to the Available Concentration, AC

In Section 4.3, the owner was asked to estimate the performances of various remedial actions, which includes estimates of the spatial distribution of the available concentration of

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[9] However, certain remedial actions, such as excavation, could release additional contamination.

a contaminant[10]. There are two separate scenarios for evaluating the spatial variation of the contaminant: this leads to the probability that a receptor would be exposed to an estimated *AC*, or *P(AC)* on-site[11]. In the first scenario, each RA_j is expected to achieve its predicted available concentration, or AC_j uniformly over the entire site. In the second, each RA_j produces a distribution of *AC* values.

UNIFORM CONCENTRATION DISTRIBUTION

The resulting AC_j after the j^{th} remedial action is assumed to be *uniform over the entire site.* In Figure 4.8, S_O represents the total site area. As an example, S_1 represents the portion of the site space remediated by RA_1 to produce the available concentration, or AC_1, as determined in Step 3A.

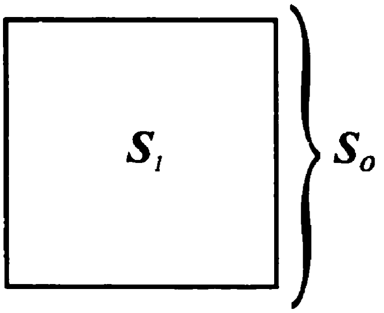

FIGURE 4.8: Site space, S_1, at uniform, highest AC_1 resulting from RA_1.

In this scenario, the entire site is at AC_1. Receptors are assumed to be not exposed to any other concentration regardless of where they are within the site. Another remedial action, RA_2, would achieve AC_2 over S_0. Figure 4.9 shows the proportion of a site area at any given level of *AC* for both RA_1 and RA_2. These ratios are equal to unity for AC_1 and AC_2, respectively, and zero for all other levels of *AC*.

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[10] Risk assessment, however, also includes the duration of exposure, or the length of time a receptor is exposed to a contaminant, as well as characteristics specific to the potential receptors. We discuss these aspects at the end of this section.

[11] Although the following discussion focuses on the contaminated site, the general approach outlined can also be applied to off-site locations.

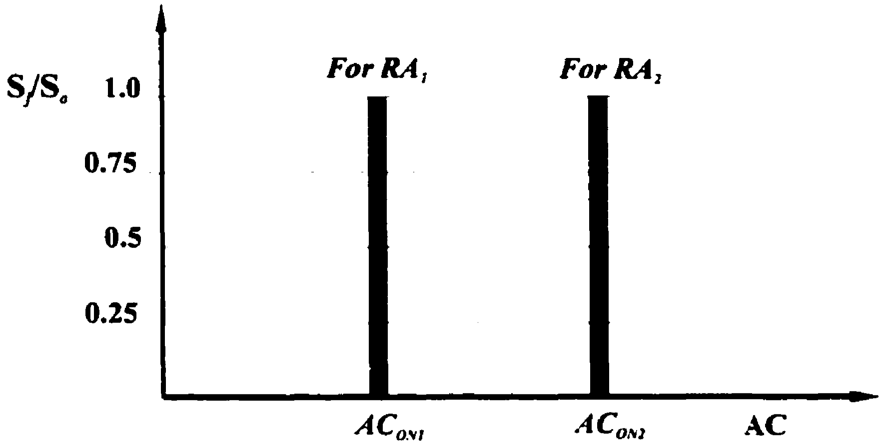

FIGURE 4.9: Site space fraction versus AC – uniform scenario for RA_1 and RA_2.

Although this scenario ignores spatial variations in *AC* and uncertainties, it may be the most practical. Not all owners will have sufficient resources to perform immediate, detailed site investigations or pilot studies prior to making significant decisions regarding the site cleanup. Furthermore, certain contaminated sites, such as former service station operations, are relatively small; assuming spatial uniformity is quite reasonable at this initial stage of decision making.

Under this assumption of uniform concentration, we need to determine which *AC* value should be used. The output from Step 2A would have shown a variation of *ACs* over the site. To determine which level of *AC* to use, we follow the conservative approach outlined in the PLCs and select the highest *AC* level, or AC_{maxj} to which receptors would be exposed to while using the site given RA_j and SU_i. This is appropriate given that the placement and movement of receptors is not known presently. A significant complicating factor in exposure assessment is the unknown effect an individual's habits (e.g., movement patterns) have on his or her exposure (Covello and Merkhofer,1993). Thus, we have the following relationship for any RA_j when assuming a uniform concentration distribution ,

$$AC_{ONj} = AC_{\max ONj} \qquad [4.5]$$

NONUNIFORM CONCENTRATION DISTRIBUTION

In reality, the contamination concentrations will be affected by the heterogeneity of the subsurface characteristics, the diffusion and transport of the contaminant, and other related factors. Thus, when receptors are present, *AC* may vary over the site space as shown in Figure 4.10 depending on the remedial action. For any given RA_j, S_{j1}, S_{j2} and S_{j3} are portions of the original site space, S_O, cleaned to respective concentrations of AC_{j1}, AC_{j2}, and AC_{j3}.

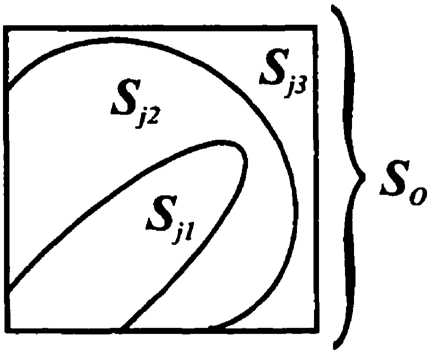

FIGURE 4.10: Site space with nonuniform, discrete ACs resulting from RA_j

The situation shown above results in Figure 4.11, describing the site space fractions at their respective *ACs*.

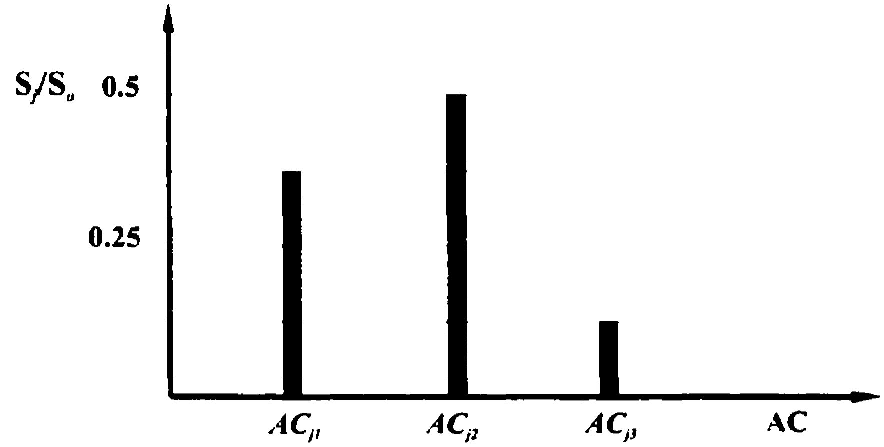

FIGURE 4.11: Site space fractions versus nonuniform, discrete ACs resulting from RA_j

Since the levels of *AC* will usually vary continuously over the site instead of existing at discrete, specific values, the site space fractions will also vary continuously. This can be approximated by plotting a histogram that displays the percentage of the total site space at different *AC* values. This is illustrated in Figure 4.12 using RA_2 as an example: the estimated lowest and highest *AC* levels attained by RA_2 are AC_{min2} and AC_{max2} respectively. This histogram can later serve as a basis for defining a distribution that describes the probability a receptor will be exposed to any range of ACs.

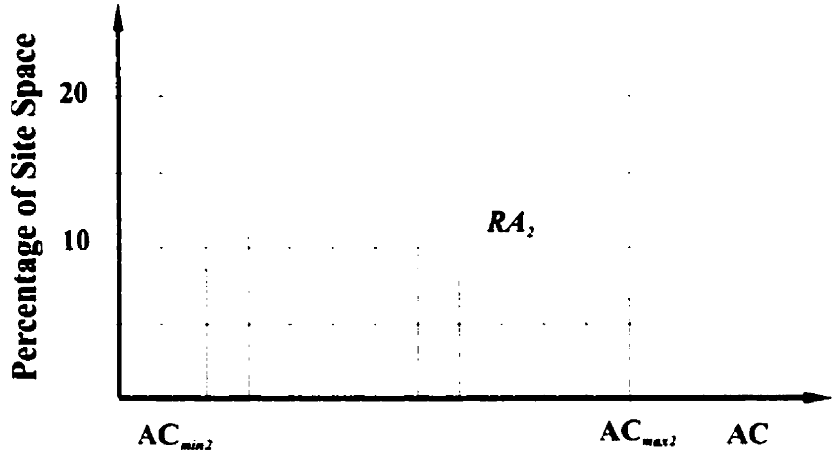

FIGURE 4.12: Histogram of concentrations based on site-space fractions for nonuniform, continuous AC for RA_2.

PROBABILITY OF ON-SITE EXPOSURE FOR UNIFORM AND NONUNIFORM CONCENTRATION DISTRIBUTIONS

Assuming that an individual (potential receptor) is uniformly and randomly located anywhere on the site, then the site space fraction, S_i/S_0 function specifies the probability of exposure to different levels of *AC* for RA_i. This is given as a probability mass function, $P_{ONi}(AC_i)$, for the uniform concentration scenario, and as a probability density function, $f_{ONi}(AC_i)$, for the nonuniform concentration scenario. The latter would be based on the frequency histogram as shown in Figure 4.12. These are illustrated in Figures 4.13 and 4.14 respectively.

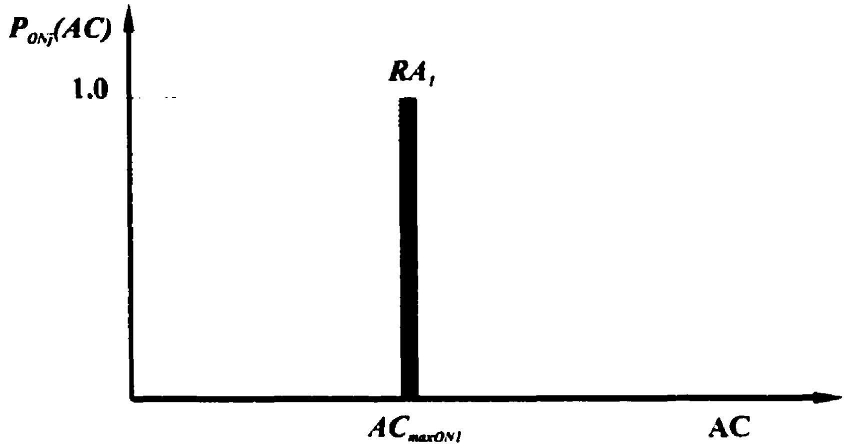

FIGURE 4.13: Probability mass function of exposure of site space to uniform AC_j (remedial action one, RA_1, shown as an example).

For the uniform concentration distribution under assumptions of certainty, the probability of *on-site* exposure given RA_j is,

$$P_{ONj}(AC) = 1, AC = AC_{\max ONj} \qquad [4.6]$$
$$= 0, AC \neq AC_{\max ONj}$$

in which AC_{maxONj} is the highest, on-site available concentration.

In the nonuniform concentration distribution under assumptions of certainty, the probability of *on-site* exposure to concentrations ranging from any AC' to any AC'' for RA_j is,

$$P(AC' < AC_{ONj} < AC'') = \int_{AC'}^{AC''} f_{ONj}(AC) dAC \qquad [4.7]$$

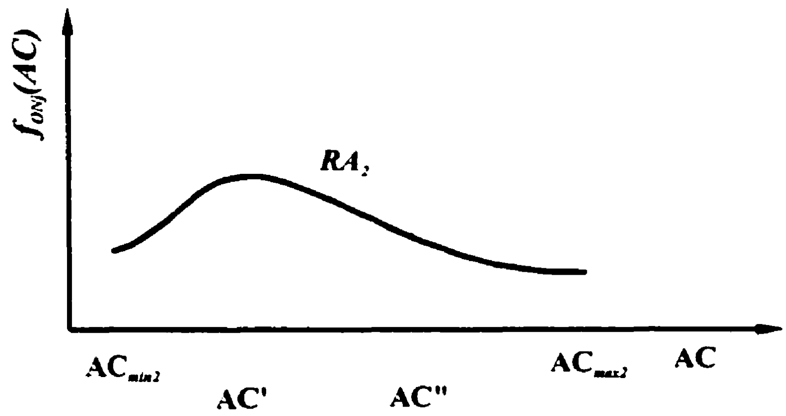

FIGURE 4.14: Probability density function of exposure of site space to nonuniform, continuous AC_j (remedial action two, RA_2, shown as an example).

EXPOSURE ROUTE MODELS

For simplicity, we will use AC for the remainder of the proposed decision methodology and assume that *if* any receptors develop health impacts after a long periods of exposure, they have been exposed to the contaminant for sufficiently lengthy periods of time. However, there is a considerable amount of literature available on the use of *exposure-route models*, which translate the results of pollutant transport and fate models into the doses actually received by the receptors (Covello and Merkhofer,1993; Health Protection Branch,1995). They generally consider the body weight of the receptors, the frequency and duration (i.e., time) of exposure, and other related factors. We will not investigate exposure route models further in this methodology, but acknowledge that it could be expanded to include such additional factors.

4.5.2 Step 4B: On-Site Adverse Health Response

The proposed decision methodology requires the owner to obtain information regarding the health impacts posed by the contaminant. This information may be expressed in several forms, such as tables of health effects or as a dose-response curve. The owner will need the assistance of health experts to determine which and what form of health data is the most pertinent given the receptors at the site.

As an example, health data may be shown in the form of a *dose–response curve*, which is, "... a means of characterizing the relationship between the dose of an agent administered, or received, and the incidence of an adverse effect in exposed populations" (Environmental Protection Office,1991b). Figure 4.15 shows such a typical, cumulative dose-response curve, $F_R(AC)$: the higher the AC level, the greater the likelihood the receptor exhibits an adverse response. Different remedial actions achieve different AC values (or "doses"), which in turn result in different probabilities of an adverse response in a single, on-site receptor, or $P(_{RON_{ij}})$.

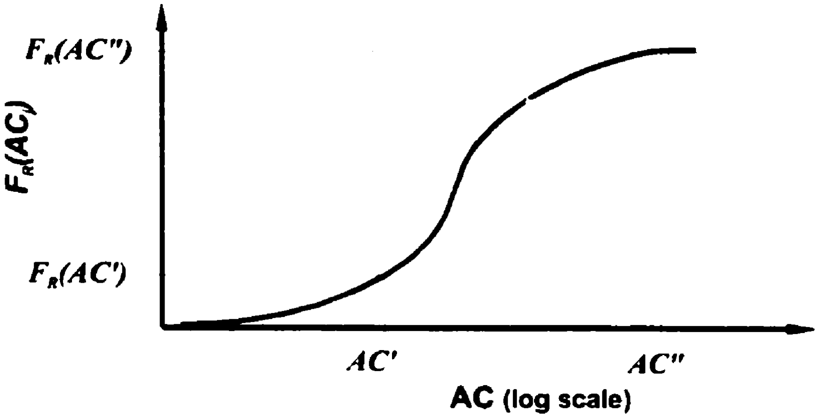

FIGURE 4.15: Dose-response curve

The probability of an adverse health response occurring for an individual, on-site receptor is,

$$P(R_{ONj}) = \int F_R(AC)P_{ONj}(AC)dAC \qquad [4.8a]$$

$$= F_R\left(AC_{\max ONj}\right) \text{for uniform distribution}$$

$$P(R_{ONj}) = \int_{AC'}^{AC''} F_R(AC)f_{ONj}(AC)dAC \quad \text{for nonuniform distribution} \qquad [4.8b]$$

There are additional measures for incorporating the uncertainty of the data sources, the capability of the modeling techniques used, the use of expert opinion, accounting for the differences between carcinogenic and non-carcinogenic substances, etc. Furthermore, the methodology can be expanded to incorporate different health response information and interpretations for different receptors (e.g., different dose-response curves may be used for children and adults).

TIME AND HEALTH RESPONSE

The owner must also consider time. For example, following the PLCs, the owner selects the highest on-site, available concentration that a receptor may be exposed to during the times he or she is present at the site, assuming a uniform concentration distribution. However, this concentration may produce one or both of the following[12].

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[12] The owner should also not discount other possible types of health effects that may be unique to the contaminant or situation at hand.

- Immediate health impacts after a short period of exposure, usually to relatively moderate or high concentrations; or
- Health effects that only materialize after a lengthy period of chronic exposure, usually to relatively low concentrations. For example, health risk data regarding cancer is often based on a person's intake of a substance over a lifetime (Freeze and McWhorton,1997; Environmental Protection Office,1991b). The timeline established in Figure 4.6 may assist in determining the receptor's exposure period and subsequent health effects. This time delay will be considered later when determining the financial cost of liability.

For this methodology, the former will be termed *short-term* adverse health responses, while the latter *long-term* adverse health responses.

Using equation 4.8 as a basis and the health information available to the owner, he or she needs to determine:

1. $P(R_{SON_I})$, or the probability of a short-term, adverse health response occurring in an individual, on-site receptor given RA_I and a brief, acute exposure period when exposed to AC_{maxON_I} in the uniform case, or the range of concentrations AC' to AC'' in the nonuniform case.
2. $P(R_{LON_I})$, or the probability of a long-term, adverse health response occurring in an individual, on-site receptor given RA_I and extended exposure of the individual during the use of the site to AC_{maxON_I} in the uniform case, or the range of concentrations AC' to AC'' in the nonuniform case. The owner may also need to estimate t_{HLON_I}, or the time when long-term health effects might appear in an on-site receptor.

4.5.3 Step 4C: Other Remaining Factors Contributing to Owner Liability

Assuming that adverse health impacts would occur, the owner must still be *found* liable in a court of law. The probability of "other" factors, $P(O_{ON_{IJ}})$, contributing to the owner's on-site liability given RA_I and SU_I depends on the efficiency and effectiveness of any relevant regulations and compliance measures, the legal precedents for owner liability, the ability of an owner to defend his or her actions, and other related factors. The legal system may be affected by the sensationalism surrounding the contaminant and the site, questionable scientific testimony, and misconceptions about the health effects (Gots,1993). Attempts to objectively evaluate the chemical may be lost in journalistic sensationalism and poorly conducted science (Lehr,1990). Opposing parties may want to widen the gap between fact and fiction in order to best present each party's plight (Gots,1993).

Estimating $P(O_{ONij})$ will likely be very subjective since a number of complex and intangible factors must be assessed. The expert opinion of legal professionals is clearly required. While there appears to be no information or precedent in the literature for actually evaluating an "other liability factor", steps can still be taken to understand the contribution of $P(O_{ONij})$ to the owner's liability. For example, the owner might consult legal counsel regarding:

- The similarity between the owner's situation and the outcomes of past similar remediation cases.
- Whether or not there is a controversy surrounding the contaminant in question.
- How $P(O_{ONij})$ may vary depending on the *due diligence* shown by the owner (Ibbotson and Phyper,1996) in addressing environmental concerns through management, preventative measures, etc.
- The objectives of current and/or newly proposed regulations.
- How differences in the owner's actions in the short-term and in the long-term affect their respective health impacts on potential receptors.

There may also be other aspects to consider depending on the site specifics. Based on these considerations, a legal professional, or perhaps risk assessment expert, may be able to provide subjective estimates of the following probabilities. These have also been divided into short-term and long-term related components because the circumstances surrounding both may be unique.

1. $P(O_{SONij})$, or the probability of "other" factors related to short-term exposures on-site; and
2. $P(O_{LONij})$, or the probability of "other" factors related to long-term exposures on-site.

4.5.4 Step 4D: Determining Off-Site Liabilities

There may also be *off-site* costs and liabilities (i.e., off-site clean up measures and health effects due to off-site contamination) should the contamination migrate beyond the site boundaries and impact adjacent properties. In general, off-site liabilities can be treated in the similar manner as on-site liabilities.

Combining the predicted performance of various remedial actions with the PLCs can identify certain adjacent properties and situations that may contribute significantly to owner liability. For example:

- A nearby grade school would be a critical case to examine if the students would be exposed to contamination.
- The initial site investigation may warrant the owner take interim remediation steps to either prevent or else mitigate off-site contamination should it be spreading rapidly. Conversely, if the contamination migrates very slowly, the owner has more latitude to decide how and when to remediate.

OFF-SITE EXPOSURE TO THE AVAILABLE CONCENTRATION

The owner should also estimate which off-site locations may be affected by the contamination for each remedial action considered in order to estimate the probability that off-site receptors would be exposed to the contamination. Initially, we propose the owner use the *uniform concentration distribution* scenario described previously in Step 4B. Again, we can use the highest available concentration of the contaminant present at any off-site properties identified by the liability conditions, especially if it is small and has relatively homogenous features. Even if the off-site property is large and has complex site features, assuming uniformity may be still advantageous at the beginning stages of the decision making. More complex approaches (e.g., *nonuniform concentration distribution* scenario) may be warranted later on as the decision methodology iterates and more information becomes available.

Following the same reasoning used to derive equation 4.6, the probability that a receptor would be exposed to the highest available, off-site concentration (AC_{maxOFF}) at the p^{th} off-site location given RA_j is,

$$\begin{aligned} P_{OFFjp}(AC) &= 1, AC = AC_{\max OFFjp} \\ &= 0, AC \neq AC_{\max OFFjp} \end{aligned} \qquad [4.9]$$

OFF-SITE ADVERSE HEALTH RESPONSE

We expect the owner to use the same health data (i.e., tables of health response, dose-response curves, etc.) that were used in determining the probability of an on-site health response to estimate the probability of an off-site response. As an example, if we again use a dose-response curve approach and continue with using the uniform concentration distribution scenario, the probability of an adverse health response occurring for an off-site individual at the p^{th} location under certainty is,

$$P(R_{OFFjp}) = F_R\left(AC_{\max OFFjp}\right) \text{for uniform distribution} \qquad [4.10]$$

As in the on-site situation, the owner must also consider time. Using equation 4.10 as the basis and the health information available to the owner, he or she needs to determine:

- $P(R_{SOFFjp})$, or the probability of a short-term, adverse health response occurring in an individual, off-site receptor given RA_j, the p^{th} location and a brief, acute exposure period when exposed to $AC_{maxOFFj}$ in the uniform case.
- $P(R_{LOFFjp})$, or the probability of a long-term, adverse health response occurring in an individual, off-site receptor given RA_j, the p^{th} location and extended exposure over the individual's lifetime to $AC_{maxOFFjp}$ in the uniform case. The owner may also need an estimate for $t_{HLOFFjp}$, or the time when long-term health effects might appear in a receptor at the p^{th} off-site location.

OFF-SITE OTHER REMAINING FACTORS CONTRIBUTING TO LIABILITY

The owner would also need a separate $P(O_{OFFjp})$ estimate for each off-site location to reflect the "other" factors that may contribute to owner liability given RA_j regarding adjacent properties. For example, if the owner is negligent in notifying a nearby daycare facility of the hazards involved in certain remediation activities (e.g., removal of lead-painted structures) the probability of being found liable is likely to increase. Unlike the on-site "other" factor however, $P(O_{OFFjp})$ does not depend on the SU_i. As in the on-site situation, $P(O_{OFFjp})$ may be divided into short-term and long-term components. The owner thus needs estimates of $P(O_{SOFFjp})$ and $P(O_{LOFFjp})$.

4.5.5 Summary of Probability Related Liability Components

Based on sections 4.5.1 to 4.5.4, the owner needs estimates for the following probabilities related to liability as shown in Table 4.1. It also shows the required owner liability calculation in each on-site/off-site and short-term/long-term scenario (equations 4.11a through 4.12b).

TABLE 4.1: Summary of probability-related liability components.
("Est." = estimated probability)

PROBABILITY, SHORT-TERM	**ON-SITE**	**Eqn.**	**OFF-SITE**	**Eqn.**
Health Response	$P(R_{SONi})$	4.8	$P(R_{SOFFjp})$	4.10
"Other" Factors	$P(O_{SONij})$	Est.	$P(O_{SOFFjp})$	Est.
Owner Liability	$P(L_{SONij})=P(R_{SONi})\ P(O_{SONij})$	**4.11a**	$P(L_{SOFFjp})= (R_{SOFFjp})\ P(O_{SOFFjp})$	**4.12a**
PROBABILITY, LONG-TERM	**ON-SITE**		**OFF-SITE**	
Health Response	$P(R_{LONi})$	4.8	$P(R_{LOFFjp})$	4.10
"Other" Factors	$P(O_{LONij})$	Est.	$P(O_{LOFFjp})$	Est.
Owner Liability	$P(L_{LONij})=P(R_{LONi})\ P(O_{LONij})$	**4.11b**	$P(L_{LOFFjp})= (R_{LOFFjp})\ P(O_{LOFFjp})$	**4.12b**

4.5.6 Step 4E: The Individual Financial Cost of Liability

There is not a "standard table of liability values" from which to estimate, for example, the cost of liability per injured receptor in dollar terms that the owner might face once actually found liable. However, an estimate of the magnitude of the financial cost of liability can still be derived for any combination of site use and remedial action by considering the following items. Again, the input of legal professionals is likely required.

1. Regulatory fines or penalties that the owner faces if found liable.
2. Whether or not the receptor could be expected to use the site safely.

3. Previous legal judgments involving similarly contaminated sites can provide a guide to the magnitude of liability expected. There are several key issues to note when examining past cases (Ibbotson and Phyper,1996).
    - the nature of the environment affected;
    - the extent of the damage inflicted;
    - the wealth and size of the polluting company and/or owner;
    - the criminality of the conduct;
    - the extent of attempts by the owner and/or polluter to comply with the regulations (e.g., if due diligence was shown through attempts to establish an appropriate environmental management system);
    - the remorse shown by the polluter;
    - the profits realized by the polluter by committing the offense; and
    - the prior criminal record of the polluter.
4. The value of a financial award also depends on the characteristics of the individuals expected at either the on-site or off-site locations. There may be considerable differences on the individual compensation depending on:
    - the age, general health, and well-being of an affected individual;
    - the severity of the health impact on the individuals;
    - the medical treatment, if any, required to treat the health impact;
    - the lifestyles of the individuals affected, and how these may be altered after any health impact; and
    - the life-earnings potential and the loss of productivity, if any, of the individuals after any health impact.

    While it may be possible to characterize all existing off-site receptors, undertaking such a detailed survey would be difficult, time-consuming, and likely resource intensive, particularly during the initial stages of decision making. It is also not known which *specific* person should be considered; there is only the probability that a person would suffer from health effects. Such a survey becomes even more problematic when considering on-site receptors. Because the owner does not specifically know which persons will occupy the site, he or she is essentially restricted to "guessing" which general categories of individuals could be potential receptors based on the future site use.

The owner can group off-site and on-site receptors into categories, (e.g., children or adults) based on the demographics of the community and the types of persons that could be expected for a specific site use. The number of individuals estimated for the a^{th} group will be designated n_a; such groupings assume individuals within a category share similar characteristics. Interpersonal comparisons can be controversial and will not be addressed further in this research. However, for the methodology, dividing all receptors into categories should allow the owner to derive an approximate estimate of the financial cost of liability.

In both the on-site and off-site scenarios, we assume that short-term health effects occur immediately and that any liability is awarded within a relatively short period of time. However, there can be considerable delay after exposure before *long-term* health effects appear. Once they do, it may take some time to establish the legal arguments for the affected individuals and for litigation to actually occur, especially if causality is difficult to prove. Because any potential health impacts may not materialize for some time, we specify a discount rate in order to determine the present value of any future liability. Although this approach is consistent with the owner's financial perspective, the use of a discount rate can be controversial (Hufschmidt et al.,1983; Swartzman,1982), and may be especially so in this methodology because the owner is in essence evaluating the potential future health impacts of individuals in the community. We will not discuss the issues involved, but recognize that the discount rate chosen can have a considerable impact on the magnitude of the owner's liability and that such an approach may not be acceptable to other stakeholders.

Based on the above information, the owner needs to estimate the following quantities.

- CL_{Sa}, or the cost of liability required to compensate each of the n_a individuals belonging to group a for short-term health effects.
- CL_{La}, or the cost of liability required to compensate each of the n_a individuals belonging to group a for long-term health effects.
- t_{LITON}, or when compensation is awarded to on-site individuals; we assume that compensation would be awarded to all affected persons at the same time.

- $t_{LITOFFp}$, or when compensation is awarded to individuals at the p^{th} off-site location; we assume that compensation would be awarded to all affected persons at one site at the same time.

4.5.7 Step 4F: Combining All Liability Components

The costs of on-site owner liability due to both short-term and long-term health effects given RA_j and SU_i are respectively,

$$L_{SON}\left(SU_i, RA_j\right) = P\left(L_{SONij}\right)\sum_{a=1}^{a=bi} CL_{Sa} n_a \qquad [4.13a]$$

$$L_{LON}\left(SU_i, RA_j\right) = P\left(L_{LONij}\right)\sum_{a=1}^{a=bi}\left\{CL_{La} n_a \frac{1}{\left(1+r\right)^{w_{ON}}}\right\} \qquad [4.13b]$$

in which

- $P(L_{SONij})$ and $P(L_{LONij})$ are the probabilities of short-term and long-term owner liability respectively as shown in Table 4.1;
- all CL terms are the costs of liability for compensating one on-site individual belonging to group a, multiplied by the number of individuals in that group, n_a, up to a total of b_i groups for SU_i: costs for short-term health effects are assumed to be immediate and are not discounted while costs for long-term health effects are future costs and are discounted;
- r is the annual discount rate; and
- w_{ON} is the number of years between when liability is actually awarded by a court of law, t_{LITON}, and when RA_j began, t_{RASj}.

The costs of off-site owner liability due to both short-term and long-term health effects given RA_j and a total of q off-site locations are respectively,

$$L_{SOFF}\left(RA_j\right) = \sum_{p=1}^{p=q}\left\{P\left(L_{SOFFjp}\right)\sum_{a=1}^{a=bp} CL_{Sap} n_{ap}\right\} \qquad [4.14a]$$

$$L_{LOFF}\left(RA_j\right) = \sum_{p=1}^{p=q}\left\{P\left(L_{LOFFjp}\right)\sum_{a=1}^{a=bp}\left\{CL_{Lap} n_{ap} \frac{1}{\left(1+r\right)^{w_{OFFp}}}\right\}\right\} \qquad [4.14b]$$

in which

- $P(L_{SOFFj})$ and $P(L_{LOFFj})$ are the probabilities of short-term and long-term owner liability respectively as shown in Table 4.1;
- all CL terms are the costs of liability for compensating one off-site individual belonging to group a, multiplied by the number of individuals in that group, n_a, up to a total of b_p groups at the p^{th} off-site location: costs for short-term health effects are immediate while costs for long-term health effects are future costs (as in equation 4.13, no discounting is performed for short-term health effects);
- r is the annual discount rate; and
- w_{OFFp} is the number of years between when liability is actually awarded by a court of law, $t_{LITOFFp}$, at the p^{th} off-site location (up to a total of q locations), and when RA_j started, t_{RASj}.

The total owner liability is therefore,

$$L(SU_i, RA_j) = L_{SON}(SU_i, RA_j) + L_{LON}(SU_i, RA_j) + L_{SOFF}(RA_j) + L_{LOFF}(RA_j) \qquad [4.15]$$

4.6 STEP 5: NET BENEFITS TO THE OWNER

The net benefits to the owner are calculated by subtracting the cost of the remedial action and the cost of liability from the benefits for each of the possible SU's and RA's combinations. Thus, the net benefit for the i^{th} site use and the j^{th} remedial action is

$$NB(SU_i, RA_j) = SB(SU_i, RA_j) - C(RA_j) - L(SU_i, RA_j) \qquad [4.16]$$

in which $SB(SU_i,RA_j)$ are the site use benefits for the i^{th} site use and the j^{th} remedial action (equation 4.4), $C(RA_j)$ is the cost of the j^{th} remedial action (equation 4.1), and $L(SU_i,RA_j)$ is the cost of liability for that site use and remedial action combination (equation 4.15).

4.7 SUMMARY OF METHODOLOGY

To assist the owner, Figure 4.16 on the following two pages shows all the steps in the methodology that require parameters that must be either estimated or calculated. It also illustrates how one parameter is related to another, enabling the owner to track how changing one variable will affect others. For example, Figure 4.16a shows that Step 4B of the methodology requires health response information, $F_R(AC)$, and the probability of exposure, $P(AC)$ in order to calculate $P(R_{ONj})$, the probability of an adverse health response for on-site receptors. $P(R_{ONj})$ is divided into short-term and long-term probabilities, or $P(R_{SONj})$ and $P(R_{LONj})$ respectively. These are then combined with $P(O_{SONij})$ and $P(O_{LONij})$, the probability of "other" liability factors, to determine the probabilities of on-site owner liability, $P(L_{SONij})$ and $P(L_{LONij})$ (shown under the *Summary of Liability Probability Components* in Figure 4.16b). Further incorporating the financial costs of liability (Step 4E) gives the cost of on-site owner liability, or $L_{SON}(SU_i, RA_j)$ and $L_{LON}(SU_i, RA_j)$, for that particular SU_i/RA_j combination (Step 4F). This graphical representation should later prove useful in Chapter Six when dealing with uncertainties in the parameters.

If the owner is unconstrained, the owner should select the combination that maximizes his or her net benefits (i.e., there is no consideration of regulations or community-related factors such as those mentioned in Chapter Three). Chapter Five applies the decision methodology outlined in this chapter to an illustrative site remediation example.

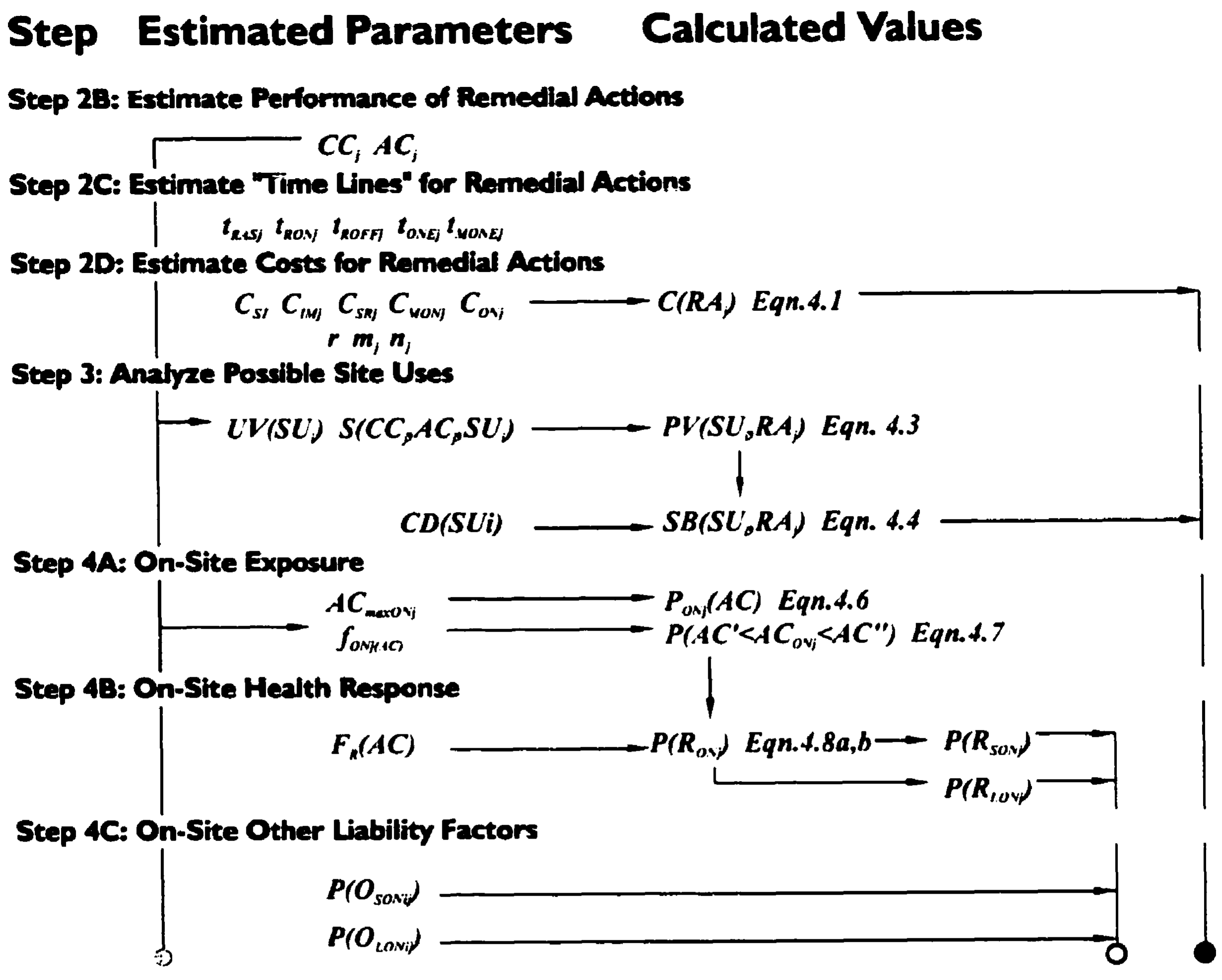

FIGURE 4.16a: Estimated and calculated parameters in the decision methodology.

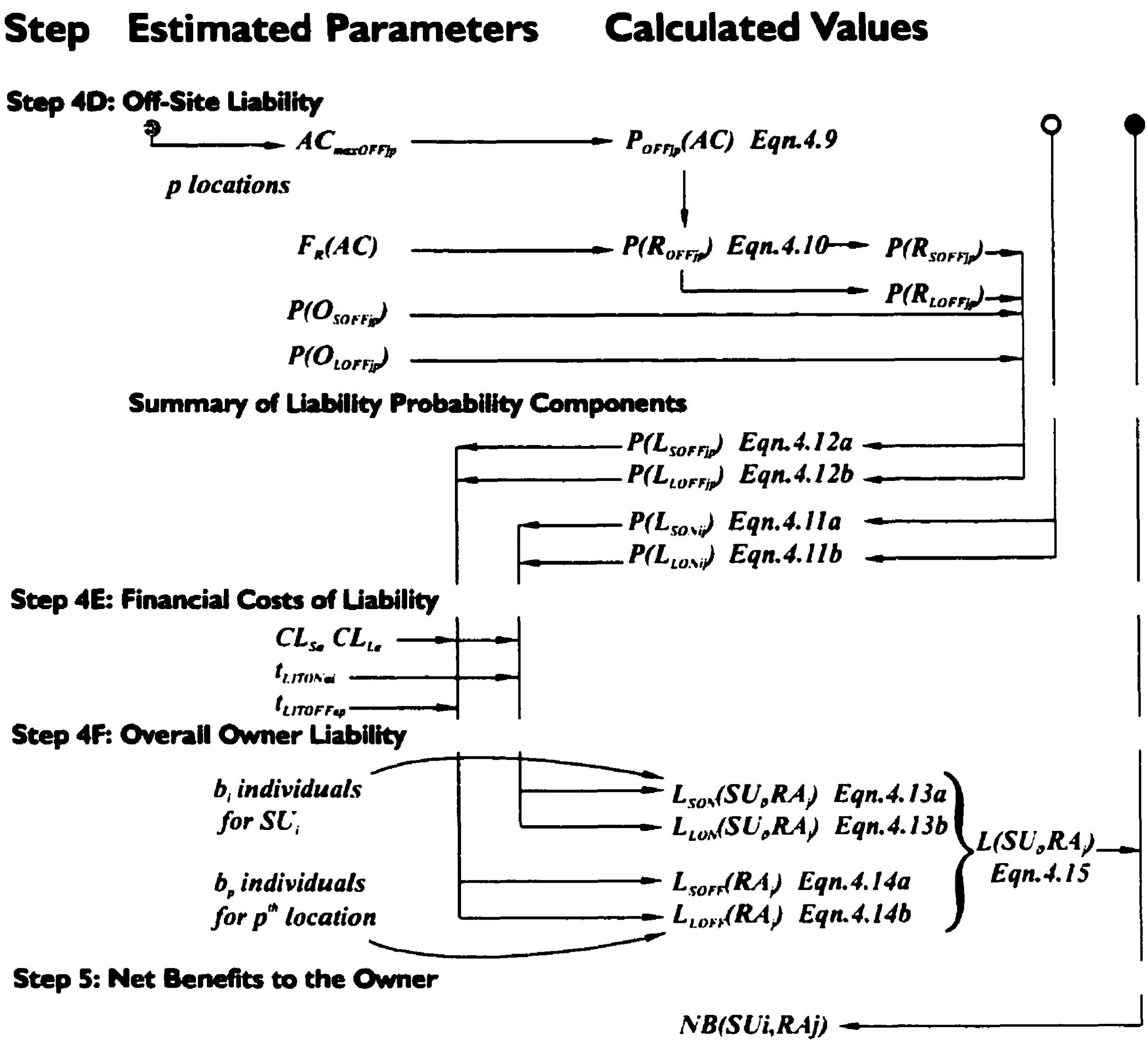

FIGURE 4.16b: Estimated and calculated parameters in the decision methodology.

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Chapter Five: Illustrative Example

The decision methodology developed through Chapters Three and Four will be applied to an illustrative example to demonstrate how it can improve the process for determining the preferred site use and remedial action for a contaminated site under certainty. An actual case study was used to establish realistic conditions for the example; however, the case study data were modified. As a result, all values in this chapter are hypothetical except for those quoted directly from outside sources (e.g., health effect data). In some situations, no actual data were available upon which to base hypothetical values. These were thus:

- Generated using industry or accepted guidelines (e.g., the property values) based on the general site characteristics; or
- Assigned to provide a complete case study. Such values are identified using footnotes or within the text.

The surface features, buildings, and layout of the actual case study have also been altered to provide a more workable case study.

The sections in this chapter correspond to those throughout Chapter Four. However, because some of the steps are iterative, some may span several sections or be combined into one. Detailed calculations can be found in Appendix B. We conclude the chapter by illustrating briefly how regulations may affect the owner's choices.

5.1 STEP 1: PRELIMINARY INVESTIGATION OF THE SITE

The site and its surrounding features are shown in Figure 5.1. It was previously leased as a small scale chemical and petroleum storage and transfer facility before the surrounding areas were rezoned to promote commercial and residential development. No chemical production actually occurred on–site. The facility has recently closed and all structures were removed, except for several partially buried storage tanks that were missed. These apparently did not appear on the original plans. The tanks were located during the site investigation and are leaking several substances into the subsurface.

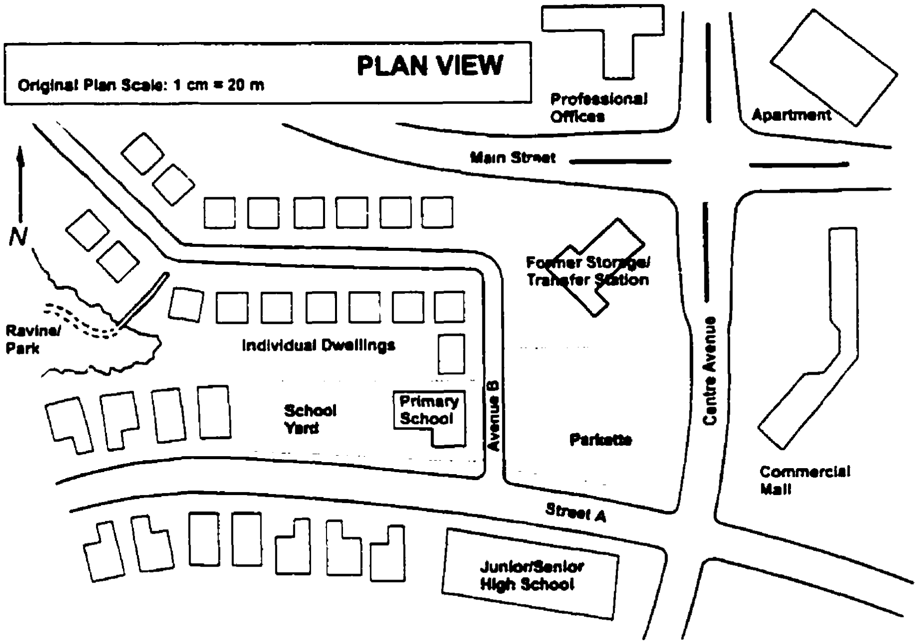

FIGURE 5.1: Plan view of case study

The community revitalization efforts have progressed quickly and the surrounding businesses and residences are relatively new. The surrounding community is being heavily marketed as a growing subdivision with all the conveniences and amenities of a major metropolitan area. The following have already been established nearby and are being promoted in order to attract more potential homeowners and businesses into the vicinity.

- A small, existing subdivision consisting of residential, detached housing that serves as a "core" for future housing projects.
- Primary and secondary schools to serve the children of the relatively young families moving into the area.
- A park to accommodate a variety of community sports functions.
- A commercial mall that offers a variety of amenities and retail products.
- Offices that provide a variety of professional and medical services.
- The local ravine is being converted to a "nature" park to entice future homeowners.

5.1.1 Step 1A: Site Investigation and Characterization

The consultant/contractor retained to perform the site testing and characterization has determined the following significant features of the site and the extent and type of contamination. This initial site investigation cost $20 000.

1. To date, no contamination has been detected beyond the site boundaries (although this is expected to soon change if no action is taken).
2. The leaking substances consist of benzene and gasoline and are located at relatively shallow depths.
3. A "channel" of high permeability sands and gravels runs underneath the site in a northeasterly to southwesterly direction. Any underground contamination is assumed to move eventually in this direction towards: i) the primary school, ii) the parkette, and iii) residential houses closest to the school.

5.1.2 Step 1B: Identify Principal Liability Conditions

Based on the site investigation, the owner establishes the following *principal liability conditions* for consideration. These would be refined as the methodology progresses.

- In this case study, the dispersion and impacts of *benzene* - specifically benzene vapor – should be examined because it is one of the main contaminants. Furthermore, it is a carcinogen, volatile, and soluble. It can easily disperse through the environment.
- Gasoline is also present but its health effects are not as well documented as some of its individual constituents. In fact, uncertainty in how to analyze the impacts of mixtures of multiple contaminants is a common problem. For liability purposes, benzene is again selected because it is perhaps the most hazardous and mobile component of gasoline.
- If benzene is located at shallow depths, it is assumed to not persist in the soil for extended periods of time because it volatizes quickly. Thus, a key condition is to examine where benzene may migrate and pose a subsequent inhalation scenario for potential receptors. Ingestion is not a significant concern because the groundwater is not and would not be used for drinking or washing purposes.
- Receptors are exposed to benzene for sufficiently lengthy time periods for health impacts to occur should they occur for that individual.
- There are up to four off-site properties ($q = 4$) that are possible locations of concerns – and therefore sources of owner liability – because they may lie in the predicted path of contaminant travel if it passes beyond the site boundaries. (Modeling the spread of contamination and the performances of the remedial actions in Step 2 should confirm which properties would likely be affected.) These are the primary school, the parkette which borders on the site boundary, and two existing houses. For simplicity, two of the

off-site locations – the two houses – will be grouped into a single off-site category because of their similarity in size and function, and their proximity to each other.

5.2 STEP 2: ANALYZING REMEDIAL ACTIONS

We assume that the owner has retained a remediation expert to examine and shortlist all the possible remedial actions (RA's), and to predict their performance in remediating the contaminated soil and groundwater in order to minimize the benzene vapor both on-site and off-site. The selection of the following remedial actions is independent of any regulations or technical considerations that may govern what is possible for the various site uses described later in the Section 5.3. Monitoring is included in all four remedial actions.

5.2.1 Step 2A/2B/2C: Estimate Performance of Remedial Actions and Time[1]

Based on the site circumstances, the owner has selected three possible remedial actions: 1) RA_0, or "do nothing"; 2) RA_1, which is based on containment; and 3) RA_2, which is a combination of pump and treat and soil vapor extraction.

"DO NOTHING" - RA_0

No remedial action would be taken, except to fence off the site from trespassers. There would also be no ongoing activities.

CONTAINMENT – RA_1

For this case study, containment refers principally to encapsulation (Angell,1991). Physical barriers, such as barrier walls, would be installed to prevent the off-site migration[2] of the contaminants. The site would also be capped to prevent their vertical migration to the site surface. Because no off-site activities are involved (e.g., no need to secure permission from adjacent property owners), there is assumed to be little delay in implementing this remedial action. Any off-site migration is assumed insignificant during its installation. Alternative

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[1] Data for RA_0 and RA_2 are based on the real case study prior to and after remediation respectively. The performance of RA_1 is based on the assumption that it works perfectly.

[2] One of the chief limitations is the uncertainty of long term reliability (Groundwater,1994). Specifically, any materials (and construction techniques) used must provide adequate short term and long term protection against vapor migration (McLearn et al.,1988). In this chapter, we assume that containment performs as expected; uncertainty is considered in Chapter Six.

forms of containment such as stabilization and/or solidification are possible (Malone and Lundquist,1994) but will not be pursued in this case study.

PUMP AND TREAT (P&T) WITH SOIL VAPOR EXTRACTION (SVE) – RA2A, RA2B.

The groundwater under the site would be continuously pumped and treated. In addition, soil vapor extraction (SVE) would be used to capture any hydrocarbon vapors. According to the literature, SVE can successfully remove benzene, provided that the soil is relatively permeable (Goldfarb et al.,1994). This combination of technologies has been reported as an effective approach (Davis and Russell,1994). Furthermore, this pump and treat/soil vapor extraction alternative can be executed to varying levels of agressiveness. For this case study, we consider two levels: medium and high, identified as RA_{2a} and RA_{2b} respectively.

The consultant suggests that the two year time period[3] is appropriate for analysis based on the site conditions and the time required to implement these remedial actions and for them to reach their maximum effectiveness. For simplicity, we assume that this two-year period is also sufficient for all monitoring activities in all remedial actions, with the exception of RA_O. Figure 5.2 shows locations identified by the principal liability conditions that may be impacted by contamination given the different remedial actions after two years. Table 5.1 lists the remediation specialist or consultant's predictions of the benzene vapor concentrations available for inhalation at each location for each specific remedial action[4]. These predictions would be given by combining hydrogeologic data with groundwater models and dispersion models[5]. Further combining these with vapor emission models (specific to benzene in this case)[6] results in an exposure pathway analysis that estimates the *AC*[7] values to which receptors may be exposed, as shown in Table 5.1.

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[3] In the actual case study used for this example, the remediation occurred over a two year period.

[4] All concentrations predicted at the end of the 2-year period are assumed constant over time in this illustrative example, but in reality, these concentrations would decrease over time. However, using constant concentrations is consistent with our principal liability conditions approach.

[5] Examples of these would include methods as outlined in Domenico and Schwartz (1990).

[6] Examples of these include models such as those described by Johnson et al. (1993).

[7] The hypothetical AC values shown in Table 5.1 were calculated using concentrations from the actual case study – assumed to be at ground level – and a dilution factor to account for atmospheric mixing up to an inhalation height (i.e., 2 m) as the benzene vaporizes. For simplicity, the same dilution factor and parameters were used for all on-site and off-site scenarios, and because this approach is

Because of the relatively small size of the site, the on-site *AC's* in Table 5.1 from each of the remedial actions is assumed to be uniformly distributed throughout the site. Furthermore, although the concentration in reality varies over the site, we assume the highest concentration for this uniform distribution in order to examine the owner's liability (i.e., via exposure and health impacts) because we cannot accurately predict where the receptors will be on the site. This approach also applies when examining the effects of the contaminant on adjacent properties for off-site liability. For example, children at the school could be expected to move randomly throughout the school property: a uniform distribution is probably as accurate as could be hoped for. These arguments are in keeping with the principal liability conditions approach.

Although it appears as if there is a sudden jump between the on-site and off-site concentrations in Table 5.1, we recognize that in reality, the concentration is continuous across the site boundary. Reasonable qualitative descriptions for on-site CC values are also provided in Table 5.1[8] based on the expected performance of the remedial actions.

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conservative, these numbers may appear to represent a "worst case" example. Recall however, that the actual case study data were simply used to establish a realistic basis for the hypothetical AC values. These AC values should be interpreted to represent only what the consultant *predicts for this illustrative example* regarding the performance of the remedial actions.

[8] Numerical values for CC's are not provided because no such quantities were available from the actual case study to develop hypothetical values. The example also does not depend significantly on quantitative estimates for CC. Qualitative estimates for CC values on-site are thus given, although they also could have been provided for off-site locations. However, to simplify the case study, we assume that the off-site AC values are adequate information for analyzing the off-site situations.

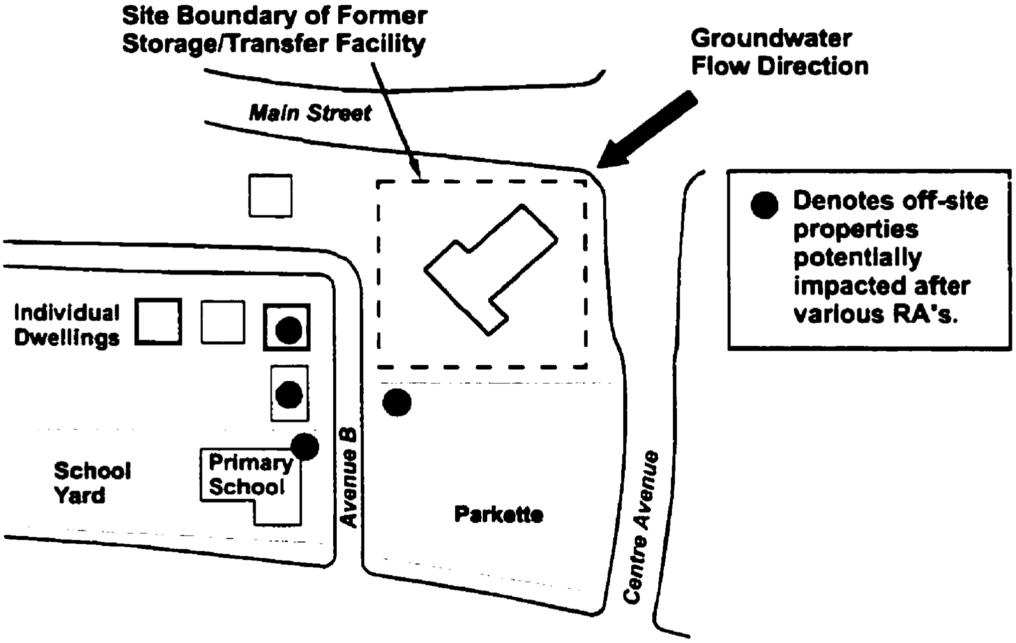

FIGURE 5.2: Specific areas predicted to be affected by benzene vapor for selected RA's.

TABLE 5.1: Estimated AC's for inhalation achieved by remedial actions after two years.

RA	*Description*	*CC (mg/m^3) On-site*	*AC (mg/m^3) On-site*	*AC (mg/m^3) Boundary Parkette*	*AC (mg/m^3) Houses*	*AC (mg/m^3) School*
$RA_{\emptyset}$	"Do nothing". Will not prevent off-site or onsite escape of contaminants.	High	0.24	0.054	0.046	0.039
RA_1	Containment and capping. Simple, less costly. "Immediate" solution. Does not reduce actual conc. of contaminant. Long term performance unknown.	High	0	0	0	0
RA_{2a}	Pump and treat with soil vapor extraction. Well documented. "Tried and true." Will actually reduce contaminant concentrations.	Mod-Low	0.0061	0	0.0029	0.0016
RA_{2b}	As above, but with increased effectiveness.	Low	0.0034	0	0.0025	0

5.2.2 Step 2D: Estimating the Owner's Costs for Remedial Actions

The consultant also estimates the costs[9] of the remedial actions, shown in Table 5.2, based on his or her familiarity and experience with similar past cases. For simplicity, no discounting is included because the time period is only two years. In general, monitoring costs decrease with the increasing aggressiveness of the remedial action.

TABLE 5.2: Present value costs of remedial actions.

RA	*Description*	*Site Investigation Cost, C_{SI}*	*Cost of RA Itself, C_{SR}*	*Ongoing Costs*	*Monitoring Costs*	*Total Remedial Action Cost($), C_{RA}*
$RA_{\emptyset}$	"Do nothing", except to fence off the site from trespassers.	20 000	0	0	540 000[10]	**560 000**
RA_1	Containment (barrier wall) and encapsulation.	20 000	400 000	25 000	125 000	**570 000**
RA_{2a}	Pump and treat with soil vapor extraction.	20 000	100 000	300 000	130 000	**550 000**
RA_{2b}	As above, but more extensive.	20 000	150 000	450 000	80 000	**700 000**

5.3 STEP 3: SITE USES (SU'S) CONSIDERED AND ESTIMATING THE OWNER'S BENEFITS[11]

The owner of the site is considering several possible site uses[12]. Based on the local market conditions, the owner is considering developing the site into: 1) a full-featured service

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[9] Because of discrepancies between the costs given by the actual case study and the hypothetical benefits calculated later in Section 5.3, the real cost data did not provide a workable illustrative example. Instead, cost values have been hypothetically assigned.

[10] Because no remediation is planned, monitoring for the "do nothing" option could be significantly more expensive than the other remedial actions because the time needed for monitoring could be more than double (Markotich, July 7,1998). To obtain an approximate value for monitoring for $RA_{\emptyset}$, we assumed monitoring would be required for five years, which would be more than double the two-year monitoring period assumed for all other remedial actions. Assuming it costs approximately $125 000/year for monitoring and a 5% discount rate, the present value of monitoring costs is approximately $540 000.

[11] No data for formulating the owner's benefits were available. All values presented in this section are based on the opinions of professional appraisers, developers, etc. using the general characteristics of the real case study.

[12] While many examples of commercial and residential uses are possible, only the service station and residential housing options are considered for the purposes of this example.

station, or 2) an extension of the residential, detached housing that already exists. The owner would also like to examine the possibility of leaving the site "as is" since this could potentially be the cheapest solution.

For the purposes of the case study, we assume that all technical considerations (e.g., construction methods) can be met for any site use/remedial action combination. Thus, any site uses that seem initially incompatible with particular remedial actions will not be discarded. For example, it seems inappropriate to construct houses with basements on a site that is only capped. Cracks in the basement may allow for infiltration and accumulation of a contaminant. Technical difficulties are assumed surmountable, although it may increase the cost of developing that site use. More importantly, however, is that an alternative site use should not be immediately eliminated without further analysis. Instead, the decision methodology should reveal which choices are preferred based solely the owner's net benefits.

Based on discussions with a major real estate company (Royal LePage, Sept.4,1997), uncontaminated land in a major Metro-Toronto area similar to this case study is valued at approximately $70 000 per acre. Our site has an area of 6400 m^2, giving it an approximate value of $111 000 if it was uncontaminated. If the owner was only concerned with selling the land as opposed to developing it, the value of the site would be independent of the intended site use. Alternatively, an owner interested in developing the site may enter an agreement with the developer. *For this case study, we will assume that the owner, the developer, and their respective consultants are one entity and that the term "owner" refers to all parties collectively.*

The owner relies on the real estate appraiser to estimate the unaffected value of the site $UV(SU_i)$, and the cost of developing the site, $C_D(SU_i)$. Any calculations in the following section and subsequent sections that require discounting assume a rate of 5%. Note that since constant worth dollars are used in this analysis, this is a real (net of inflation) discount rate.

$SU_{\emptyset}$: "DO NOTHING"

The site is essentially left in its current contaminated condition. No efforts will be undertaken to develop the site. Because it is currently unused, its value to the owner is currently zero: for the purposes of this case study, we assume that the site will not be sold to a third party. Fencing will be erected to prevent trespassing at an estimated cost of $12 000, and this would be part of the cost of development, $C_D(SU_{\emptyset})$.

There would also be an annual property tax because the owner still retains possession of the site. For simplicity, we assume this tax would be based on the uncontaminated value of the land, $111 000[13] and include this in $C_D(SU_{\emptyset})$[14]. This property tax would be approximately $1400 per year (City of Toronto, July 6,1998), assuming this annual tax amount remains relatively constant over a 20 year period. The total $C_D(SU_{\emptyset})$ for the "do nothing" site use is $29 500 and includes both the property tax and the cost of fencing.

SU_1: DEVELOP THE SITE INTO A FULL-FEATURED SERVICE STATION

If the site is developed into a fully featured service station (i.e., car wash, repair bays, convenience store, fuel dispenses), the present worth of the unaffected value[15] of the site is approximately,

$$UV_1 = \$3\ 246\ 000$$

The cost to develop such a facility, $C_D(SU_1)$, is approximately $2 000 000, and we assume that this includes the costs of services, permitting, etc. A very profitable service station in a favorable location would generate profits of $90 000 to $100 000 per year after annual costs

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[13] This may be a reasonable assumption because as far as the municipality is concerned, the owner could cleanup and develop the land.

[14] The total tax paid for the site if it left vacant is: $\$1400\frac{\left[(1+0.05)^{20}-1\right]}{0.05(1+0.05)^{20}}=\$17500$

[15] To develop UV_1 for the case study, we assume the total unaffected value for this site use includes the profits and the cost of development. Using a discount rate of 5%, UV_1 was calculated as,

$$UV_1 = \$2000000 + \$100000\frac{\left[(1+0.05)^{20}-1\right]}{0.05(1+0.05)^{20}}$$

$$UV_1 = \$2000000 + \$1246221$$

$$UV_1 = \$3246221$$

such as taxation have been considered, and is expected to last 15 to 20 years. For our example, we assume a service station at the site will generate $100 000 per year for 20 years because of the lack of nearby competition and the demands of car owners from the nearby businesses and single-family and multi-family dwellings.

SU_2: DEVELOP THE SITE INTO RESIDENTIAL, DETACHED HOUSING

The median price of detached houses in an area similar to that of our case study is $225 000 (Real Estate News,Aug.15,1997). Given that there is enough room to develop 10 lots in our case study, the total unaffected value for this site use would be,

$$UV_2 = 10(\$225\ 000) = \$2\ 250\ 000$$

For developing a housing project, a developer would seek a profit margin of 10% to 15% for developing a housing project (Wong, Sept.2,1997; Royal LePage,Sept.4,1997). These values may be significantly higher (i.e., 50% to 100%) depending on the actual situation. The area in the example has favorable market conditions due to the nearby amenities (i.e., schools, shopping, etc.). Because of this, we assume that the $225 000 median price includes a 50% profit margin, resulting in a cost of development, or $C_D(SU_2)$, of $150 000 per house. For the purposes of this example, we assume that $C_D(SU_2)$ includes all necessary costs (i.e., services, housing construction, permits, etc.). Furthermore, because the time for construction and transfer of property to the homeowner is relatively short, we will not perform any discounting.

Table 5.3 summarizes the *unaffected values* for the three site uses described above as well as the cost of site development, C_D.

TABLE 5.3: Unaffected values and development costs for different site uses.

SU	*Description*	*Unaffected Value, UV*	*Cost of Site Use Development, C_D*
SU0	"Do nothing". Leave the site abandoned.	$0	$29 500
SU1	Develop the site into a commercial property. A modern service station.	$3 246 000	$2 000 000
SU2	Develop the site into residential, detached housing.	$2 250 000	$1 500 000

5.3.1 Finalizing the Owner's Site Use Benefits Considering Stigma

To complete the benefits analysis, we also require estimates for stigma, or the reduction in site value[16] due to any remaining contaminant concentration, CC, and any remaining contaminant available concentration, AC, after remediation given the intended site use. Using the AC values from Table 5.1 as a basis, "low, medium, and high" descriptions of the contaminant and available concentrations are developed and used by the appraiser to estimates the values for stigma, as shown in Table 5.4.

In Table 5.4, there is a zero stigma value assigned to the "do nothing" and the commercial site uses because the owner retains possession of the site. Stigma only affects site benefits when the property is sold or rented.

For a residential site use, homeowners are assumed to have legitimate concerns about any remediation efforts performed on properties purchased for their families. For example, even if the contamination is fully controlled through containment, knowing that it exists may result in higher stigma, despite the low concentrations to which the residents might actually be exposed. In Table 5.4, the total stigma is shown for all ten houses: it is assumed that each house carries an equal amount of stigma. For the purposes of this example, stigma is assumed to reduce the uncontaminated value about 18% for the "do nothing" alternative. As the aggressiveness of the remedial action increases, less stigma results.

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[16] No actual values were available for estimating stigma. Values were assigned hypothetically to reflect the arguments presented in Chapter Four.

TABLE 5.4: Stigma for each potential on-site use and remedial action combination.

Site Use, SU	*Remedial Action, RA*	*CC Approx.*	*AC Approx.*	*Estimated Stigma, S ($)*
SU_Z None	RA0: none	High	High	**0**
	RA1: contain	High	Low	**0**
	RA2a: P&T;SVE	Mod-Low	Low	**0**
	RA2b: P&T;SVE	Low	Low	**0**
SU_1 Service Station	RA0: none	High	High	**0**
	RA1: contain	High	Low	**0**
	RA2a: P&T;SVE	Mod-Low	Low	**0**
	RA2b: P&T;SVE	Low	Low	**0**
SU_2 Houses	RA0: none	High (as is)	High	**400 000**
	RA1: contain	High (as is)	Low	**250 000**
	RA2a: P&T;SVE	Mod-Low	Low	**150 000**
	RA2: P&T;SVE	Low	Low	**75 000**

Table 5.5 summarizes the values used to determine the owner's site use benefits for the three site uses and four remedial actions considered in this case study.

TABLE 5.5: Summary of values used to determine the owner's site use benefits.

Site Use, SU	*Remedial Action, RA*	*Unaffected Value, UV ($)*	*Estimated Stigma, S ($)*	*Property Value, PV($)*	*Cost of Develop C_D ($)*	*Site Use Benefits, SB ($)*
SU_Z None	RAØ: none	**0**	**0**	**0**	**29 500**	**0**
	RA1: contain	**0**	**0**	**0**	**29 500**	**0**
	RA2a: P&T;SVE	**0**	**0**	**0**	**29 500**	**0**
	RA2b: P&T;SVE	**0**	**0**	**0**	**29 500**	**0**
SU_1 Service Station	RAØ: none	**3 246 000**	**0**	**3 246 000**	**2 000 000**	**1 246 000**
	RA1: contain	**3 246 000**	**0**	**3 246 000**	**2 000 000**	**1 246 000**
	RA2a: P&T;SVE	**3 246 000**	**0**	**3 246 000**	**2 000 000**	**1 246 000**
	RA2b: P&T;SVE	**3 246 000**	**0**	**3 246 000**	**2 000 000**	**1 246 000**
SU_2 Houses	RAØ: none	**2 250 000**	**400 000**	**1 850 000**	**1 500 000**	**350 000**
	RA1: contain	**2 250 000**	**250 000**	**2 000 000**	**1 500 000**	**500 000**
	RA2a: P&T;SVE	**2 250 000**	**150 000**	**2 100 000**	**1 500 000**	**600 000**
	RA2b: P&T;SVE	**2 250 000**	**75 000**	**2 175 000**	**1 500 000**	**675 000**

5.4 STEP 4: DETERMINING OWNER LIABILITY

The last major portion of the decision methodology is to estimate the liability to the owner for the various combinations of site uses and remedial actions. *Step 1B: Identifying the Principal Liability Conditions,* has already been completed. Furthermore, because of the simplifying assumptions used throughout this case study, *off-site liability will be examined alongside on-site liability where appropriate. Step 4D, Off-Site Liability* is thus not discussed as a separate section.

5.4.1 Step 4A (and Step 4D) : On-Site and Off-Site Exposure

As stated earlier, we have assumed the *uniform concentration distribution* case. The maximum AC level (and unquantified CC levels) expected after any remedial action occurs uniformly throughout the entire site. Given that the site has an area of only 6400 m^2, this is not an unreasonable assumption. Moreover, the development venture undertaken is relatively small in scale: the owner is assumed to have – or only want to commit - limited relatively small in scale: the owner is assumed to have – or only want to commit - limited resources to conduct a detailed exposure analysis. Thus, $P(AC_{maxON_i})=1$ for any RA_i performed on the site itself.

$P(AC_{maxOFF_i})$ is also equal to unity for all off-site properties shown in Figure 5.2 that are predicted to be impacted by the contamination. The contaminant is assumed to occur uniformly at its maximum, predicted concentration over the off-site property.

More sophisticated methods of quantifying exposure are possible. Additional values can be estimated for factors such as the contact rate and exposure frequency in order to determine an actual intake dosage. To simplify the details of our example, we have assumed that any receptors will be exposed to whatever AC is estimated for sufficient lengths of time such that an adverse response could be realized. However, we recognize that any detailed exposure analysis would refine this assumption provided the information was available.

5.4.2 Step 4B: Adverse Health Response

Health concerns form the basis for two of our key issues:

1. The owner is concerned about the cost of liability from any adverse health effects.
2. The community wants to avoid any adverse health effects.

The consultant will either undertake a health study, or else retain the services of a health expert to provide information on the health effects arising from benzene exposure. The following is an example of the type of information available.

Benzene enters the human body via *inhalation and dermal absorption* (Proctor and Hughes,1996). The effects and concentrations at which effects occur due to short-term exposure are shown in Table 5.6.

TABLE 5.6: Short-term effects of benzene vapor on human beings.
(From: Aksoy,1988, p.62)

Air conc. (ppm)	*Air conc. (mg/m^3)*	*Exposure (min.)*	*Short term Effects*
19 000 – 20000	60 800 – 64 000	5 – 10	Fatal
7500	24 000	30	Dangerous to life
3000	9600	30	Endurable
1500	4800	60	Serious symptoms
500	1600	60	Symptoms of illness
50 – 150	160 – 480	300	Headache, lassitude, weariness
25	80	480	None

Note that 1 ppm = 3.2 mg/m^3 for benzene vapor

Benzene is also considered a human carcinogen. Humans appear to be more susceptible to the leukemogenic potential than animal species (Aksoy,1988; Proctor and Hughes, 1996). In our example, the available concentrations appear to be too low to produce short-term health impacts. Therefore, $P(R_{SON})$ and $P(R_{SOFF})$ are assumed to be zero as shown in Tables 5.7 and 5.8.

To assess long-term effects, there are various methods for calculating the incremental cancer risk posed by low doses over a lifetime of exposure. We do not examine the advantages or disadvantages of any specific method, but expect that the health expert will select the most appropriate procedure. A common method is the linearized multi-stage model (Kolluru,1996) used by the U.S. Environmental Protection Agency (EPA), although the American Society for Testing and Materials (ASTM) states, "... there is no general agreement in the scientific community that this is the appropriate model to use." (ASTM E 1739-95) In this illustrative example, we use the above model to predict the long-term $P(R_{LON})$ and $P(R_{LOFF})$ values[17] listed in Tables 5.7 and 5.8. We assume that the cancer caused by benzene is acute myelogenous leukemia, and as a principal liability condition, also assume this cancer results in death (Government of Canada,1993).

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[17] The general form of the linearized multi-stage model is:
incremental cancer risk = slope factor $[mg/(kg\text{-}d)]^{-1}$ X concentration (mg/m^3)
X breathing rate (m^3/d) / body mass (kg)
We assumed the slope factor to be 2.9×10^{-2} $[mg/(kg\text{-}d)]^{-1}$ for benzene, the average inhalation or breathing rate to be 23 m^3/d, and the average body mass to be 70 kg for an adult male (Environment Protection Office, 1991b). The concentrations available for inhalation are from Table 5.1.

This is only a rudimentary assessment of health effects for the purposes of this example. A health specialist would be able to provide further guidance as to the proper calculation and interpretation of health data for the owner's specific circumstances. For example, there would be different assumed breathing rates and body masses depending on the age (i.e., children, elderly) and gender. However, *we ignore these differences* to keep the illustrative example simple. We also assume that individuals are exposed to low doses of benzene for 20 years, the time period used earlier to characterize the site uses, and that this is sufficiently long enough to constitute a life-time exposure. In reality, children in the school would be exposed for only up to seven years.

TABLE 5.7: Estimated $P(R_{SON})$ and $P(R_{LON})$ on-site.

RA	*Description*	*AC (mg/m^3) On-site*	*$P(R_{SON})$*	*$P(R_{LON})$*
$RA_{\varnothing}$	"Do nothing".	0.24	0	0.0023
RA_1	Containment and encapsulation.	0	0	0
RA_{2a}	Pump and treat with soil vapor extraction.	0.0061	0	5.8×10^{-5}
RA_{2b}	As above.	0.0034	0	3.2×10^{-5}

TABLE 5.8: Estimated $P(R_{SOFF})$ and $P(R_{LOFF})$ at off-site locations.

Off-site	*Boundary/Parkette*			*Houses*			*School*		
RA	*AC mg/m^3*	*$P(R_{SOFF})$*	*$P(R_{LON})$*	*AC mg/m^3*	*P (R_{SOFF})*	*P (R_{LOFF})*	*AC mg/m^3*	*P (R_{SOFF})*	*P (R_{LOFF})*
$RA_{\varnothing}$	0.054	0	5.1×10^{-4}	0.046	0	4.4×10^{-4}	0.039	0	3.7×10^{-4}
RA_1	0	0	0	0	0	0	0	0	0
RA_{2a}	0	0	0	0.0029	0	2.8×10^{-5}	0.0016	0	1.5×10^{-5}
RA_{2b}	0	0	0	0.0025	0	2.4×10^{-5}	0	0	0

5.4.3 Step 4C: Other Liability Factors

The owner's lawyer can make several reasonable assumptions when estimating *P(O)*, or the contribution of other factors to liability. $RA_{\varnothing}$ will result in a high probability of liability because of the following:

- Benzene is a well-documented, hazardous chemical. If school children or residential dwellings are exposed to it, it is almost certain that there will be a public outcry.

- Benzene found on off-site properties will almost assuredly result in liability due to the contaminant "trespassing" onto adjacent property.

Conversely, the contribution of other liability factors may be less significant if:

- There may be less concern if the site is developed into a commercial venture, especially a service station. The use and distribution of chemicals is expected.
- Because benzene is well documented, there is not likely to be any accompanying sensationalism.

In Chapter Four, there were separate *P(O)* values for each possible on-site/off-site and short-term/long-term health impact situation within each *SU /RA* combination. For simplicity, *P(O)* estimates are provided only for the overall categories of "on-site" and "off-site", as shown in Table 5.9. All off-site locations are treated in the same manner and are assumed to have equal *P(O)* values. The values given are hypothetical and attempt to quantify the arguments presented in Section 4.5.3.

TABLE 5.9: Probability of "other" liability factors.

Site Use, SU	*Remedial Action, RA*	*$P(O_{ON})$*	*$P(O_{OFF})$*	*Comments*
SU_Z None	RA_Z: none	0.8	0.8	Estimated to be "0.8" because no remedial action is even attempted; seen as owner irresponsibility.
	RA_1: contain	0.15	0.15	Estimated to be "0.15" because even though there is no site use, remedial actions are still performed.
	RA_{2a}: P&T;SVE	0.15	0.15	As above.
	RA_{2b}: P&T;SVE	0.15	0.15	As above.
SU_1 Service Station	RA_Z: none	0.8	0.8	Estimated to be "0.8" because no remedial action is even attempted; seen as owner irresponsibility.
	RA_1: contain	0.25	0.35	Estimated to be "0.25" on-site. Although it is only being used for commercial purposes, RA_1 does not address the contamination source. Estimated to be "0.35" off-site because off-site locations will have children, but the nearby contamination source is untreated and only contained.
	RA_{2a}: P&T;SVE	0.20	0.20	Estimated to be "0.20" because unlike containment, the source of the contamination is being treated with RA_{2a}.
	RA_{2b}: P&T;SVE	0.15	0.15	Estimated to be "0.15" because RA_{2b} is more effective than RA_{2a}.
SU_2 Houses	RA_Z: none	0.9	0.9	Estimated to be "0.9" because no remedial action is even attempted with expected influx of families.
	RA_1: contain	0.35	0.35	Estimated to be "0.35" off-site because both on-site and off-site locations will have children, but the contamination source is untreated and only contained.
	RA_{2a}: P&T;SVE	0.20	0.20	Estimated to be "0.20" because unlike containment, the source of the contamination is being treated with RA_{2a}.
	RA_{2b}: P&T;SVE	0.15	0.15	Estimated to be "0.15" because RA_{2b} is more effective than RA_{2a}.

5.4.4 Step 4E: Evaluating the Individual Financial Costs of Liability[18]

The following outlines how the owner approximates the financial costs of liability in this example.

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[18] Efforts were unsuccessful in finding consistent case histories that documented personal injury awards as the result of exposure to contamination. All values stated are hypothetical.

ON-SITE AND OFF-SITE RECEPTORS

The owner's estimates of the number of on-site individuals can be determined by considering the number of individuals expected to occupy a particular site use. The number of potential receptors is shown in Table 5.10. All receptors are divided into two major categories: adults and children.

TABLE 5.10: Expected on-site receptors.

SU	*Description*	*Receptors*	*Number of Adults and Children*
SU_z	"Do nothing". Leave the site abandoned.	0	Assume that fencing is effective in keeping any individuals from venturing on-site.
SU_1	Develop the site into a modern service station.	3	Assume the site requires 2 full-time attendents and 1 full-time mechanic.
SU_2	Develop the site into residential, detached housing.	34	Assume that there are, on average, 2 adults and 1.4 children per household. Given 10 houses, this results in 20 adults and 14 children.

The number of receptors at each off-site location can also be estimated in a similar manner. However, because these locations are already in use, it is possible to use demographic surveys to estimate the number of current occupants, as shown in Table 5.11.

TABLE 5.11: Off-site receptors.

Off-site Use Description	*Receptors*	*Number of Adults and Children*
Parkette.	8	Children with adult supervision often use the parkette. There are usually 1 adult and 7 children.
Existing houses.	8	Each of the two houses that may be affected by the contamination has 2 adults and 2 children, giving a total of 4 adults and 4 children.
Primary school.	225	There are currently 20 adults and 205 children present at the primary school.

INDIVIDUAL FINANCIAL COST OF LIABILITY

The financial cost of liability per individual is estimated from previous judgments in court-awarded settlements, insurance claims, and health care costs for contamination and remediation situations similar to this example. We rely on the expertise of legal and/or actuarial professionals to provide these estimates.

We assume the hypothetical costs given in Table 5.12 for both adults and children in the scenario of incurable cancer and death resulting from long-term, low-dose exposure. (As discussed earlier, there would be no short-term health impacts.) These values are contentious because a monetary value is placed on life and health; it can be argued that it is not possible to quantify a person's worth. The values are not intended to be truly indicative of an individual's worth but are representative of the range of values used to estimate the value of an individual's life (Kornhauser,1990). Another challenge is to distinguish between different groups of people. For this example, we assume that children have a greater value than adults. Within each group, we assume that one individual is equal to another.

TABLE 5.12: Individual financial cost of liability.

Health Condition	*Type of Receptor*	*Individual Financial Cost of Liability*
Incurable cancer and death.	Adult	$1 500 000
	Child	$3 000 000

All long-term impacts (cancer and death) are assumed to manifest by the end of the 20-year time period and any liability payment to occur immediately thereafter. This payment is discounted back over this 20-year period using a discount rate of 5%.

5.4.5 Step 4F: Estimating the Overall Financial Liability

Table 5.13 presents the financial cost of liability to the owner for each site use and remedial action combinations in this case study as calculated using equations 4.13 to 4.15. The accompanying spreadsheet in Appendix B details how the liability components in the case study were combined. Liability ranges from $0 for combinations with containment because we have assumed it works perfectly, to a high of approximately $144 000 for the SU_2/RA combination. No remediation is undertaken, yet a site use with numerous receptors (i.e., families) is being proposed. However, liability does not seem to be as prominent a cost as one might have originally expected. This is most likely due to the relatively low AC values and subsequent low probabilities of adverse health responses.

TABLE 5.13: Financial cost of liability to owner for SU/RA combinations.

Site Use, SU	*Remedial Action, RA*	*Estimated Financial Cost of Liability (\$)*
$SU_\varnothing$ None	$RA_\varnothing$: none	\$77 800
	RA_1: contain	\$0
	RA_{2a}: P&T;SVE	\$580
	RA_{2b}: P&T;SVE	\$24
SU_1 Service Station	$RA_\varnothing$: none	\$81 000
	RA_1: contain	\$0
	RA_{2a}: P&T;SVE	\$790
	RA_{2b}: P&T;SVE	\$33
SU_2 Houses	$RA_\varnothing$: none	\$144 000
	RA_1: contain	\$0
	RA_{2a}: P&T;SVE	\$1000
	RA_{2b}: P&T;SVE	\$150

5.5 STEP 5: CALCULATING THE NET BENEFITS TO THE OWNER

Table 5.14 summarizes the financial net benefits to the owner under various combinations of remedial actions and site uses. Detailed calculations are shown in Appendix B.

TABLE 5.14: Financial net benefits to the owner for different SU/RA combinations.

All values in (\$)	**$RA_\varnothing$: Do nothing**	**RA_1: Contain/Cap**	**RA_{2a}: P&T;SVE**	**RA_{2b}: P&T;SVE**
$SU_\varnothing$: None	**-667 000**	**-600 000**	**-580 000**	**-730 000**
SU_1: Service Stn.	**605 000**	**676 000**	**695 000**	**546 000**
SU_2: Houses	**-354 000**	**-70 000**	**49 000**	**-25 000**

All SU_1 (service station) combinations produce significant net benefits for the owner, while the others produce either very low or negative net benefits. The similar net benefits of the SU_1/RA_1 and SU_1/RA_{2a} combinations are most likely due to the similar costs of remediation and the low values of overall owner liability: the probabilities of adverse health responses were very low due to the relatively low AC values. The owner must now decide which SU_1

combination to pursue because under certainty all choices appear viable. Under regulations or uncertainty however, there may be additional factors that the owner needs to consider. The uncertainty analyses presented in Chapter Six may be able help the owner narrow his or her choices further.

The positive net benefits of the RA_0 ("do nothing")/SU_1(service station) combination at first seems counterintuitive because the "do nothing" scenario suggests liability would be a significant cost, and this was reflected in the P(O) factor. However, the probabilities of adverse health responses were very low due to the relatively low AC values that occur even without remediation - and when combined with the high site use benefits expected and the virtually zero cost of remediation - significant net benefits to the owner were still possible. This is in spite of the high monitoring costs as well. There may be situations in which such development may be considered. For example, there may be sufficient *natural attenuation* inherent in the local environment such that additional remediation efforts are not necessary. (However, we caution that the performance of this combination is based on the parameters of this illustrative example and under the assumption of certainty.)

The combination of SU_2 (housing) with RA_{2a} (moderate pump and treat) also produces positive net benefits, although these are significantly less than those produced by the SU_1 combinations. This is mostly due to the lower benefits received from a residential site use. The other housing combinations did not perform as well because of either increased stigma and/or liability (SU_2/ RA_0 and SU_2/RA_1) or due to increased costs (SU_2/RA_{2b}).

The results of the certainty analysis should thus help the owner select or at least narrow the field of possible SU/RA combinations to pursue. The results for the other combinations that are less favorable can also prove useful: the owner can examine how his or her net benefits may change if tradeoffs need to be made when considering other stakeholders. A parallel methodology for the community is needed to complement the methodology developed here.

5.6 THE EFFECTS OF REGULATIONS

Regulations essentially limit what options are possible under given circumstances in order to safeguard human and/or environmental health. In this section, we will apply the *MOEE Guideline for the Clean Up of Contaminated Sites in Ontario (1996)* to our case study to examine how the owner's choices of site use/remedial action combinations may be affected.

For the purposes of our case study, we use the *generic approach* described by the guideline. As explained in Appendix A, the generic approach consists of criteria based on the allowable concentration levels for various contaminants and accounts for a variety of pathway exposure scenarios (e.g., from soil to indoor air). The criteria were developed from environmental exposure models that rely on protective/conservative assumptions about contaminant exposure (MOEE,1996). In a practical sense, this may be thought of as a "look-up table" approach in which allowable contaminant levels are given for the *general* proposed site use conditions (e.g., residential development with no use of groundwater for human consumption). This may be the most realistic regulatory situation an owner faces, especially at the beginning stages of remediation when less is known about the site, or if the owner does not have the resources to conduct a site specific risk assessment.

In keeping with our example, we will use criteria relevant to benzene vapor. According to the guideline:

> Restoration of groundwater quality to either potable or nonpotable levels ensures the following: Protection against exposure from vapours which may migrate to indoor air (basements) from volatile chemicals in groundwater (MOEE,1996).

All generic soil criteria are also purported to ensure, "... ambient air quality and groundwater quality criteria will not be exceeded if there are contaminant vapours or if there is contaminant leaching from the soil." (MOEE,1996). For simplicity in illustrating regulatory effects, the groundwater criteria is used to back-calculate the benzene vapor concentration used to develop the guidelines.

Table B of the guideline provides generic criteria for surface soil and groundwater for residential/parkland and industrial/commercial land uses in a nonpotable groundwater situation. The allowable concentration of benzene is 1900 μg/L, or 1.9 mg/L. This value needs to be translated into benzene vapor values applicable to the circumstances of our case study.

The *Rationale for the Development and Application of Generic Soil, Groundwater, and Sediment Criteria for Use at Contaminated Sites in Ontario (May 1996)* used the following model to estimate the allowable groundwater concentrations that would result in acceptable indoor air concentrations.

$$[OHM]_{air} = [OHM]_{gw} (\alpha\ d\ H\ C) \qquad [5.1]$$

in which:

- $[OHM]_{air}$ is the target indoor air concentration (μg/m^3);
- $[OHM]_{gw}$ is the calculated groundwater concentration of the oil or hazardous material (i.e., benzene at 1900 μg/L) which would result in an indoor air concentration less than or equal to $[OHM]_{air}$;
- α is a calculated attentuation factor relating the indoor air concentration to the concentration in the soil gas directly above the groundwater source. The MOEE used a dimensionless value of 5×10^4;
- d is a modification factor to convert theoretical groundwater:soil gas equilibrium concentrations to realistic environmental concentrations. This dimensionless value is based upon observations and the professional judgment of specialists. The MOEE used a value of 0.1;
- H is Henry's Law Constant in its dimensionless form (i.e., for benzene, 0.225);
- C is a conversion factor (1000 L/m^3).

In this case, $[OHM]_{air}$ is approximately 21 μg/m^3, or 0.021 mg/m^3. Table 5.15 compares this concentration against those achieved by the various proposed remedial actions.

TABLE 5.15: Comparing AC's achieved by remedial actions against guideline.

RA	*Description*	*AC (mg/m^3) On-site*	*AC (mg/m^3) Boundary Parkette*	*AC (mg/m^3) Houses*	*AC (mg/m^3) School*	*Allowable AC (mg/m^3) based on MOEE Guideline (1996).*
N/A	Current conditions.	N/A	N/A	N/A	N/A	
$RA_{\varnothing}$	"Do nothing".	0.24	0.054	0.046	0.039	0.021
RA_1	Containment and capping.	0	0	0	0	0.021
RA_{2a}	Pump and treat with soil vapor extraction.	0.0061	0	0.0029	0.0016	0.021
RA_{2b}	As above.	0.0034	0	0.0025	0	0.021

Based on the assumptions made about certainty and the site conditions, it appears that all remedial actions except for the "do nothing" alternative are capable of meeting the guideline requirements.

Imposing a regulatory framework limits the owner's choices. Under the assumptions of this example, we can conclude that:

- Combinations that include no remedial action are not acceptable. This contrasts with one of the conclusions in the previous section in which, according to the net benefits, the "do nothing" and service station combination would be acceptable. The owner may now have to select an option according to criteria other than that which maximizes net benefits.
- All other remedial actions produce acceptable performance.
- It would be instructive to examine how remedial actions acceptable under certainty according to regulatory criteria perform under uncertainty, particularly if a remedial action achieves a level close to the regulated concentration under certainty.

Extending the decision methodology to include constraints such as regulations would thus appear to have practical applications. Chapter Seven addresses this as a possibility for future research.

5.7 EXTENSION OF THE ILLUSTRATIVE EXAMPLE

In this chapter, we applied the decision methodology to an illustrative example to demonstrate:

- The relationship between the components of the methodology;
- How each of the owner's objectives of benefits, costs, and liability can be evaluated; and
- How expert opinion and/or information may be incorporated.

At the end, the methodology identified which preferred site use and remedial action combination generate the maximum net benefits for the owner. We concluded the example by demonstrating the impact of regulations; in general, the owner will have fewer choices. The conclusions were, of course, based on certainty and the assumptions specific to this chapter. Chapter Six demonstrates the effect of uncertainty by: 1) explaining how uncertainty affects the decision methodology and how it can be modeled, and 2) applying uncertainty to the illustrative example.

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Chapter Six: Extension of the Decision Methodology for the Owner Under Uncertainty

The methodology has so far assumed that all variables required for decision making are known or can be calculated with certainty. This chapter presents a straightforward approach for including uncertainty in the decision methodology. A flowchart of the complete methodology is shown in Figure 6.1.

We first examine several general considerations for analyzing uncertainty before discussing the possible sources of uncertainty for each of the owner's objectives (i.e., benefits, costs, and liability). This discussion is intended to help the owner understand uncertainty and how it might affect the owner's decisions[1]. The methodology then proposes a two-step approach for including uncertainty, consisting of an extreme case analysis followed by a probabilistic analysis. These steps are then applied to the illustrative example of Chapter Five to show how the revised methodology can be applied. Throughout the chapter we comment on where further research is needed to improve our uncertainty analysis.

In the methodology in Chapter Four, experts are asked to provide estimates for the various parameters needed to formulate the owner's benefits, costs, and liability for any site use/remedial action combination. These represent what the experts can provide to the "best of their ability" and are assumed to be known with certainty: we assumed the experts do not suffer from a lack of information, incorrect information, inability, or poor judgment. As a result, these values would likely be "centrally located" (e.g., close to the mean value of that parameter for those given circumstances). In this chapter, experts are asked to estimate how these values might vary because of uncertainty, such as in a "worst case" or "best case" scenario. Although such an analysis, particularly the worst case scenario, seems at first similar to the principal liability conditions (PLC's) approach in Chapter Four, the two differ in their scope. For example, following the PLC's, the owner may use the highest available concentration, AC, predicted to occur and assume it occurs uniformly over the site.

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[1] In developing the illustrative example in Chapter Five, it was evident that the results were very sensitive to the values assumed, pointing to the need to examine the effects of the assumptions.

However, all conditions leading up to the prediction are assumed to be known with certainty. Under uncertainty, models, hydrogeological parameters, or other elements used to predict this AC may be questioned. Substituting different values to capture these various uncertainties and "re-running" the methodology described in Chapter Four illustrates how the owner's net benefits are affected when extreme values are used. This is Step Six of the methodology, or the extreme case analysis.

The methodology then proposes the owner conduct a probabilistic analysis to model the net benefits using estimated probability distributions provided by experts for the owner's benefits, costs, and liability. Although estimating these distributions may be very difficult, the results may be useful for decision making when combined with the previous extreme case analysis.

This chapter presents a straightforward treatment of uncertainty, but it is not an exhaustive examination on uncertainty analysis. Specifically:

1. The methodology focuses on uncertainties that ultimately affect the site owner's net benefits. Other stakeholders may certainly be affected by uncertainties: considering such effects would be vital to an expanded, comprehensive methodology as described in Chapter One.
2. The estimates required by the methodology for incorporating uncertainty may not be as easily obtained as those needed under the assumptions of certainty in Chapter Four. In such cases, the methodology suggests possible means of deriving such estimates and/or what further research is needed.

6.1 GENERAL CONSIDERATIONS FOR UNCERTAINTY

This section presents aspects of uncertainty that apply to the overall decision methodology. Uncertainty is caused by the absence of information which may or may not be obtainable (Rowe,1994). However, there are various reasons or causes for uncertainties and different types of uncertainty. Knowing how particular aspects of site remediation are associated with specific types of uncertainty can improve our ability to understand and estimate them.

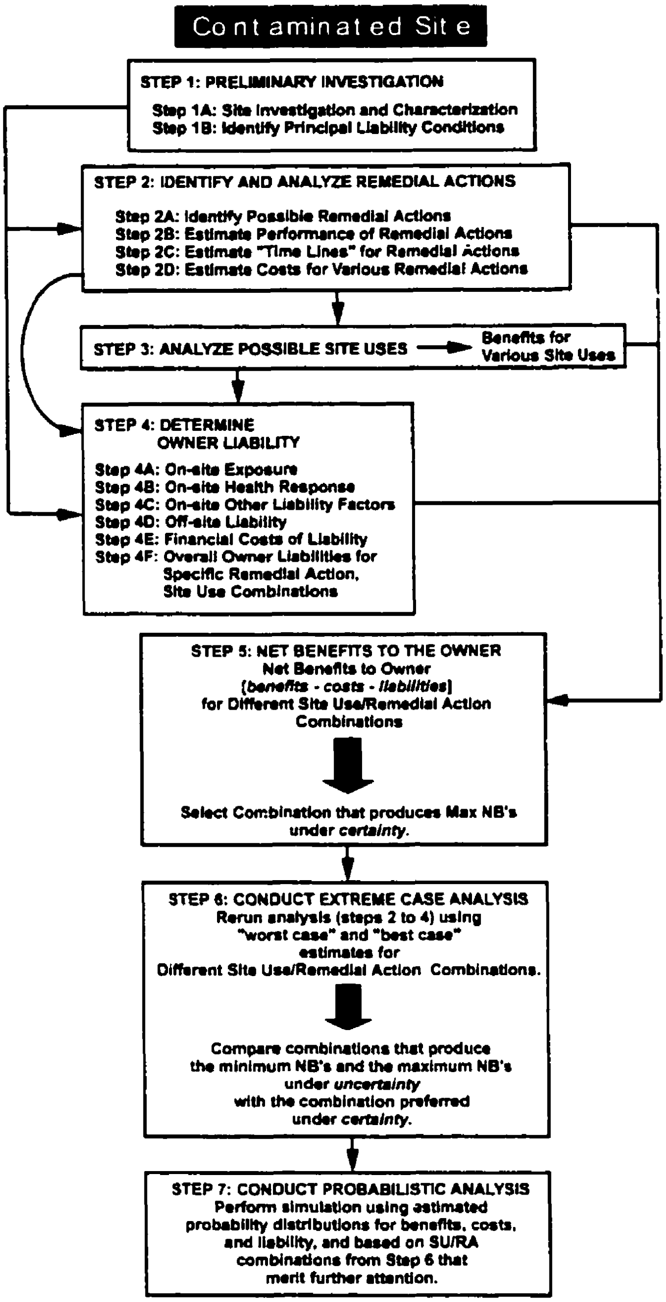

FIGURE 6.1: Decision methodology incorporating uncertainty analyses.

6.1.1 Types of Uncertainty

Uncertainty can be divided into four categories (Rowe,1994).

TEMPORAL UNCERTAINTY

Temporal uncertainty is uncertainty in the past and the future. For example, records of the chemicals stored, used, or processed on the site may be incomplete or simply not available.

The owner may be unable to audit or investigate properly the chemicals present at a site before beginning any clean up effort.

STRUCTURAL UNCERTAINTY

Structural uncertainty stems from complexity in the situation. For example, the highly heterogeneous nature of subsurface soils and structures can reduce the accuracy of modeling and predicting the movement and remediation of contaminants. From a financial perspective, fluctuating market conditions can render it difficult to establish which site use would garner the most benefits.

METRICAL UNCERTAINTY

Metrical uncertainty involves uncertainty in measurement and evaluation. For example, there may be insufficient data to assess accurately the potential health impacts posed by certain contaminants. The literature may also report conflicting evidence of toxicity. Furthermore, new and/or experimental remediation techniques are unlikely to have a reliable performance record. Predicting their in-situ performance and costs may prove difficult. Even the performance of frequently used techniques, such as "pump and treat", may be difficult to ascertain.

TRANSLATIONAL UNCERTAINTY

Translation uncertainty arises from the explanation or communication of uncertain results. For example, misunderstandings may result in community opposition to how a site clean up is conducted and/or the eventual site use may interfere or delay the remediation activities. This may drive up the costs and predicted benefits may not materialize.

6.1.2 Expert Opinion

We require expert input for characterizing uncertainty but recognize that it can be difficult to estimate. There are methods (e.g., by lottery analysis) to help experts better define the uncertainties behind their estimates, and even to construct a probability curve. For example, Keeney (1980) outlines how a series of questions can help the expert determine the subjective probability that a specific outcome will occur based on his or her experience, judgment, and knowledge. The decision methodology will not explore such methods in detail, but emphasizes that instead of simply using an expert's "guess", more precise methods are available for eliciting these estimates.

For every decision problem, professional judgment is used, either directly or indirectly (Keeney,1980). Different experts will likely assess uncertainty through different perspectives and favor different approaches, as shown in Table 6.1. Although each approach may be valid for a specific purpose, such differences may also lead to the aforementioned translational uncertainty, or misunderstandings in communication (Rowe,1994). The *approach* and *limitations* columns in Table 6.1 are adapted from Rowe (1994). The *implications* column illustrates how the approach may affect the decision methodology. The owner should recognize that each expert may be biased when giving his or her opinion on an issue.

TABLE 6.1: Different perspectives on assessing uncertainty.

Approach	*Limitations*	*Implications*
Scientific risk Provides the best estimate of risk and the ranges of uncertainty above and below the best estimate.	Tendency to measure quantifiable aspects instead of critical but difficult-to-measure aspects.	Consultants and vendors called in to comment on the remedial actions may focus on and believe significant resources should be devoted to quantifiable issues. Hard-to-quantify issues (e.g., liability) that may be equally important may not be given equal treatment.
Regulatory risk Assure, with a given degree of confidence, that the actual risk does not exceed the risk estimate.	Very high margins of safety, may have high cost and preclude some beneficial activities.	Health experts and any involved regulatory agencies are likely to approach any site remediation issues conservatively. Lawyers may advise the owner to follow regulations strictly to avoid liability.
Design engineering Use conservative designs to produce engineering with minimum liability.	Very high margins of safety and may have high cost. Subject to unwelcome surprises when applied in new environments.	Appraisers and lawyers may favor conservative "plans of action" to ensure acceptance of the plan. They may also be more comfortable with "tried and true" approaches since their opinion may be based heavily on previous experiences.
Performance management Risks are one parameter for balancing risks, costs, benefits, and performance of any engineering. Uncertainty addressed in all four previous items.	Risks can be modeled, but not measured. Empirical verification of performance is often very difficult.	The owner - perhaps the only "nonexpert" - would probably want a balanced opinion as to what will happen in any SU/RA combination, in order to avoid undue liability and cost, yet still accomplish his or her goals.

6.2 CONSIDERATIONS IN COST UNCERTAINTIES

The owner's costs depend on the remedial action, RA_i, used to remediate the contaminated site. Chapter Four outlined the basic cost elements for RA_i or,

$$C(RA_j) = C_{SI} + C_{IMj} + C_{SRj} + \frac{C_{MONj}\left[(1+r)^{mj} - 1\right]}{i(1+r)^{mj}} + \frac{C_{ONj}\left[(1+r)^{nj} - 1\right]}{r(1+r)^{nj}} \qquad [4.1]$$

Cost estimates provided by the vendor/consultant will likely be uncertain if there are uncertainties regarding the technical aspects of remediation. These may include:

- the extent of contamination and the difficulties in establishing this during the site investigation;
- uncertainty regarding whether any interim measures are required;
- performance of the site remediation under the specific site circumstances; etc.

There may also be uncertainties in cost not directly related to site remediation issues, such as:

- variability in labor costs for site remediation workers; and
- delays or errors in remediation due to the mistakes on the part of consultants (e.g., choosing inappropriate modeling techniques).

The owner faces an important tradeoff. Uncertainty regarding the success of any particular *RA* can be probably reduced, but likely only by expending more resources to perform more thorough site investigations, improved modeling and analysis of the site situation, greater extent of remediation, more thorough monitoring, etc. Such actions are likely to increase the cost of remediation overall. Thus, the decision methodology may have to be iterated several times – with more information becoming known each time - before selecting the preferred combination.

There are methods and modeling techniques available to better characterize the site circumstances and exposure scenarios and hence reduce uncertainty. Examples of this can be found in Rautman and Istok (1996) and Goodrich and McCord (1995). This methodology does not provide technical guidance regarding such approaches; we assume the vendor or consultant will employ the most appropriate technique. We expect that a sophisticated means of characterizing uncertainty might be used if:

- the owner has the resources to do so;
- liability is extreme should the RA fail; and
- initial attempts to characterize uncertainty prove inadequate.

6.3 CONSIDERATIONS IN SITE USE BENEFITS UNCERTAINTIES

The decision methodology requires calculating the owner's *net site use benefits* for various site use and remedial action combinations. These benefits would be based on the appraised property value, *PV*, of the site after remediation. However, assessing property values is inexact because of the uncertainties involved and the considerable amount of experience and judgment possibly required. Furthermore, the use of property values in environmental contexts is often controversial. Much of the literature on the use of property values is devoted to the effects a noxious facility (e.g., landfill, incinerator) has on the property value of *surrounding* sites. We intuitively expect a site that has negative impacts (e.g., via contamination of nearby water wells) would decrease the value of adjacent lands, while positive effects (e.g., through establishing a park) should increase the values. The adjacent site owner may be unable to fully enjoy his or her property due to the physical and nonphysical impacts from a nearby waste facility: the owner's groundwater supply may be contaminated, and the community image may be spoiled by the facility's presence. Values of properties near waste facilities or other undesirable facilities should be either significantly lower than other similar properties, or at least demonstrate a definite correlation to another variable, such as the distance between the property and the facility. For example, the further away the property, the less likely the facility can affect it.

However, while such assumptions are plausible, it has not been consistently supported by the literature - one study often contradicts another (Mundy, 1992). For example, Nelson et al. (1992) concluded from their study that landfills do depress the values of nearby residential properties, but that these depressions varied according to the operation of the landfill. Conversely, Zeiss and Atwater (1989a) statistically analyzed the property values around a landfill and an incinerator and found that there was no significant correlation between the values and the presence of the waste facilities, even when there were observed physical impacts. Their research appears more indicative of the literature: waste facilities have neither consistent nor significant effects on property values.

In the following sections, we discuss how the arguments regarding the effects on the property values of adjacent sites can also be used to understand uncertainties for the property value of the owner's site.

6.3.1 Measurement Uncertainties

In Chapter Four, the property value of a site was given by,

$$PV(SU_i, RA_j) = UV(SU_i) - S(CC_j, AC_j, SU_i) \qquad [4.3]$$

in which we assumed that the appraiser could estimate with certainty both the unaffected value of the site as well as the stigma. However, there are sources of error due to the appraisal process. For example, the unaffected value of any SU_i may be difficult to assess because the appraiser is unable to find a similar site for comparison (i.e., similar amenities, surrounding community). Both UV and S may also be uncertain because much depends on the appraiser's skill to interpret what impact any remaining contamination has on the site value.

The site use benefits were given by,

$$SB(SU_i, RA_j) = PV(SU_i, RA_j) - C_D(SU_i) \qquad [4.4]$$

Factors unrelated to site remediation itself, such as unexpected increases in the cost of materials or labor unrest, can contribute to uncertainties in correctly estimating C_D, or the cost of development.

6.3.2 Uncertainty Due to Information and Buyer Characteristics

The lack of information or misinformation and buyer characteristics may also contribute to the uncertainties of site use benefits to the owner. Potential property buyers are assumed to have "perfect" knowledge about the site and any potential impacts. However, these buyers may be uninformed or even misinformed, and as a result, stigma may not be a concern. Although it seems underhanded to withhold information from potential buyers, it has occurred in property transactions around contaminated sites (Edelstein,1988). Such buyers may unknowingly agree to pay a price that is higher than the appraised property value of the site. Even if such buyers later become "informed" of any impacts at some point and decide to relocate, they may in turn not discount the value of their properties and instead seek a higher price for their property. This could lead to a higher ownership turnover rate.

Furthermore, certain buyers may be less sensitive than others to any potential impacts. The owner may choose not to reduce the site value by effectively ignoring the effects of stigma and simply wait for "insensitive" buyers (Zeiss and Atwater,1989a). However, because there should be a smaller population of such buyers, any land that may pose potential problems should remain on the market for a longer period.

Zeiss (1990) examined these two arguments in the context of sites surrounding a noxious facility, but despite their plausibility, concluded that the postulated outcomes of: 1) increased time on the market, and 2) increased turnover rate, are not supported. Instead, residents may stay and adapt to the facility. Buyers may also be less sensitive to the noxious facility. Edelstein (1988) discovered that buyers may be coming from communities that experience more severe environmental impacts, rendering those posed by the new community less significant.

The effects of information variability and buyer sensitivity may similarly affect buyers considering the owner's site after it has been remediated and redeveloped. The lack of information and/or insensitive buyers may result in the owner realizing benefits different from those predicted by the appraiser. Even if contamination related problems arise at some future point, some site occupants may have adapted to the site conditions, ensuring the owner will still realize some site use benefits (e.g., through rent income). The owner may have a considerable amount of control over the information regarding the site itself (regulations not withstanding). However, this methodology does not advocate the owner engage in unfair or dishonest practices.

There may be also "off-site" factors, such as community opposition, that can affect the owner's benefits. The likelihood that the owner realizes the predicted benefits may be significantly reduced if the community raises legal challenges to the owner's proposals for site remediation and eventual site use. An important implication of the uncertainties surrounding site use benefits is that property value guarantees (PVG's) may be ineffective, although they are often used as a means to entice potential site buyers or appease the community from taking legal action. Zeiss and Atwater (1989b) and Edelstein (1988) suggest this may be because PVG's are an "after-the-fact" measure: the damage is occurring or has already impacted the physical environment of the community.

Based on research by Edelstein (1988), Kiel (1995), and Zeiss (1990), we hypothesize that the accuracy of using property values to evaluate sites in the local community - including the owner's site – is based on the situation of the community. For example:

- Communities that have hosted a contaminated site for many years may be well aware of the health problems and any mitigation measures, and may have well established lines of communication with the site owner. They would have more than likely adapted to the site's existence and its impacts (if any). The community may be more "stable" and as a result, any property value estimates may be more certain than the following situation.
- Communities comprised of young families with children (i.e., concern for their safety), and/or that have just discovered the site poses a potential health problem, could be expected to react strongly to the site. There may be a high degree of uncertainty regarding any property value estimates. Site use benefits may not even materialize for the owner if legal challenges are launched to block the owner's plans for the site.

The owner could examine the community history and its demographics to gauge the community's "acceptance" of any proposed site use and remedial action. This is a rudimentary approach for analyzing the uncertainties behind site use benefits, but may be useful as a preliminary analysis if estimating uncertainty for individual elements (e.g., stigma) proves difficult, particularly at the beginning stages of decision making.

6.4 CONSIDERATIONS IN LIABILITY UNCERTAINTIES

Liability is still generally accepted by environmental consultants as the key factor behind site cleanups (A&WMA Brownfields Workshop,1997) because many owners would like to avoid it. In practice, the owner may prefer to work with conservative estimates to avoid risk. However, many factors used in these estimates may be uncertain. For example, the principal liability conditions specify that the most toxic contaminant out of a mixture should be used to determine the health effects. This assumes that the most toxic component can be determined, and that any health effects will manifest as predicted. The following discussion provides some examples of how uncertainties can arise in the different components of liability. The owner should realize that there may be additional sources of uncertainty unique to his or her situation.

Uncertainties regarding the probability of exposure, *P(AC)*, are related to the uncertainties surrounding the prediction and performance of the various remedial actions. Should remedial actions not perform as expected, AC values could be higher or lower at various locations on-site and at off-site locations.

There are several significant sources of uncertainty when evaluating P(R), the probability of an adverse health response. For example:

- Health data in the literature[2] may be incomplete, inconsistent, or inconclusive.
- There may be disagreements on how the health data should be extrapolated and/or interpreted for the site circumstances (e.g., can the effects of very low doses be accurately determined).
- The validity of the health data may be questioned (e.g., can results from animal studies be applied to human subjects; are clinical conditions the same as those that would be experienced by individuals actually exposed to the contaminant).

For *P(O)*, or the contribution of other factors to liability, lawyers will be needed to provide their opinion on three additional issues that can lead to uncertainty.

- There may be disputes over the "facts" of the site remediation.
- Assuming the facts themselves are not in dispute, there may disagreements over which facts are relevant, and how the facts should be applied to the dispute at hand.
- Assuming all issues regarding the facts have been resolved, there can be uncertainties regarding the interpretation of applicable government regulations, policies, and statutes in determining liability.

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[2] As an example, Saunders et al. (1997) conducted an extensive review of the epidemiological literature and concluded that, "The studies reviewed did not provide convincing evidence of causal relationships between hazardous waste site exposure and adverse human health effects, in particular because of poor exposure measurement."

There are difficulties in estimating the individual financial cost of liability: how can the monetary worth of an individual's demise or illness be accurately assessed? However, the willingness by insurance companies to now offer insurance products for remediation suggests that certain parties have gained experience and judgment when approaching cleanups (Roddewig,1996). Although they may be still controversial, future estimates on the financial cost of liability may be less difficult to estimate.

6.5 EXTREME CASE ANALYSIS FOR UNCERTAINTY

An extreme case analysis, similar to that shown in Chapter Three, gives the range of effects of uncertainty on the owner's net benefits. The owner reapplies the decision methodology using new values provided by the experts that represent the extremes of what could happen, rather than using values for what is likely to happen. This approach is not sophisticated, but does allows the owner to grasp quickly the different situations that could arise. It can also serve as a initial screening tool to decide which situations merit more complicated means of uncertainty analyses (Keeney,1980). Figure 6.2 shows the details of both Steps Six and Seven.

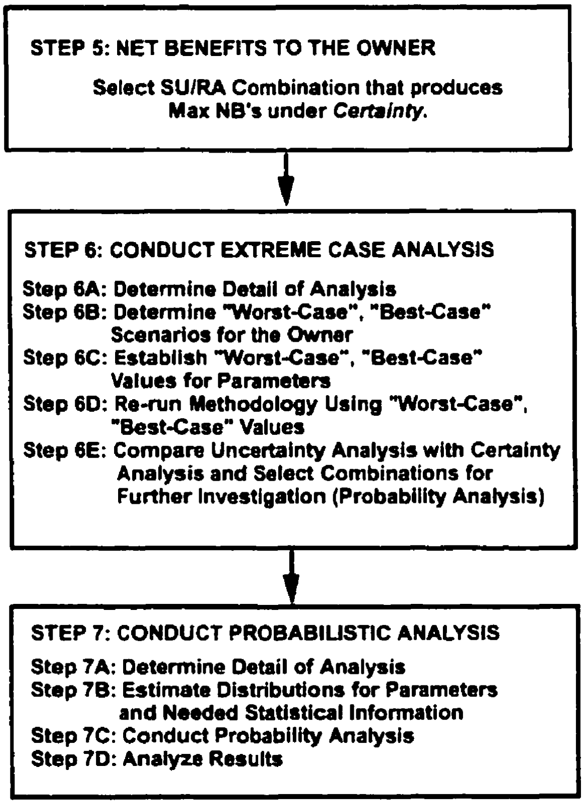

FIGURE 6.2: Steps six and seven of the decision methodology.

6.5.1 Step 6A: Determine Detail of Analysis

For the extreme case analysis, the owner can vary individual parameters that are estimated for the methodology, such as the available concentrations, to determine how his or her net benefits are affected. This would constitute a "micro-level" analysis. Alternatively, the owner can conduct a "macro-level" analysis in which overall parameters are changed, such as the calculated values of liability. There may be several plausible reasons for such an analysis. For example, the appraiser may feel unsure of his/her ability to accurately describe the distributions of the individual components leading up to the site use benefits. Instead, he/she may simply have some idea as to how the overall property values can vary. A combination of a micro- and macro-level analysis may also be appropriate. Figures 4.16a and 4.16b from Chapter Four illustrate how one parameter relates to another and how calculated values are derived, and can be used as a guide to determine which parameters/values – and hence level of analysis - should be varied. The owner needs to determine, in consultation with his or her experts, the level of detail required for the extreme case analysis.

For example, if the owner discovers that the real estate appraiser is uncertain about the estimates for stigma, S, but that the unaffected value, UV, and the cost of development, C_n are known with reasonable certainty, the methodology can be re-run using different values for that one parameter.

Conversely, the owner may opt for varying the overall parameters of site use benefits, remedial costs, and liability if there are significant uncertainties that cannot be easily resolved. For example, if there is a very high level of uncertainty surrounding liability because of a significant lack of information, dividing liability into its respective components of exposure, response, and other factors may not be possible unless the owner expends significant resources to further study the situation. Given these possible difficulties, the owner may simply ask for the lawyer's estimates on how the overall liability, $L(SU_i,RA_j)$, might vary instead of estimating the uncertainties for each liability component.

6.5.2 Step 6B: Determine Owner's "Worst-Case", "Best-Case" Scenarios

Chapter Four used single point estimates for the various parameters in the decision methodology. For analyzing the effects of uncertainty, the decision methodology proposes the owner use values that represent the "worst-case" and "best-case" scenarios. However, instead of restricting the owner to a fixed definition for these two scenarios, the methodology proposes the owner, in consultation with his or her experts, define what constitutes the "worst-case" and the "best-case". This flexibility is important given that the circumstances surrounding site remediation are likely to vary from one site to another.

The owner should determine what *fractiles* constitute the "worst-case" and the "best-case", and then select the values that correspond to these fractiles for the parameters to be varied. Typical fractiles include 0.1, 0.05, 0.01 at one end, and 0.90, 0.95, 0.99 at the other end: the owner can also choose other fractiles that might be appropriate. For example, the appraiser may provide a median property value for a particular site use, or the value at the 0.50 fractile, which would represent the appraiser's point estimate as outlined in Chapter Four. The worst-case might be the property value at the 0.05 fractile, while the best-case might be the property value at the 0.95 fractile.

There are at least two methods for determining these fractiles.

1. Keeney (1980) outlines a method that requires asking the expert a series of questions to establish a probability distribution for a variable based on his or her subjective estimates.
2. For certain parameters, data may be available for determining their distribution. Zeiss and Atwater (1989a), for example, accessed listings of sales prices for their property value analyses.

In both cases, probability distributions are established describing the variable of concern. From these, the owner can select the values from the distribution that correspond to the fractiles that represent the scenarios the owner wishes to consider.

6.5.3 Step 6C: Establish "Worst-Case", "Best-Case" Values for Parameters

The execution of this step depends on: 1) the level of detail to be analyzed, and 2) how the owner has defined what represents extreme scenarios. As an example, Table 6.2 shows some of the parameters that can be chosen; the owner should include whatever parameters he or she deems appropriate using Figure 4.16 as a guide. For illustrative purposes, we use the descriptors "min" and "max" to indicate that the owner substitutes values for the parameters according to his or her "worst-case" and "best-case" descriptions. Table 6.2 also indicates how the different "min" and "max" values could be combined to derive the two extreme scenarios of "worst-case" and "best-case". For example, combining the unaffected value at the 0.10 fractile with the cost of stigma at the 0.90 fractile would significantly decrease the owner's site use benefits, and thus represents a "worst-case" scenario. Note that there would be values for each SU_i/RA_j combination.

TABLE 6.2: Example of combination of parameters for "worst-case" and "best-case" scenarios.

Parameter/Value		*Worst-Case*	*Best-Case*
$SB(SU_i,RA_j)$	UV, Unaffected value	min	max
Site Use	S, Stigma	max	min
Benefits	C_D, Cost of development	max	min
$C(RA_j)$	C_{SI}, Site investigation	max	min
Remedial	C_{IM}, Interim remediaion	max	min
Action Cost	C_{SR}, Remedial action	max	min
	C_{MON}, Monitoring costs	max	min
	C_{ON}, Ongoing costs	max	min
$L(SU_i,RA_j)$[3]	P(AC) Prob. of exposure	max	min
Owner Liability	P(R) Prob. of a health response	max	min
	P(O) Prob. of "other" factors	max	min
	C_L Individual cost of liability	max	min
	... etc.		

6.5.4 Step 6D: Re-run Methodology Using "Worst-Case", "Best-Case" Values

The owner should now re-run the methodology (Steps 2 to 5) using the values he or she has chosen in Step 6C. When the extreme case analysis is complete, the owner should have for every SU_i/RA_j combination considered:

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[3] There are many estimated parameters and calculated values used to determine owner liability. The level of detail of analysis will depend on the information available and the ability of the experts.

- Net benefits based on "normal" values from the certainty analysis from Chapter Four.
- Net benefits based on "worst-case" values.
- Net benefits based on "best-case" values.

6.5.5 Step 6E: Compare Uncertainty Analysis with Certainty Analysis and Select Combinations for Further Investigation

After completing the extreme case analysis, the owner should compare the SU_i/RA_j combination preferred under certainty against the results produced under uncertainty in order to determine which combinations merit further investigation. (Because we now use the terms certainty and uncertainty side-by-side, we stress that in this methodology *certainty* does not mean the results are "guaranteed" to occur. Instead, certainty means the experts have provided values to the best of their ability.)

The owner can perform a qualitative comparison, but to assist the owner, the methodology proposes that the owner rank the combinations according to their net benefits for the certainty and the two uncertainty analyses. Table 6.3 shows an example of this procedure: all entries shown are for illustrative purposes only.

TABLE 6.3: Example of ranking combinations.

Comb.	*"Worst-Case"*	*Certainty*	*"Best Case"*	*Further Investigate?*
SU_0/RA_0	4	4	4	Yes
SU_0/RA_1	5	5	5	No
SU_0/RA_2	6	6	6	No
SU_1/RA_0	3	2	3	No
SU_1/RA_1	1	1	1	Yes
SU_1/RA_2	2	3	2	Yes
... etc.				

Arranging and ranking the combinations is a useful means of screening them and allows the owner to examine how the preferred SU_i/RA_j combination under certainty fares in the worst-case or best-case scenarios. If it is also preferred in these other scenarios, the owner has a reasonable degree of assurance that this particular combination is the one to pursue for remediation. From a practical, decision-making perspective, such agreement would offer the owner a "degree of comfort" in selecting that combination. The methodology proposes

that such a combination be further investigated via a probabilistic analysis because it can reveal additional details important to decision making.
Ranking can also reveal how other combinations, which did not perform as well as the preferred choice under certainty, fare under uncertainty. Such combinations may merit further investigation when considering the owner's attitudes towards risk. In general, people are *risk averse* when making a decision for a situation that only occurs once; that is, people prefer the choice that yields less benefits but is "certain" to occur instead of selecting the choice that is "less certain" but may yield higher benefits (de Neufville,1990)[4].

If we extend the argument above, a risk averse decision maker may not choose the alternative that fares well under "normal" circumstances, but instead choose the alternative that performs better under worse conditions. As an example, the owner may have thought that SU_1/RA_0 in Table 6.3 was a reasonable combination to consider given that it was ranked second from the certainty analysis. However, under the "worst-case", it falls to third place. If the owner is risk averse, and if he or she is only concerned with this one remediation project, SU_1/RA_2 could be a more promising combination for further investigation because it performs better in the "worst-case" than SU_1/RA_0. The opposite situation in which the decision maker is risk-prone is also possible.

In the above discussion, the criteria the owner used for deciding which combinations may require more investigation depended on how well it performed. The owner may also have other criteria, such as regulatory constraints, for selecting combinations for further investigation. For example, in Chapter Five, the preferred combination would unlikely be permitted by regulations. However, the next preferred combination also produced significant net benefits and would possibly be permitted. As a result, the owner would want to include this second combination in the probabilistic analysis.

Lastly, combinations that produce insignificant net benefits under all three cases can most likely be eliminated from further analysis unless the owner has a compelling reason for doing otherwise. This staged approach allows the owner to conserve effort by refining what the probabilistic analysis must consider (Keeney,1980). However, one combination that the owner should not dismiss after the extreme case analysis is the one that represents the *status quo* (e.g., $SU_{\emptyset}/RA_{\emptyset}$). Although it may fare poorly against other combinations in many remediation projects, it is useful as a basis of comparison.

An extension of this methodology would be to perform a sensitivity analysis for an extreme case (e.g., selecting additional values such as 0.95 or 0.99 fractile for the "worst-case") to determine how the SU/RA combination ranking changes.

6.6 PROBABILISTIC ANALYSIS

For the second step of uncertainty analysis, the owner conducts a stochastic probabilistic analysis of the net benefits using estimated probability distributions for the parameters or calculated values to be varied. The results of the probabilistic analysis can provide additional information not revealed by the extreme case analysis and can also serve as a "check" on the expert's estimates for the extreme case analysis. Establishing the distributions needed for a probabilistic analysis may be difficult. Nevertheless, with the input of experts, some plausible but rudimentary characterization may be possible by using techniques such as those outlined by Keeney (1980) (Step 6B above).

6.6.1 Step 7A: Determine Detail of Analysis

As in Step 6A, the owner should select the level of detail for the probabilistic analysis. The owner can opt for a micro-level analysis if there is sufficient data available. This may be possible for "technical" parameters, such as the available concentration, in which modeling efforts from the steps required under certainty may have already produced distributions. Alternatively, a macro-level analysis would consist of using probability distributions to represent his or her benefits, costs, and liability in order to produce a distribution of net benefits for various *SU/RA* combinations. Realistically, the owner may not be able to obtain distributions for certain variables that comprise benefits – and particularly liability – given their qualitative nature. As a result, the owner may choose to run a marco-level probabilistic analysis at the beginning stages of decision making until more information is available.

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[4] Because the situation occurs only once, the decision maker does not have the advantage of seeing the how the

6.6.2 Step 7B: Establish Distributions for Parameters/Values and Needed Statistical Information

TYPES OF DISTRIBUTIONS

The owner should establish the types of probability distributions for the parameters or values he or she has chosen. There are several methods for finding these distributions.

1. In carrying out Steps 2 through 4 of the methodology, the various modeling techniques used may have already established spatial distributions for various parameters upon which to base a probability distribution. We expect that such distributions could be available for technically-oriented variables rather than those that depend on qualitative assessments (e.g., P(O)).
2. The owner may select common distributions, such as a normal distribution, to represent the probability distribution of a particular parameter or value. This requires expert judgment for justifying the selection of one distribution over another.
3. The expert's subjective opinions can be used to describe the probability distribution for a specific parameter or value, as outlined previously in Step 6B.

DETERMINING PARAMETERS FOR DISTRIBUTIONS

The owner also needs to determine the parameter values for the distributions (e.g., means, standard deviations). This may be readily available for item (1) above if there are sufficient data, but may not be as easily obtained for items (2) and (3). For (2), it may be possible to ask the expert for his or her estimate of such statistical parameters (i.e., what is the mean and standard deviation?) (Keeney,1980). For (3), needed parameters may be calculated from the "expert-described" distributions. Keeney (1980) notes that this last alternative may be easier than having the expert directly estimate any needed statistical parameters.

At this point, the owner may find it convenient to arrange all the necessary information into a table, as shown in Table 6.4. The table and its entries are shown for *illustration only*; the level of detail, statistical parameters, and exact values will depend on the owner's situation and available information. Entries are required for each SU_i/RA_j combination.

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outcomes turn out "on average" given many similar situations.

TABLE 6.4: Example of information needed for probabilistic analysis.

Parameter/Value	*Distribution*	*Mean*	*Std. Dev.*
$SB(SU_i,RA_j)$ Site Use Benefits	e.g., normally distributed	μ_{SBij}	σ_{SBij}
$C(RA_j)$ Remedial Action Cost	e.g., lognormally distributed	μ_{Cj}	σ_{Cj}
$L(SU_i,RA_j)$ Owner Liability	e.g., normally distributed	μ_{Lij}	σ_{Lij}

Depending on the circumstances, there may be significant limitations in establishing the probability distributions and required statistical parameters for the probabilistic analysis. We have suggested several means of overcoming this difficulty, but the owner must still overcome:

- A general lack of information or data in the literature regarding the distribution of variables, such as liability. Researching what these distributions are and their characteristics could prove immensely useful to future decision makers.
- Biases in expert judgment. Experts may bias their opinions due to their value judgments, or else may deliberately do so in order to secure a contract from the owner (Keeney,1980). For example, a vendor or consultant may underestimate remediation costs so that the owner favors a particular course of action.
- "Availability" of a similar event in recent memory (Keeney,1980). For example, if a similar site-remediation project recently encountered heavy losses due to liability, estimates for liability components for the remediation project at hand may be higher than otherwise.

More research is needed to improve the robustness of the decision methodology in handling these difficulties.

6.6.3 Step 7C: Conduct Probabilistic Analysis

The owner should establish the procedures for running the probabilistic analysis (e.g., algorithms to be used, the number of runs for the analysis, etc.) based on the distributions and statistical parameters chosen in Step 7B. This methodology will not discuss the mechanics and proper execution of a probabilistic analysis but assumes that the owner has access to experts who can undertake such an analysis. The reader is referred to papers such as Burmaster and Anderson (1994) for additional information regarding probabilistic assessments. At the conclusion of this step, the owner should have probability distributions describing the owner's net benefits for each of the SU/RA combinations considered.

6.6.4 Step 7D: Analyze Probabilistic Analysis Results

The owner should compare the resulting net benefits distribution of each SU/RA combination against each other. Although a probabilistic analysis may not highlight a preferred *SU/RA* combination as clearly, it can provide additional information not revealed in an extreme case analysis. For example, the owner would be able to examine how his or her net benefits vary over their entire range, as opposed to only three net benefits values revealed by the extreme case analysis (i.e., two extremes and a "normal" scenarios).

The methodology proposes the owner perform the following:

- Comparing the measures of central tendency of the net benefits distributions (i.e., mean, median, or mode) should indicate which combination tends to produce the maximum net benefits.
- Comparing the range and the variances of the net benefits distributions indicates the scatter or dispersion of the net benefits. Combinations that have less dispersion indicate the net benefits are more closely clustered around a central value, suggesting that there is less variability behind these net benefits estimates.
- Comparing the shape and extent of the tails of the distributions could be useful for owners who are risk averse or risk prone. Risk averse owners could be expected to avoid combinations that produce distributions with tails that extend significantly into the lower fractiles (i.e., region of minimal net benefits). Risk prone owners however may seek combinations that produce tails extending into the higher fractiles in order to "gamble" on obtaining greater net benefits. It would also be useful to compare these tails to the results of the extreme case analysis in order to see if there is general agreement between the two, or significant disagreement which may be due to errors in either analysis.

The owner can perform additional comparisons if so desired. Guidance can be found in the literature regarding the comparison of distributions (for example, see Dorfman,1967). It is also possible to combine the owner's net benefits distributions with a utility function describing his or her attitude towards risk. The SU/RA combination that produces the highest expected utility would be the preferred choice (de Neufville and Stratford,1971). These more sophisticated means of uncertainty analysis could be included in further research to extend the decision methodology.

6.7 EXTREME CASE ANALYSIS ON ILLUSTRATIVE EXAMPLE

The following section demonstrates how the net benefits of the owner are affected in a "worst" case example following the methodology outlined in this chapter and using the illustrative example presented in Chapter Five. To reduce the number of tables and values that would have to be shown, *the "best" case analysis is not presented*, however, it would be performed in a similar manner. Several important assumptions should be noted.

- Selected values from the illustrative example in Chapter Five have been modified to provide a "worst case" scenario under uncertainty. Except where noted otherwise, we emphasize that all values stated are hypothetical and are not necessarily based on values from the actual case study. This is due in part to the limited data available from the actual case study.
- For simplicity and to reduce the amount of data that needs to be presented, not all parameters from Chapter Five have been modified to account for uncertainty.
- As in Chapters Four and Five, several of the steps have been combined for efficiency.

6.7.1 Step 6A: Determine Detail of Analysis

For the illustrative example, the owner decides that a combined macro-level and micro-level analysis that focuses on intermediate values, such as stigma, is suitable for modeling uncertainty in the extreme case analysis. The owner also feels that sections of the certainty analysis are already conservative because of the principal liability conditions (e.g., assuming the highest AC value occurs uniformly throughout the site) and that re-analyzing such parameters under uncertainty is not necessary.

The owner, however, is less comfortable with values that require a higher degree of subjective estimation, such as P(O). These will be varied to represent the uncertainties caused by the lack of information available for characterizing the values.

6.7.2 Step 6B: Determine Owner's "Worst-Case" Scenario

In consultation with the experts, the owner decides that values at the 0.90 fractile represent the "worst-case". For example, combining the values for the remedial cost and stigma at the 0.90 fractile ("maximum" cost and stigma) should significantly lower the owner's site use benefits. In this illustrative example, all hypothetical values are assumed to represent 0.90 fractile.

6.7.3 Step 6C: Establish "Worst Case" Values for Parameters

UNCERTAINTY IN REMEDIAL COSTS

This example assumes that all four remedial actions *can* achieve their respective AC values shown in Table 5.1. As a result, the AC values are unchanged. In addition, there are also no uncertainties raised regarding the site characterization[5]. However, there have been questions raised regarding the cost estimates: labor, material, equipment, monitoring, and ongoing remedial activities costs are suspected to be more expensive than originally predicted under certainty. As a result, the cost of any RA_i is greater than before, as shown in Table 6.5.

TABLE 6.5: Present value costs of remedial actions under "worst case".

RA	*Description*	*Site Investigation Cost, C_{SI}*	*Cost of RA Itself, C_{SR}*	*Ongoing Costs*	*Monitoring Costs*	*Total Remedial Action Cost($), C_{RA}*
$RA_{\emptyset}$	"Do nothing", except to fence off the site from trespassers.	20 000	0	0	650 000	**670 000**
RA_1	Containment (barrier wall) and encapsulation.	20 000	500 000	50 000	180 000	**750 000**
RA_{2a}	Pump and treat with soil vapor extraction.	20 000	150 000	430 000	180 000	**780 000**
RA_{2b}	As above, but more extensive.	20 000	200 000	600 000	100 000	**920 000**

UNCERTAINTY IN THE SITE USE BENEFITS

For simplicity, the unaffected value of any site use, UV_i, and its cost of development, CD_i, remain unchanged from Chapter Five. However, in this example the appraiser is assumed to have relatively little experience with remediation projects and thus has difficulties in assessing stigma. Stigma estimates should be increased to account for uncertainties in his/her ability. Table 6.6 shows the stigma values given uncertainties behind their estimation, while Table 6.7 gives the modified site use benefits.

TABLE 6.6: Stigma for each potential on-site SU/RA combination under "worst case".

Site Use, SU	*Remedial Action, RA*	*CC Approx.*	*AC Approx.*	*Estimated Stigma, S ($)*
SU_0 None	RA0: none	High	High	**0**
	RA1: contain	High	Low	**0**
	RA2a: P&T;SVE	Mod-Low	Low	**0**
	RA2b: P&T;SVE	Low	Low	**0**
SU_1 Service Station	RA0: none	High	High	**0**
	RA1: contain	High	Low	**0**
	RA2a: P&T;SVE	Mod-Low	Low	**0**
	RA2b: P&T;SVE	Low	Low	**0**
SU_2 Houses	RA0: none	High	High	**600 000**
	RA1: contain	High	Low	**400 000**
	RA2a: P&T;SVE	Mod-Low	Low	**200 000**
	RA2b: P&T;SVE	Low	Low	**150 000**

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[5] In reality, more information about the site characteristics and contamination could be discovered during the implementation of a remedial action. This could lead to different AC values, changes in remedial actions, different costs, or a combination of all three.

TABLE 6.7: Summary of values used to determine the owner's site use benefits under "worst case".

Site Use, SU	*Remedial Action, RA*	*Unaffected Value, UV ($)*	*Estimated Stigma, S ($)*	*Property Value, PV($)*	*Cost of Develop C_D ($)*	*Site Use Benefits, SB ($)*
SU_0 None	RA0: none	0	0	0	29 500	0
	RA1: contain	0	0	0	29 500	0
	RA2a: P&T;SVE	0	0	0	29 500	0
	RA2b: P&T;SVE	0	0	0	29 500	0
SU_1 Service Station	RA0: none	3 246 000	0	3 246 000	2 000 000	1 246 000
	RA1: contain	3 246 000	0	3 246 000	2 000 000	1 246 000
	RA2a: P&T;SVE	3 246 000	0	3 246 000	2 000 000	1 246 000
	RA2b: P&T;SVE	3 246 000	0	3 246 000	2 000 000	1 246 000
SU_2 Houses	RA0: none	2 250 000	600 000	1 650 000	1 500 000	150 000
	RA1: contain	2 250 000	400 000	1 850 000	1 500 000	350 000
	RA2a: P&T;SVE	2 250 000	200 000	2 050 000	1 500 000	550 000
	RA2b: P&T;SVE	2 250 000	150 000	2 100 000	1 500 000	600 000

UNCERTAINTIES IN LIABILITY

Uncertainties in liability are affected by uncertainties in exposure, health response, "other" factors, and the financial cost of liability. We assume here that there are no uncertainties in exposure (AC). The probability of exposure P(AC) is still equal to "one" for the values of AC (all other AC values have a probability of zero) assumed in Chapter Five. However, in this example, since there is uncertainty in the health data, new "worst-case" P(R) values are estimated. These are assumed to be approximately one order of magnitude greater than those used in Tables 5.7 and 5.8, and are shown in Tables 6.8 and 6.9.

TABLE 6.8: Estimated $P(R_{SON})$ and $P(R_{LON})$ on-site under "worst case".

RA	*Description*	*AC (mg/m^3) On-site*	*$P(R_{SON})$*	*$P(R_{LON})$*	*Comments*
RA_0	"Do nothing".	0.24	0	0.020	
RA_1	Containment and encapsulation.	0	0	0	For RA_1, the health specialist does not estimate a "worst case" $P(R_{LON})$ value because the remediation specialist still predicts containment will work. There is no AC exposure "data" that the health specialist can use as a basis for judgment.
RA_{2a}	Pump and treat with soil vapor extraction.	0.0061	0	5.0×10^{-4}	
RA_{2b}	As above.	0.0034	0	3.0×10^{-4}	

TABLE 6.9: Estimated $P(R_{SOFF})$ and $P(R_{LOFF})$ at off-site locations under "worst case".

Off-site	*Boundary/Parkette*			*Houses*			*School*		
RA	*AC mg/m^3*	*$P(R_{SOFF})$*	*$P(R_{LON})$*	*AC mg/m^3*	*P (R_{SOFF})*	*P (R_{LOFF})*	*AC mg/m^3*	*P (R_{SOFF})*	*P (R_{LOFF})*
RA_0	0.054	0	5.0×10^{-3}	0.046	0	4.0×10^{-3}	0.039	0	2.5×10^{-3}
RA_1	0	0	0	0	0	0	0	0	0
For RA_1, the health specialist does not estimate a "worst case" $P(R_{LON})$ value because the remediation specialist still predicts containment will work. There is no AC exposure "data" that the health specialist can use as a basis for judgment.									
RA_{2a}	0	0	0	0.0029	0	3.0×10^{-4}	0.0016	0	1.5×10^{-4}
RA_{2b} As above.	0	0	0	0.0025	0	2.5×10^{-4}	0	0	0

There is also uncertainty about the P(O) estimates. As a result, new P(O) values representing the 0.90 fractile for any given SU/RA combination are provided. Table 6.10 shows the values for $P(O_{ON})$ and $P(O_{OFF})$. Although the methodology allows for each off-site location to have a different $P(O_{OFF})$ values, we assume that the stated value for $P(O_{OFF})$ applies for all off-site locations.

TABLE 6.10: Probability of "other" liability factors under "worst-case".

Site Use, SU	*Remedial Action, RA*	*$P(O_{ON})$*	*$P(O_{OFF})$*	*Comments*
$SU_{\emptyset}$ None	$RA_{\emptyset}$: none	0.9	0.9	Estimated to be "0.9" because no remedial action is even attempted; seen as owner irresponsibility.
	RA_1: contain	0.25	0.25	Estimated to be "0.25" because even though there is no site use, remedial actions are still performed.
	RA_{2a}: P&T;SVE	0.25	0.25	As above.
	RA_{2b}: P&T;SVE	0.25	0.25	As above.
SU_1 Service Station	$RA_{\emptyset}$: none	0.9	0.9	Estimated to be "0.9" because no remedial action is even attempted; seen as owner irresponsibility.
	RA_1: contain	0.35	0.45	Estimated to be "0.35" on-site. Although it is only being used for commercial purposes, RA_1 does not address the contamination source. Estimated to be "0.45" off-site because off-site locations will have children, but the nearby contamination source is untreated and only contained.
	RA_{2a}: P&T;SVE	0.25	0.25	Estimated to be "0.25" because unlike containment, the source of the contamination is being treated with RA_{2a}.
	RA_{2b}: P&T;SVE	0.20	0.20	Estimated to be "0.20" because RA_{2b} is more effective than RA_{2a}.
SU_2 Houses	$RA_{\emptyset}$: none	0.95	0.95	Estimated to be "0.95" because no remedial action is even attempted with expected influx of families.
	RA_1: contain	0.45	0.45	Estimated to be "0.45" off-site because both on-site and off-site locations will have children, but the contamination source is untreated and only contained.
	RA_{2a}: P&T;SVE	0.25	0.25	Estimated to be "0.25" because unlike containment, the source of the contamination is being treated with RA_{2a}.
	RA_{2b}: P&T;SVE	0.20	0.20	Estimated to be "0.20" because RA_{2b} is more effective than RA_{2a}.

The individual financial cost of cancer and death for the worst case could, for example, be estimated by finding the 0.90 fractile of what has been awarded for damages in similar remediation-related projects in the past. For illustrative purposes, we assume these costs as shown in Table 6.11 are 33% greater than those assumed under certainty in Chapter Five. For simplicity, the number and types of receptors and the discount rate of 5% remain unchanged from Chapter Five.

TABLE 6.11: Individual financial cost of liability under "worst case".

Health Condition	*Type of Receptor*	*Individual Financial Cost of Liability*
Incurable cancer and death.	Adult	$2 000 000
	Child	$4 000 000

Table 6.12 presents the financial cost of liability to the owner for each site use and remedial action combination in this example. The accompanying spreadsheet in Appendix C illustrates how the liability components were combined.

TABLE 6.12: Financial cost of liability to owner for SU/RA combinations under "worst case".

Site Use, SU	*Remedial Action, RA*	*Estimated Financial Cost of Liability ($)*
$SU_{\emptyset}$ None	$RA_{\emptyset}$: none	812 800
	RA_1: contain	0
	RA_{2a}: P&T;SVE	12 800
	RA_{2b}: P&T;SVE	600
SU_1 Service Station	$RA_{\emptyset}$: none	853 500
	RA_1: contain	0
	RA_{2a}: P&T;SVE	13 100
	RA_{2b}: P&T;SVE	600
SU_2 Houses	$RA_{\emptyset}$: none	1 545 000
	RA_1: contain	0
	RA_{2a}: P&T;SVE	17 400
	RA_{2b}: P&T;SVE	2600

Table 6.12 reveals that liability ranges from a low of $0 to a high of $1 545 000. Despite significant increases in the amount of liability compared to the liability values in Table 5.13, liability appears insignificant for most combinations (i.e., less than $20 000), even for the remedial actions (RA_{2a}, RA_{2b}) that do not benefit from the assumption of "perfect performance" and therefore zero liability (i.e., RA_1, containment)[6]. However, liability has increased dramatically for all $RA_{\emptyset}$ combinations, mostly due to the "worst-case" P(R) values.

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[6] Even if the containment option were to fail completely, its liability may not be anymore than that produced by $RA_{\emptyset}$ ("do nothing") for the same site use, and most likely even less because the containment could be expected to hold the contaminant for at least some period of time, reducing the period of unmitigated exposure.

6.7.4 Step 6D/6E: Re-run Methodology Using "Worst-Case" Values and Compare with Results from Certainty Analysis

Table 6.13 summarizes the financial net benefits to the owner under various combinations of remedial actions and site uses for both the certainty analysis from Chapter Five, and the "worst case" analysis in this chapter.

TABLE 6.13: Financial net benefits to the owner under certainty and uncertainty.

UNDER CERTAINTY

All values in ($)	$RA_{\emptyset}$: Do nothing	RA_1: Contain/Cap	RA_{2a}: P&T;SVE	RA_{2b}: P&T;SVE
$SU_{\emptyset}$: None	-667 000	-600 000	-580 000	-730 000
SU_1:Service station	605 000	676 000	695 000	546 000
SU_2: Houses	-354 000	-70 000	49 000	-25 000

UNDER UNCERTAINTY – 'WORST CASE"

All values in ($)	$RA_{\emptyset}$: Do nothing	RA_1: Contain/Cap	RA_{2a}: P&T;SVE	RA_{2b}: P&T;SVE
$SU_{\emptyset}$: None	-1 512 000	-780 000	-822 000	-950 000
SU_1:Service station	-277 000	496 000	453 000	325 000
SU_2: Houses	-2 065 000	-400 000	-247 000	-323 000

In addition, the combinations are ranked as shown in Table 6.14.

TABLE 6.14: Ranked site use/remedial action combinations to be analyzed for probabilistic analysis.

Comb.	*"Worst-Case"*	*Certainty*	*Further Investigate?*
$SU_{\varnothing}/RA_{\varnothing}$	11	11	Yes; represents status quo.
$SU_{\varnothing}/RA_1$	8	10	No.
$SU_{\varnothing}/RA_{2a}$	9	9	No.
$SU_{\varnothing}/RA_{2b}$	10	12	No.
$SU_1/RA_{\varnothing}$	5	3	No; although it performs well under certainty, there are other combinations that perform better in *both* analyses.
SU_1/RA_1	1	2	Yes; it is the preferred combination under uncertainty, and performs well under certainty.
SU_1/RA_{2a}	2	1	Yes; it is the preferred combination under certainty, and performs well under uncertainty.
SU_1/RA_{2b}	3	4	No; there are two other combinations that produce higher NB's. However, the actual NB's produced are still positive and significant.
$SU_2/RA_{\varnothing}$	12	8	No.
SU_2/RA_1	7	7	No.
SU_2/RA_{2a}	4	5	No.
SU_2/RA_{2b}	6	6	No.

The relative rankings for most SU/RA combinations based on this "worst-case" analysis are similar to those from the certainty analysis, but there are several significant exceptions.

The SU_1 (service station) with the $RA_{\varnothing}$ (do nothing) combination that produced positive net benefits for the owner under certainty did not do so under uncertainty because of the increased liability in the "worst-case" scenario. The other remaining combinations involving $RA_{\varnothing}$ also produced much lower net benefits. However, all remaining SU_1 combinations fared well when compared to the other site uses in both analyses. This is probably due to the greater site use benefits generated by the service station as compared to the residential or no site use alternatives, and the fact that some form of remedial action reduces liability.

The SU_2/RA_{2a} produced positive net benefits for the owner under certainty, but not under uncertainty. This is mostly the result of increases in remedial costs and stigma under uncertainty, instead of liability.

Based on the arguments presented earlier in Step 6E, three combinations will be selected for further investigation via a probabilistic analysis: $SU_{\varnothing}/RA_{\varnothing}$, SU_1/RA_1, and SU_1/RA_{2a}.

- The $SU_{\varnothing}/RA_{\varnothing}$ combination produces significant negative net benefits but it will still be analyzed because it represents the status quo as described in our illustrative example and serves as a basis for comparison.
- SU_1/RA_1 and SU_1/RA_{2a} are the top-ranked combinations in both the certainty and uncertainty analyses. SU_1/RA_1 is preferred under uncertainty while SU_1/RA_{2a} is preferred under certainty. However, the actual difference in net benefits between the two combinations is minimal: the probabilistic analysis may reveal additional information to help the owner decide which is the preferred combination.
- The extreme case analysis and ranking of combinations explicitly demonstrates what might have been intuitively decided by a risk-averse owner: the SU1/ $RA_{\varnothing}$ is not a "good" alternative to pursue despite its performance under certainty. In this example, a risk averse owner has some assurance that the two top choices perform well in both "worst-case" and in the certainty scenario.
- The remainder of the combinations will not be examined since they do not produce significant net benefits and the owner does not have a compelling reason to do otherwise. However, the owner may still find the remaining analysis useful should the circumstances change. For example, SU_1/RA_{2b} did not maximize the owner's net benefits but it did produce significant net benefits. This may be option for the owner to pursue if other stakeholders demand a more aggressive remedial action than RA_1 or RA_{2a}.
- As stated in Section 6.5.5, the owner can perform a sensitivity analysis to determine how the rankings of different SU/RA combinations change if different fractiles are selected.

6.8 PROBABILISTIC ANALYSIS OF ILLUSTRATIVE EXAMPLE

For the second part of our uncertainty analysis, a probabilistic analysis is performed on the illustrative example. The following describes the details of the analysis as outlined in Step 7 of the methodology.

6.8.1 Step 7A:Determine Detail of Analysis

To simplify this example, we assume the owner opts for a macro-level analysis when conducting the probabilistic analysis on the three selected SU/RA combinations. The owner is reasonably satisfied with the results from the extreme case analysis, but would like to see if the probabilistic analysis reveals additional details on a general level. Only the overall benefits, costs, and liability will be modeled as distributions. Furthermore, in the instance of liability, it may be both difficult and inefficient to isolate specific aspects of liability given the relatively small impact it has on the net benefits of most SU/RA combinations.

6.8.2 Step 7B: Establish Distributions for Parameters/Values and Needed Statistical Information

The owner depends on expert judgment to establish the type of probability distributions to be used as well as any needed statistical parameters.

TYPES OF DISTRIBUTION

Based on expert judgment, the following assumptions are used to model the owner's benefits, costs, and liability in this illustrative example.

- Site use benefits are normally distributed.
- Costs are lognormally distributed. Most costs could be expected to cluster around the specified mean, but remediation costs could increase significantly if an unforeseen problem arises.
- Liability is modeled as a combination of a density and a mass function. Based on our arguments in Chapter Four, there is a finite probability that the owner will not be found liable. Thus, for this illustrative example only, there is a probability that $P(L=0)$ is positive. The remaining probability represents $P(L>0)$, and is assumed to be normally distributed given the lack of data to suggest otherwise.

DETERMINING PARAMETERS FOR DISTRIBUTIONS

To determine the mean values for the benefits and costs, the same values calculated in Chapter Five are used for the respective SU_i or RA_j. For this example, these values likely represent – or are at least very close to - what the mean value might be for that variable. Standard deviations have also been provided for each distribution. Both are shown in Table 6.15.

Liability has two parts: 1) no liability, which is modeled as an impulse probability, $P(L=0)$; and 2) as a normal distribution for $P(L>0)$. Also, the liability means (and standard deviations) are the same for cases (2) and (3) of the probabilistic analysis. In this example, if the remedial action fails and allows the contaminant to escape, it is as if no remedial action was pursued for that site use (i.e., $SU_1/RA_\varnothing$). The difference in remedial actions is reflected in the P(L=0) values. All hypothetical P(L=0) values have been chosen to reflect the circumstances surrounding any particular combination. In Table 6.15, for case 1, P(L=0) is equal to 0.20, indicating that the owner is very likely to be found liable. Although no site use is foreseen, the contamination is unchecked and will in all likelihood migrate off-site and impact off-site receptors. In case 2, P(L=0) increases to 0.60 because the contamination will be contained while the owner develops a service station. In case 3, P(L=0) increases to 0.80 because the contamination will actually be removed.

Values for the standard deviations[7] are shown in Table 6.15. However, these estimates may not be very accurate and with more information and research, better estimates may be possible. The standard deviations for liability are quite large compared to the means, reflecting the generally little data available and the often highly contentious nature of liability. Calculating the standard deviation of the cost may also be difficult because of the often proprietary nature of cost information, although there may be more data available than for liability. Of the three, calculating the standard deviation for the site use benefits may be the most feasible because of more readily accessible data (e.g., appraisal and property value databases). As a result, the coefficients of variations for the site use benefits and costs in Table 6.15 are not as large as those for liability.

TABLE 6.15: Data used for probabilistic analysis.

Case	SU/RA Combination	Site Use Benefits (mean & standard deviation) *Normal dist.*	Cost of Remediation (mean & standard deviation) *Lognormal dist.*	Liability (mean & std. dev.; probability of *no* liability) *Mass function & normal dist.*
1	$SU_\varnothing/RA_\varnothing$	μ_B= -29 500 σ_B= 10 000	μ_C= 560 000 σ_C= 100 000	μ_L= 77 800 σ_L= 35 000 P(L=0)= 0.20
2	SU_1/RA_1	μ_B= 1 246 000 σ_B= 150 000	μ_C= 570 000 σ_C= 100 000	μ_L= 81 000 σ_L= 40 000 P(L=0)= 0.60
3	SU_1/RA_{2a}	μ_B= 1 246 000 σ_B= 150 000	μ_C= 550 000 σ_C= 75 000	μ_L= 81 000 σ_L= 40 000 P(L=0)= 0.80

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[7] The standard deviations were chosen to be reasonable estimates and provide interesting results for illustrative purposes.

6.8.3 Step 7C: Conduct Probabilistic Analysis

For this illustrative example, the following was performed.

- A Monte Carlo simulation was performed to randomly sample distributions for the benefits, costs, and liabilities to determine the distribution of the owner's net benefits.
- Visual basic programs in Microsoft Excel97 were written to perform the probabilistic analysis. The distributions were sampled 5000 times. For each iteration, the net benefits were calculated by subtracting the randomly sampled cost and liability from the benefits.
- The means, standard deviations, and shapes of the random sampling distributions were checked to ensure that the probabilistic analysis was performing correctly. Although more rigorous statistical tests can be performed, these measures were assumed sufficient for demonstrating how the probabilistic analysis can be used in the decision methodology.
- The randomness leading to the uncertainties of the benefits, costs, and liabilities are assumed to be independent of one another.

Figures 6.3a to 6.3c display the net benefits distributions, shown as histograms, to the owner for each SU/RA combination. For comparison purposes, the net benefits values for each combination from the extreme case analysis have been manually drawn on the figures. Appendix D shows the individual distributions for the benefits, costs, and liability for each SU/RA combination, while Appendix E shows the Excel 97 Visual Basic programs that were written to perform the probabilistic analysis.

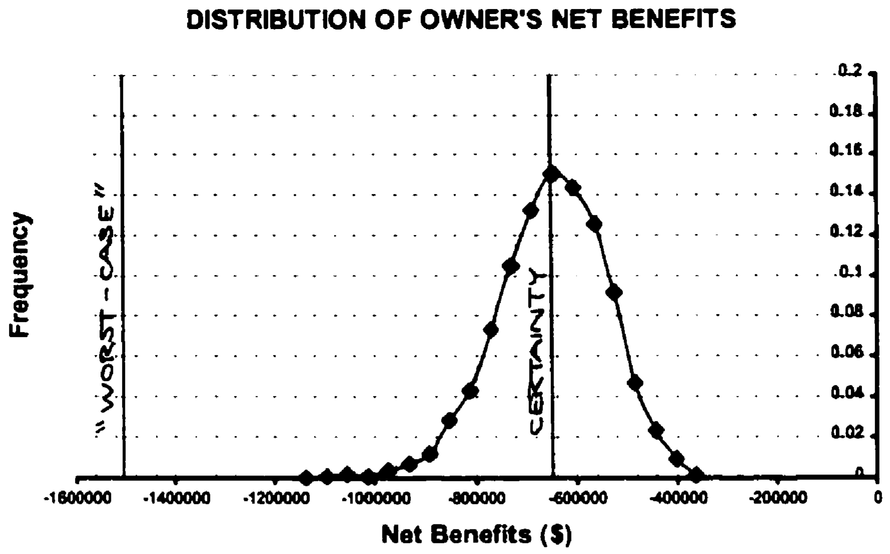

FIGURE 6.3a: Net benefits for $SU_{\emptyset}/RA_{\emptyset}$.

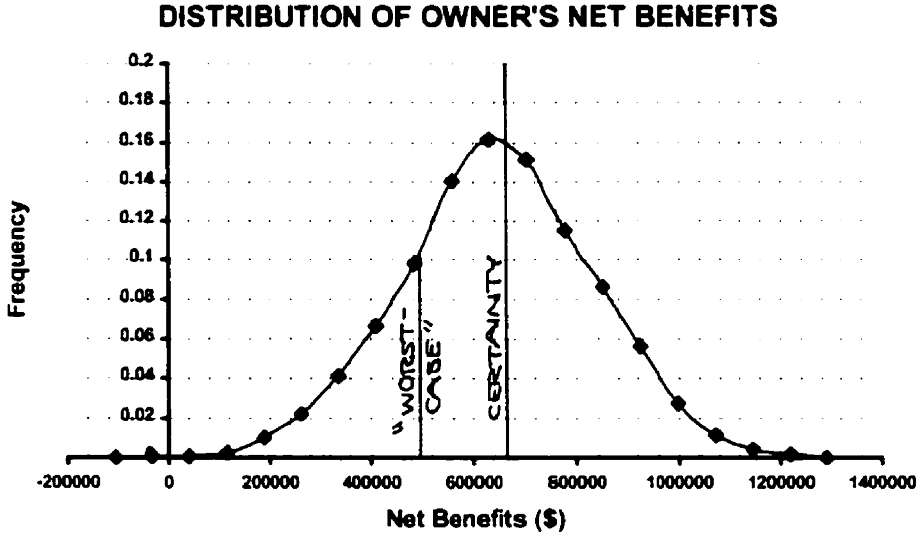

FIGURE 6.3b: Net benefits for SU_I/RA_I.

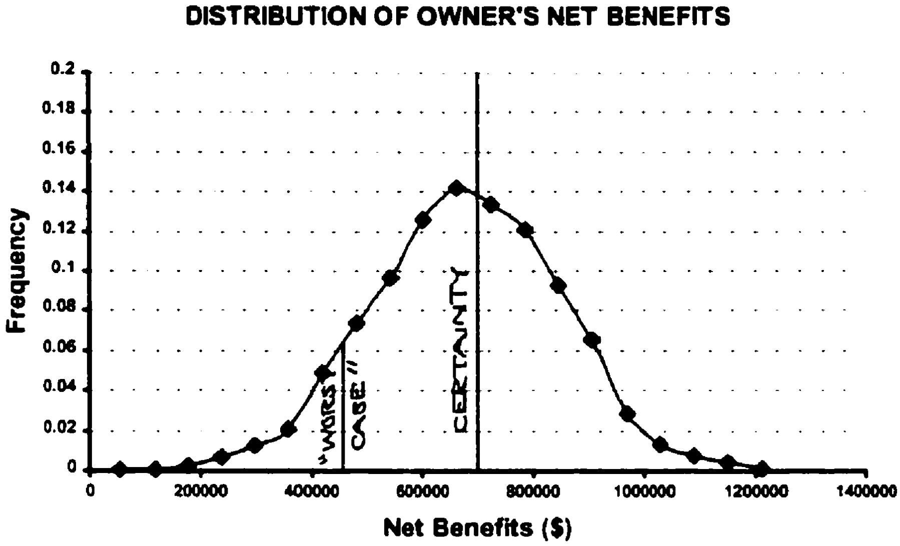

FIGURE 6.3c: Net benefits for SU_1/RA_{2a}.

The net benefits from the certainty analysis fall at the approximate centres of the net benefits distributions produced by the probabilistic analysis. Conversely, the worst case net benefits which were calculated using the 0.10 fractiles for selected parameters do not appear to lie at the corresponding 0.10 fractile on the probabilistic analysis distributions. In this example and more generally, they would not coincide exactly because:

- The information and assumptions used in developing the probabilistic analysis may not be consistent with those used to formulate the values at the chosen fractiles in the extreme case analysis. The experts, when formulating their opinions, may also not be using the same information in a consistent manner from one step of the uncertainty analysis to another.
- There may also be theoretical considerations that can lead to discrepancies between the results from point-value analyses and those from probabilistic analyses, as shown by Cullen (1994) for health risk estimates.

6.8.4 Step 7D: Analyze Probabilistic Analysis Results

The net benefits distributions for both SU_1/RA_1 and SU_1/RA_{2a} combinations indicate that the owner is likely to garner positive net benefits; there appears to be very little chance that the owner will "lose" money. From an economic perspective, these combinations merit serious consideration by the owner. Both produce distributions centred at approximately the same mean (just under $700 000) and both appear to have similar frequencies of occurring.

The results of the probabilistic analysis generally support the conclusions of the extreme case analysis, but in this example, it does not provide enough information for the owner to identify clearly the preferred SU/RA combination. Both combinations appear to have approximately the same spread of values, ranging from $0 up to $1 200 000. This is not surprising since both had similar costs, and liability is not as significant a factor because of the low exposure concentrations. The SU_1/RA_1 combination does appear to have a slightly greater range of positive net benefits because points are plotted further out along the tails than for SU_1/RA_{2a}. This may simply be a result of the low resolution of the graphical output. In this specific example, one combination is not clearly superior to the other.

The probabilistic analysis, however, still provides information relevant to decision making. The net benefits distribution for the $SU_\emptyset/RA_\emptyset$ combination does not produce significant benefits to the owner. The high cost of remediation appears to have "pushed" the net distribution curve well into the negative range and has a much more significant impact than liability. The analysis further indicates that the status quo is not beneficial to the owner. A risk averse owner would also have further assurance that the two top choices perform well through the entire range of net benefits even under uncertainty. In general, this illustration of how the net benefits vary over a range would be useful to risk averse or risk prone owners: the extreme case analysis only presented specific point estimates. Although the latter is perhaps easier to interpret and to use in the initial stages of decision making, by using both approaches, the owner can better interpret the effects of uncertainty on decision making.

If this example were an actual remediation project, the owner could use other criteria for making a final decision. This could include examining how regulations or other stakeholders, such as the community, prefer one SU/RA combination to the other, and thus what additional tradeoffs the owner might have to consider. The owner could also perform additional studies by focusing the uncertainty analysis on factors, such as the discount rate, not varied the first time.

6.9 CONCLUSION

This chapter demonstrated how uncertainty can be incorporated into the decision methodology, and how understanding the issues that contribute to uncertainty (e.g., the property value controversy) can improve our analysis to better prepare decision makers.

A two-step approach using an extreme case analysis and a probabilistic analysis was proposed for examining uncertainty. While there are advantages and disadvantages[8] of the extreme case analysis (point analysis) versus the probabilistic analysis (Monte Carlo simulation), the two-step approach takes advantage of both analyses where they can be most useful.

1. The simpler extreme case analysis allows uncertainty to be readily understood and more easily communicated. Furthermore, it can also act as a screening mechanism: only plausible solutions or situations need be examined by more sophisticated or computationally intensive methods.
2. The probabilistic analysis reveals more details about how uncertainty can vary in specific circumstances. However, sophisticated methods will require more data to operate successfully; such data may or may not be obtainable. For example, in our illustrative example, assumptions about the distributions and other statistical data were required. Any results should be discussed with respect to the circumstances under which the analysis was conducted.

Even if a single preference is not clearly indicated at the end of the uncertainty analysis, the owner has rationally eliminated choices that are unlikely to prove beneficial while highlighting the ones that merit serious consideration using a structured, transparent process. However, more research is needed in order to better characterize the statistical parameters and to interpret expert opinions used to describe uncertainty. The final chapter suggests what further research should be undertaken.

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[8] Hattis and Burmaster (1994) discuss the advantages and disadvantages in a health assessment context.

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Chapter Seven: Conclusion

This research developed a decision methodology for helping the owner of a contaminated site select: 1) the preferred remedial action, and 2) the preferred site use for a contaminated site. Site remediation is currently a pressing environmental concern, especially as more jurisdictions advocate *brownfields* redevelopment. Existing decision methodologies and regulatory regimes often incompletely or inadequately address many of the issues important in site remediation. This research attempts to bridge some of these deficiencies by devising a methodology that incorporates concepts and techniques from a wide range of disciplines relevant to site remediation. In this final chapter, we summarize the major elements of the decision methodology, emphasize its contribution to site remediation, and discuss what further research is needed.

7.1 SUMMARY OF THE DECISION METHODOLOGY

The decision methodology is a framework into which the various issues of site remediation can be placed in context and assessed from the owner's perspective. We began the research by reviewing existing methodologies and what problems needed to be addressed. In general, most existing decision methodologies developed for site remediation:

- focus on the technical aspects of remediation;
- assume implicitly that the site owner had already chosen a future site use;
- depend on achieving regulatory compliance;
- frequently do not provide guidance on how to acquire and interpret any needed information;
- usually do not consider other stakeholder interests (e.g., local community) in the decision process; and
- usually restrict themselves to technical uncertainties and do not address, for example, economic uncertainties.

Even though new regulatory approaches (e.g., RBCA) offer greater clarity and flexibility in site cleanups, they remain largely "procedural" devices and offer relatively little insight on how to address these issues.

Three important issues were identified that are generally not adequately addressed in existing methodologies:

1. There are often conflicting objectives for each stakeholder (e.g., cost vs. liability);
2. There are general site uses that are possible; and
3. There are various types of uncertainties that are often not fully understood or even addressed.

Using a simple, hypothetical example of site remediation, we illustrated how these three issues might affect decision making for a contaminated site. Not unexpectedly, the example illustrated that decisions favored by one party may not fulfill the desires of another. The owner may, for example, decide to abandon the site if he or she face negative net benefits in certain situations. Furthermore, the example established the basic framework for the proposed decision methodology. The owner's decisions are examined through the economic objectives of minimizing remedial costs, maximizing site use benefits, and minimizing liability. The preferred solution produces the maximum net economic benefits to the owner. The local community may also share similar objectives, such as maximizing site use benefits, but is also assumed to want to minimize any health impacts.

The remainder of this research concentrated on devising a straightforward, economically-based methodology for the owner to assist him or her in selecting the preferred site use (SU)/remedial action (RA) combination. To facilitate this, concepts and expert opinion from a diverse range of disciplines were brought together under a single framework. The methodology proposed five steps that help determine the owner's benefits, costs, and liability given various situations.

1. Step One requires the site be investigated. All significant characteristics should be identified and the owner should begin identifying principal liability conditions. These are the situations or circumstances in which liability can be expected to occur and help guide the user in selecting the variables in later analysis (e.g., which contaminant should be studied).
2. Step Two involves estimating the performance and costs of various remedial actions that can be realistically used to clean the site. The methodology emphasizes that outside

expertise is needed: vendors of various remedial technologies and/or remediation specialists will have to provide the owner with this information.

3. Step Three requires estimating the possible site use benefits for the owner given all site uses and remedial actions considered. Property appraisers will be needed to perform the site valuation. Site appraisal should also account for stigma, which results from the concerns or fears of potential buyers of the future site regarding any contamination remaining on the site. Stigma may decrease the property value and hence decrease the site use benefits the owner might receive.
4. Step Four estimates the liability the owner may face given different SU/RA combinations. Liability is itself subdivided into four components:
   - The potential for exposure to any remaining contamination after remediation. This is evaluated by considering the fraction of site space at any level of contamination, which can be estimated by the vendor or the consultant.
   - The likelihood that an adverse health response will occur, which can be evaluated by considering the available health response data (e.g., dose-response curves) and/or consulting with health experts.
   - The probability of "other" factors contributing to the owner actually being found liable in a court of law. Lawyers can be asked to estimate this probability based on criteria such as the due diligence demonstrated by the owner, the severity of the contamination, etc.
   - The financial cost of liability for each individual that might be affected by the contamination. Lawyers could also be asked to estimate this cost.

   The above components, when combined, determine the owner's liability.
5. Step Five involves calculating which SU/RA combination produces the most net economic benefits to the owner. From his or her perspective, this combination is the preferred solution.

These steps were then applied to an illustrative example to demonstrate how it can be applied; specifically, what information was needed and how it could be incorporated. Simplifying assumptions were used throughout in order to produce a manageable case study. Finally, we also demonstrated briefly how imposing a regulatory framework limits the choices available to the owner.

In the final stage of the methodology, we included the effects of uncertainty and considered how they might affect the decision methodology. We examined:

- The general considerations for analyzing uncertainty. For example, we emphasized that techniques exist for soliciting from experts opinions regarding uncertainties about their own estimates.
- What factors can lead to uncertainty behind each of the owner's objectives (i.e., benefits, costs, and liability).
- The techniques through which uncertainty would be incorporated into the methodology. Specifically, uncertainty would be modeled using: i) an extreme case analysis that compared extreme scenarios under uncertainty (e.g., "worst case and best case") and the expected case examined previously under certainty; and ii) a stochastic probabilistic analysis that would require estimating distributions for the owner's benefits, costs, and liability. Both approaches analyze the effect of uncertainty on the owner's net benefits and hence the preferred SU/RA combination.
- Lastly, these approaches were applied to the illustrative case study presented previously in order to demonstrate how the methodology can be used.

7.2 CONTRIBUTION TO SITE REMEDIATION

This research has made several significant advancements in how decisions are made for site remediation.

1. This methodology provides explicit guidance on how needed information can be acquired and interpreted for decision making. Existing methodologies usually state what information is needed but not how it can be obtained. Moreover, this methodology is adaptive: extensive resources or complex analytical methods are not needed in the beginning stages of decision making. However, it can adapt to more sophisticated analyses as more information becomes available.
2. The methodology does not restrict itself from the outset to finding the remedial action that best serves a predetermined site use but recognizes that different combinations of remedial actions and site uses are possible. It helps the owner select the preferred site use and remedial action combination by rationally and comprehensively examining relevant factors. Similarly, the methodology does not limit itself to regulatory

constraints but examines what combinations are desirable based on the owner's benefits, costs, and liability. The owner can then consider how regulations may restrict these choices.

3. In the past, liability has been frequently mentioned but often not fully explained. This research appears to be the first treatment that acknowledges and attempts to integrate the different factors contributing to liability in a site remediation context. It also acknowledges the contribution of "other" factors to liability, a factor that although possibly implied, appears to have been rarely acknowledged explicitly in the decision methodologies currently in the literature. Moreover, by acknowledging "other" liability factors, this methodology recognizes variables that are not - nor will likely ever be - easily quantifiable but nevertheless can have a significant impact on decision making for site remediation.
4. The methodology attempts to be as comprehensive as possible through its explicit use of concepts, techniques, and expertise from several diverse fields (e.g., real estate appraisal to health assessment). The underlying mechanism for decision making is simple: select the site use/remedial action combination that maximizes the owner's net benefits. The challenge is in explicitly recognizing what factors are needed from which disciplines, how they can be used to evaluate the owner's objectives, and then integrating them into a single, coherent methodology that aids the owner in decision making. This methodology may also be advantageous when the owner must present his or her analysis to other stakeholders.

This decision methodology adopts a fundamentally different approach from existing methodologies when assisting the owner to make decisions regarding site remediation. We emphasize that the purpose of this methodology is to help inform decision-making from the owner's perspective and to help understand why a certain site use and remedial action combination are preferred; the results of the methodology should not be taken as the final decision. The methodology is not a substitute for sound judgment. The final decision regarding site remediation will have to be made in consultation with other stakeholders, such as the community.

7.3 LIMITATIONS AND FURTHER RESEARCH

The decision methodology represents a significant step forward for site remediation, but considerably more research is needed. Further research includes:

1. The approach undertaken in this research can be expanded to include other stakeholders. Specifically, devising a second decision methodology for the local community would complement the owner's methodology, which focuses on his or her financial considerations for site cleanups. There may also be distinct groups with differing views within the community, and tradeoffs made between these groups; devising a separate methodology for each distinct group is also a possibility. We assume that these additional methodologies would promote to a greater extent non-financial objectives, such as community image and the health and well-being of the residents and the ecosystem. The combination of the methodologies should provide a more balanced perspective on site remediation.
2. This methodology considered human health and largely ignored ecological health. The owner's methodology can be expanded to include such aspects: even if human health is not affected, liability can still arise because of transgressions against the environment.
3. While use of the methodology in any specific remediation project depends on the actual site circumstances, there are instances in which assumptions and procedures can be refined. For example, there may be other resources from which to estimate the financial costs of liability instead of asking a legal professional. Insurance companies are now beginning to offer coverage for a variety of site remediation projects. There may soon be – if not already – more extensive databases regarding actual amounts of liability that are paid. Moreover, the availability of insurance products may alter how the owner views his or her benefits, costs, and liability.
4. The impact of regulations has only been briefly addressed in this methodology. Because regulatory frameworks can significantly restrict the choices that are eventually made, a more thorough investigation is warranted. Future work could include the effects of regulations directly into the methodology.
5. There are advantages and disadvantages of using this methodology (or any other decision methodology for that matter) versus following a course prescribed by regulations. Research could examine how the owner would estimate and weigh tradeoffs between the insight and progressive decision process this methodology offers

against the probable lower cost and faster completion of remediation by meeting regulations.

6. For uncertainty, the methodology assumed that the owner's benefits, costs, and liability could be represented by common probability distributions. Future research could attempt to determine these distributions based on information from actual site remediation projects.
7. The decision methodology can be expanded to include more sophisticated means of interpreting and comparing the results from the probabilistic analysis (i.e., net benefits distributions for different SU/RA combinations), such as through the use of utility theory.
8. This methodology was chiefly developed to analyze one contaminant. Expanding the methodology to facilitate examining multiple contaminants would improve its overall applicability.
9. Testing the decision methodology in a real site remediation case would help determine its usability in a practical setting. Using "real" information would also help validate the decision methodology as a legitimate decision making tool.

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Appendix A

A.1 THE MOEE GUIDELINE - CLEAN UP APPROACHES

In the MOEE Guideline for Use at Contaminated Sites in Ontario (1996), there are essentially three approaches that can be used when cleaning up a contaminated site: the *background, generic, or site-specific approach*. Details of each are presented in the following table.

Background	▪ Can be used at any site. ▪ Site is essentially remediated to background levels for contaminants. ▪ MOEE has provided a table of background concentrations. ▪ Guidance is given for assessing background concentration levels of contaminants not listed by MOEE. ▪ Background concentrations are divided into two categories: agricultural use, and all other uses.

Generic	▪ To protect human health, ecological health, and the natural environment.
	▪ Effects-based criteria for soil, ground water, and sediment quality.
	▪ Generic criteria consist of allowable contaminant concentration levels and account for pathway exposure scenarios (e.g., from soil to indoor air).
	▪ To determine which generic criteria are appropriate for any given site, they are based on the following attributes:
	  ▪ land use (agricultural, residential/parkland, commercial/industrial)
	  ▪ restoration of groundwater quality (potable or nonpotable)
	  ▪ depth of soil restoration (full-depth or stratified)
	  ▪ soil texture and soil pH
	▪ Institutional uses such as schools, hospitals, and daycares are included in the residential/parkland category. Industrial/commercial sites that will no longer be used must have restricted access if they are not remediated.
	▪ Both groundwater criteria categories provide for the protection against vapors that may arise from chemicals and also protect aquatic receptors. However, in the non potable case, the water is not restored to the point of human consumptability. Restoration to the non potable criteria can only be considered in select situations and consideration must also be given to present and future ground water uses.
	▪ In the full depth clean up, the entire depth of contamination is remediated according to the generic criteria. In the stratified depth clean up, different generic criteria are applied to contaminated soils lying greater than 1.5 m below the surface. This assumes that contaminated subsurface soils are unlikely to reach surface receptors, and thus a less stringent clean up will offer comparable protection.
	▪ Different generic criteria are applied depending on the soil's texture and pH. Both characteristics can affect the mobility, and thus exposure potential, of certain contaminants.
	▪ Generic criteria are not applicable if the site is designated as a *sensitive site* (e.g., a nature reserve, wildlife habitat).

Site-Specific	▪ An SSRA (Site-Specific Risk Assessment) uses site specific considerations to estimate the risk posed by contaminants to human health, ecological health, and the natural environment. It is based on *human health risk assessment, ecological risk assessment*, and *risk management* protocols.
	▪ An SSRA can be used to:
	  ▪ modify generic criteria by considering site specific exposure and receptor circumstances, and site characteristics; or
	  ▪ develop all site-specific human health or ecological criteria.
	▪ Risk management involves decisions, strategies, or techniques that limit or manage the estimated risk. Two levels of risk management are considered.
	  ▪ Level 1 focuses on specific technical requirements (e.g., allowable lower concentration limits) that should be followed.
	  ▪ Level 2 focuses on methods to inhibit exposure pathways (e.g., restricting site access). It also deals with how risk can be modified depending on the socio-economic or technical feasibility considerations (e.g., the amount of funding available for cleanup).
	▪ Certain administrative requirements must be fulfilled, including:
	  ▪ a community-based communication program;
	  ▪ discussions with the local public authority; and
	  ▪ an independent peer review.

TABLE A.1: Summary of clean–up approaches under the MOEE Guideline

A.2 COMPARING THE MOEE GUIDELINE AND THE DECISION METHODOLOGY

The similarities and differences between the Guideline and the decision methodology are discussed in greater detail below, and includes comments from the Advisory Committee on Environmental Standards (ACES,1994), which reviewed the MOEE Guideline when it was in its draft stages.

- Cost is perhaps the most immediate concern for the owner when making tradeoffs in site remediation projects. The new MOEE Guideline does not offer any insight on how a proponent or land owner should assess these tradeoffs.

- Uncertainties are generally not addressed in the Guideline. There is, however, an implicit assumption that by following the generic cleanup criteria established in the Guideline, some of the uncertainties about health or exposure are acknowledged. As the Guideline states:

  > These criteria have been developed using environmental exposure models which rely on conservative or protective assumptions about exposure to contaminants.(p.10)

- The MOEE Guideline has a "sensitive site" designation. Conversely, the proposed decision methodology does not begin with any preset definitions. By incorporating and analyzing all relevant objectives, the proposed decision methodology should identify the preferred remedial action and site use for a set specific conditions[1].

- In the case of using generic criteria, the intent of the decision methodology and the Guideline are similar in principle. Depending on the physical parameters and exposure potential of the contaminants at the site, both the Guideline and the decision methodology offer some flexibility in choosing how the site will be remediated. However, the Guideline offers little advice on which generic criteria should be applied.

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[1] A sensitive site classification may emerge after the decision methodology has been applied to several case studies. It may then be possible to categorize a contaminated site *prior* to it being subject to any decision process regarding its clean up.

Presumably, the user of the guidelines will assess which criteria best satisfies the tradeoffs faced. It is this decision process that the methodology addresses.

- While the Guideline offers flexibility in the level of clean up that must be achieved given an intended land use, it does not address whether or not a previously contaminated site *should* be remediated to facilitate a particular use. The decision methodology would consider the tradeoffs between remediating a site and its potential future uses in view of the identified objectives.

- ACES (1994) originally found that the stratified depth cleanup approach was supported because of the flexibility offered in remediation[2]. An extensive site remediation may not be necessary, or in some cases, even desirable (i.e. if large quantities of contaminants would be released during clean up) to protect human health or the environment. The Guideline, however, does not recommend how to decide under what conditions a partial clean up or full clean up is preferable. Again, the decision methodology intends to assist the proponent in making such decisions.

- The site-specific approach is in some respects the most similar aspect of the proposed guidelines to the decision methodology. In developing the underlying basis for the methodology, it is recognized that a site-specific approach may select the most appropriate remedial action in most instances. In general, the SSRA was supported by the ACES (1994) review because of the flexibility and thus potential cost savings it offered. However, it was also expressed that the SSRA option could be more open to abuse, or that a lower level of human health/environmental protection would be achieved. Conversely, by explicitly recognizing the owner's liability in a variety of situations, any abuse or misuse of the decision methodology should be prevented. The liability associated with a clearly inadequate remedial action should be a deterrent.

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[2] The decision methodology will not debate whether or not the 1.5 m depth is scientifically appropriate.

In essence, the decision methodology is a structure through which an SSRA could be conducted. The methodology outlines the important objectives, the tradeoffs, the impacts of various uncertainties, and helps identify the preferred remedial action and site use. An SSRA - or any risk-based assessment for that matter - would analyze specific elements within the methodology: what are the risks posed by certain remediation techniques; how would changing the land use affect the exposure scenarios; what are the health risks posed by the contaminants[3].

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[3] Repeated testing of the methodology in a variety of situations may result in the categorization of certain remediation cases. This may help streamline the decision process in future, similar scenarios.

Appendix B

B.1 ILLUSTRATIVE EXAMPLE UNDER CERTAINTY

The following spreadsheet shows the calculations used to calculate the owner's net benefits under certainty as shown in Chapter Five.

EVALUATING THE OWNER'S NET BENEFITS UNDER CERTAINTY (CHAPTER 5)

Site Use SU	UV($) Gross	RA	CC Approx.	AC Approx.	Stigma S($)	PV($)	C(RA) ($)	CD(SU) ($)	Liability	OnSite	OffSite Bound	OffSite Houses	OffSite School	Com	Total L($)	NB ($)
SU0	0	**RA0:**	high	high	0	0	**560000**	**29500**	P(AC)	1	1	1	1		**77805.73**	**-667305.7**
Do Nothing		**none**							P(R)	0.0023	5.10E-04	4.40E-04	3.70E-04			
									P(O)	0.8	0.8	0.8	0.8	D		
									CL (adult)	1500000	1500000	1500000	1500000	A		
									n (adult)	0	1	4	20			
									CL (child)	3000000	3000000	3000000	3000000	A		
									n (child)	0	7	4	205			
									PV factor	n=20 year	r=5%		0.3769	A		
	0	**RA1:**	high	low	0	0	**570000**	**29500**	P(AC)	1	1	1	1		**0**	**-599500**
		contain							P(R)	0	0	0	0	E		
		cap							P(O)	0.15	0.15	0.15	0.15	C		
									CL (adult)	1500000	1500000	1500000	1500000	A		
									n (adult)	0	1	4	20			
									CL (child)	3000000	3000000	3000000	3000000	A		
									n (child)	0	7	4	205			
									PV factor	n=20 year	r=5%		0.3769	A		
	0	**RA2a:**	mod-low	low	0	0	**550000**	**29500**	P(AC)	1	1	1	1		**575.4698**	**-580075**
		P&T							P(R)	5.80E-05	0	2.80E-05	1.50E-05			
		SVE							P(O)	0.15	0.15	0.15	0.15	C		
									CL (adult)	1500000	1500000	1500000	1500000	A		
									n (adult)	0	1	4	20			
									CL (child)	3000000	3000000	3000000	3000000	A		
									n (child)	0	7	4	205			
									PV factor	n=20 year	r=5%		0.3769	A		
	0	**RA2b:**	low	low	0	0	**700000**	**29500**	P(AC)	1	1	1	1		**24.42312**	**-729524**
		P&T							P(R)	3.20E-05	0	2.40E-05	0			
		SVE							P(O)	0.15	0.15	0.15	0.15	C		
									CL (adult)	1500000	1500000	1500000	1500000	A		
									n (adult)	0	1	4	20			
									CL (child)	3000000	3000000	3000000	3000000	A		
									n (child)	0	7	4	205			
									PV factor	n=20 year	r=5%		0.3769	A		

Site Use SU	UV($) Gross	RA	CC Approx.	AC Approx.	Stigma S($)	PV($)	C(RA) ($)	CD(SU) ($)	Liability	OnSite	OffSite Bound	OffSite Houses	OffSite School	Com	Total L($)	NB ($)
SU1	3246000	**RA0:**	high	high	0	**3246000**	**560000**	**2000000**	P(AC)	1	1	1	1		**80926.46**	**605073.5**
Commercial		**none**							P(R)	0.0023	5.10E-04	4.40E-04	3.70E-04			
Service									P(O)	0.8	0.8	0.8	0.8	D		
Station									CL (adult)	1500000	1500000	1500000	1500000	A		
									n (adult)	3	1	4	20			
									CL (child)	3000000	3000000	3000000	3000000	A		
									n (child)	0	7	4	205			
									PV factor	n=20 year	r=5%		0.3769	A		
	3246000	**RA1:**	high	low	0	**3246000**	**570000**	**2000000**	P(AC)	1	1	1	1		**0**	**676000**
		contain							P(R)	0	0	0	0	E		
		cap							P(O)	0.25	0.35	0.35	0.35	F, H		
									CL (adult)	1500000	1500000	1500000	1500000	A		
									n (adult)	3	1	4	20			
									CL (child)	3000000	3000000	3000000	3000000	A		
									n (child)	0	7	4	205			
									PV factor	n=20 year	r=5%		0.3769	A		
	3246000	**RA2a:**	mod-low	low	0	**3246000**	**550000**	**2000000**	P(AC)	1	1	1	1		**786.9672**	**695213**
		P&T							P(R)	5.80E-05	0	2.80E-05	1.50E-05			
		SVE							P(O)	0.2	0.2	0.2	0.2	G		
									CL (adult)	1500000	1500000	1500000	1500000	A		
									n (adult)	3	1	4	20			
									CL (child)	3000000	3000000	3000000	3000000	A		
									n (child)	0	7	4	205			
									PV factor	n=20 year	r=5%		0.3769	A		
	3246000	**RA2b:**	low	low	0	**3246000**	**700000**	**2000000**	P(AC)	1	1	1	1		**32.56416**	**545967**
		P&T							P(R)	3.20E-05	0	2.40E-05	0			
		SVE							P(O)	0.15	0.15	0.15	0.15	N		
									CL (adult)	1500000	1500000	1500000	1500000	A		
									n (adult)	3	1	4	20			
									CL (child)	3000000	3000000	3000000	3000000	A		
									n (child)	0	7	4	205			
									PV factor	n=20 year	r=5%		0.3769	A		

Site Use SU	UV($) Gross	RA	CC Approx.	AC Approx.	Stigma S($)	PV($)	C(RA) ($)	CD(SU) ($)	Liability	OnSite	OffSite Bound	OffSite Houses	OffSite School	Com	Total L($)	NB ($)
SU2	2250000	**RA0**:	high	high	400000	**1850000**	**560000**	**1500000**	P(AC)	1	1	1	1		**143704.6**	**-353704.6**
Residential		**none**							P(R)	0.0023	5.10E-04	4.40E-04	3.70E-04			
Detached									P(O)	0.9	0.9	0.9	0.9	K		
Housing									CL (adult)	1500000	1500000	1500000	1500000	A		
									n (adult)	20	1	4	20			
									CL (child)	3000000	3000000	3000000	3000000	A		
									n (child)	14	7	4	205			
									PV factor	n=20 year	r=5%		0.3769	A		
	2250000	**RA1**:	high	low	250000	**2000000**	**570000**	**1500000**	P(AC)	1	1	1	1		**0**	**-70000**
		contain							P(R)	0	0	0	0	E		
		cap							P(O)	0.35	0.35	0.35	0.35	H		
									CL (adult)	1500000	1500000	1500000	1500000	B		
									n (adult)	20	1	4	20			
									CL (child)	3000000	3000000	3000000	3000000	B		
									n (child)	14	7	4	205			
									PV factor	n=20 year	r=5%		0.3769	B		
	2250000	**RA2a**:	mod-low	low	150000	**2100000**	**550000**	**1500000**	P(AC)	1	1	1	1		**1082.08**	**48918**
		P&T							P(R)	5.80E-05	0	2.80E-05	1.50E-05			
		SVE							P(O)	0.2	0.2	0.2	0.2	G		
									CL (adult)	1500000	1500000	1500000	1500000	B		
									n (adult)	20	1	4	20			
									CL (child)	3000000	3000000	3000000	3000000	B		
									n (child)	14	7	4	205			
									PV factor	n=20 year	r=5%		0.3769	B		
	2250000	**RA2b**:	low	low	75000	**2175000**	**700000**	**1500000**	P(AC)	1	1	1	1		**154.6798**	**-25155**
		P&T							P(R)	3.20E-05	0	2.40E-05	0			
		SVE							P(O)	0.15	0.15	0.15	0.15	N		
									CL (adult)	1500000	1500000	1500000	1500000	B		
									n (adult)	20	1	4	20			
									CL (child)	3000000	3000000	3000000	3000000	B		
									n (child)	14	7	4	205			
									PV factor	n=20 year	r=5%		0.3769	B		

COMMENTS for Certainty Scenario (Chapter 5)

A Because the AC is so low, we assume only long-term health effects would occur (e.g., developing cancer).

C P(O) is only estimated to be only "0.15" because there is no site use, yet remedial actions are still performed.

D P(O) is estimated to be "0.80" because no remedial action is even attempted: perceived as owner irresponsibility.

E P(R) is "0" because we have assumed that containment (RA1) works perfectly.

F P(O) is estimated to be "0.25" onsite. Although the site is only being used for commercial purposes, containment (RA1) does not rid the contamination source.

G P(O) is estimated to be "0.20" because, unlike in containment (RA1), the source of the contamination is being addressed with RA2a.

H P(O) is estimated to be "0.35" because either the onsite or offsite locations will have families (i.e., children in basements, gardening, etc.) but the nearby contamination source is untreated and only contained (RA1).

K P(O) is estimated to be "0.9" since no remedial action is performed but a housing development will still be built.

N P(O) is estimated to be "0.15" because RA2b is more effective than RA2a.

Appendix C

C.1 ILLUSTRATIVE EXAMPLE UNDER UNCERTAINTY

The following spreadsheet shows the calculations used to calculate the owner's net benefits under uncertainty as shown in Chapter Six.

EVALUATING THE OWNER'S NET BENEFITS UNDER UNCERTAINTY (CHAPTER 6)

Site Use SU	UV($) Gross	RA	CC Approx.	AC Approx.	Stigma S($)	PV($)	C(RA) ($)	CD(SU) ($)	Liability	OnSite	OffSite Bound	OffSite Houses	OffSite School	Com	Total L($)	NB ($)
SU0	0	**RA0:**	high	high	0	**0**	**670000**	**29500**	P(AC)	1	1	1	1		**812747.2**	**-1512247**
Do Nothing		**none**							P(R)	0.02	5.00E-03	4.00E-03	2.50E-03			
									P(O)	0.9	0.9	0.9	0.9	D		
									CL (adult)	2000000	2000000	2000000	2000000	A		
									n (adult)	0	1	4	20			
									CL (child)	4000000	4000000	4000000	4000000	A		
									n (child)	0	7	4	205			
									PV factor	n=20 year	r=5%		0.3769	A		
	0	**RA1:**	high	low	0	**0**	**750000**	**29500**	P(AC)	1	1	1	1		**0**	**-779500**
		contain							P(R)	0	0	0	0	E		
		cap							P(O)	0.25	0.25	0.25	0.25	C		
									CL (adult)	2000000	2000000	2000000	2000000	A		
									n (adult)	0	1	4	20			
									CL (child)	4000000	4000000	4000000	4000000	A		
									n (child)	0	7	4	205			
									PV factor	n=20 year	r=5%		0.3769	A		
	0	**RA2a:**	mod-low	low	0	**0**	**780000**	**29500**	P(AC)	1	1	1	1		**12833.45**	**-822333**
		P&T							P(R)	5.00E-04	0	3.00E-04	1.50E-04			
		SVE							P(O)	0.25	0.25	0.25	0.25	C		
									CL (adult)	2000000	2000000	2000000	2000000	A		
									n (adult)	0	1	4	20			
									CL (child)	4000000	4000000	4000000	4000000	A		
									n (child)	0	7	4	205			
									PV factor	n=20 year	r=5%		0.3769	A		
	0	**RA2b:**	low	low	0	**0**	**920000**	**29500**	P(AC)	1	1	1	1		**565.35**	**-950065**
		P&T							P(R)	3.00E-04	0	2.50E-04	0			
		SVE							P(O)	0.25	0.25	0.25	0.25	C		
									CL (adult)	2000000	2000000	2000000	2000000	A		
									n (adult)	0	1	4	20			
									CL (child)	4000000	4000000	4000000	4000000	A		
									n (child)	0	7	4	205			
									PV factor	n=20 year	r=5%		0.3769	A		

Site Use SU	UV($) Gross	RA	CC Approx.	AC Approx.	Stigma S($)	PV($)	C(RA) ($)	CD(SU) ($)	Liability	OnSite	OffSite Bound	OffSite Houses	OffSite School	Com	Total L($)	NB ($)
SU1	3246000	**RA0:**	high	high	0	**3246000**	**670000**	**2000000**	P(AC)	1	1	1	1		**853452.4**	**-277452.4**
Commercial		**none**							P(R)	0.02	5.00E-03	4.00E-03	2.50E-03			
Service									P(O)	0.9	0.9	0.9	0.9	D		
Station									CL (adult)	2000000	2000000	2000000	2000000	A		
									n (adult)	3	1	4	20			
									CL (child)	4000000	4000000	4000000	4000000	A		
									n (child)	0	7	4	205			
									PV factor	n=20 year	r=5%		0.3769	A		
	3246000	**RA1:**	high	low	0	**3246000**	**750000**	**2000000**	P(AC)	1	1	1	1		**0**	**496000**
		contain							P(R)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	E		
		cap							P(O)	0.35	0.45	0.45	0.45	F, H		
									CL (adult)	2000000	2000000	2000000	2000000	A		
									n (adult)	3	1	4	20			
									CL (child)	4000000	4000000	4000000	4000000	A		
									n (child)	0	7	4	205			
									PV factor	n=20 year	r=5%		0.3769	A		
	3246000	**RA2a:**	mod-low	low	0	**3246000**	**780000**	**2000000**	P(AC)	1	1	1	1		**13116.12**	**452884**
		P&T							P(R)	5.00E-04	0	3.00E-04	1.50E-04			
		SVE							P(O)	0.25	0.25	0.25	0.25	G		
									CL (adult)	2000000	2000000	2000000	2000000	A		
									n (adult)	3	1	4	20			
									CL (child)	4000000	4000000	4000000	4000000	A		
									n (child)	0	7	4	205			
									PV factor	n=20 year	r=5%		0.3769	A		
	3246000	**RA2b:**	low	low	0	**3246000**	**920000**	**2000000**	P(AC)	1	1	1	1		**587.964**	**325412**
		P&T							P(R)	3.00E-04	0	2.50E-04	0			
		SVE							P(O)	0.2	0.2	0.2	0.2	N		
									CL (adult)	2000000	2000000	2000000	2000000	A		
									n (adult)	3	1	4	20			
									CL (child)	4000000	4000000	4000000	4000000	A		
									n (child)	0	7	4	205			
									PV factor	n=20 year	r=5%		0.3769	A		

Site Use SU	UV($) Gross	RA	CC Approx.	AC Approx.	Stigma S($)	PV($)	C(RA) ($)	CD(SU) ($)	Liability	OnSite	OffSite Bound	OffSite Houses	OffSite School	Com	Total L($)	NB ($)
SU2	2250000	**RA0:**	high	high	600000	**1650000**	**670000**	**1500000**	P(AC)	1	1	1	1		**1545365**	**-2065365**
Residential		***none***							P(R)	0.02	5.00E-03	4.00E-03	2.50E-03			
Detached									P(O)	0.95	0.95	0.95	0.95	K		
Housing									CL (adult)	2000000	2000000	2000000	2000000	A		
									n (adult)	20	1	4	20			
									CL (child)	4000000	4000000	4000000	4000000	A		
									n (child)	14	7	4	205			
									PV factor	n=20 year	r=5%		0.3769	A		
	2250000	**RA1:**	high	low	400000	**1850000**	**750000**	**1500000**	P(AC)	1	1	1	1		**0**	**-400000**
		contain							P(R)	0	0	0	0	E		
		cap							P(O)	0.45	0.45	0.45	0.45	H		
									CL (adult)	2000000	2000000	2000000	2000000	A		
									n (adult)	20	1	4	20			
									CL (child)	4000000	4000000	4000000	4000000	A		
									n (child)	14	7	4	205			
									PV factor	n=20 year	r=5%		0.3769	A		
	2250000	**RA2a:**	mod-low	low	200000	**2050000**	**780000**	**1500000**	P(AC)	1	1	1	1		**17356.25**	**-247356**
		P&T							P(R)	5.00E-04	0	3.00E-04	1.50E-04			
		SVE							P(O)	0.25	0.25	0.25	0.25	G		
									CL (adult)	2000000	2000000	2000000	2000000	A		
									n (adult)	20	1	4	20			
									CL (child)	4000000	4000000	4000000	4000000	A		
									n (child)	14	7	4	205			
									PV factor	n=20 year	r=5%		0.3769	A		
	2250000	**RA2b:**	low	low	150000	**2100000**	**920000**	**1500000**	P(AC)	1	1	1	1		**2623.224**	**-322623**
		P&T							P(R)	3.00E-04	0	2.50E-04	0			
		SVE							P(O)	0.2	0.2	0.2	0.2	N		
									CL (adult)	2000000	2000000	2000000	2000000	A		
									n (adult)	20	1	4	20			
									CL (child)	4000000	4000000	4000000	4000000	A		
									n (child)	14	7	4	205			
									PV factor	n=20 year	r=5%		0.3769	A		

COMMENTS for Uncertainty Scenario (Chapter 6)

A	Because the AC is so low, we assume only long-term health effects would occur (e.g., developing cancer).
C	P(O) is only estimated to be "0.25" because there is no site use, yet remedial actions are still performed.
D	P(O) is estimated to be "0.90" because no remedial action is even attempted: perceived as owner irresponsibility.
E	P(R) is "0" because we have assumed that containment (RA1) works perfectly.
F	P(O) is estimated to be "0.35" onsite. Although the site is only being used for commercial purposes, containment (RA1) does not rid the contamination source.
G	P(O) is estimated to be "0.25" because, unlike in containment (RA1), the source of the contamination is being addressed with RA2a.
H	P(O) is estimated to be "0.45" because either the onsite or offsite locations will have families (i.e., children in basements, gardening, etc.) but the nearby contamination source is untreated and only contained (RA1).
K	P(O) is estimated to be "0.95" since no remedial action is performed but a housing development will still be built.
N	P(O) is estimated to be "0.20" because RA2b is more effective than RA2a.

Appendix D

D. I PROBABILISTIC ANALYSIS ON ILLUSTRATIVE EXAMPLE

This appendix shows the probability distributions for the owner's net benefits, site use benefits, costs, and liability used in the probabilistic analysis of the illustrative example. Samples of the calculated output have also been included.

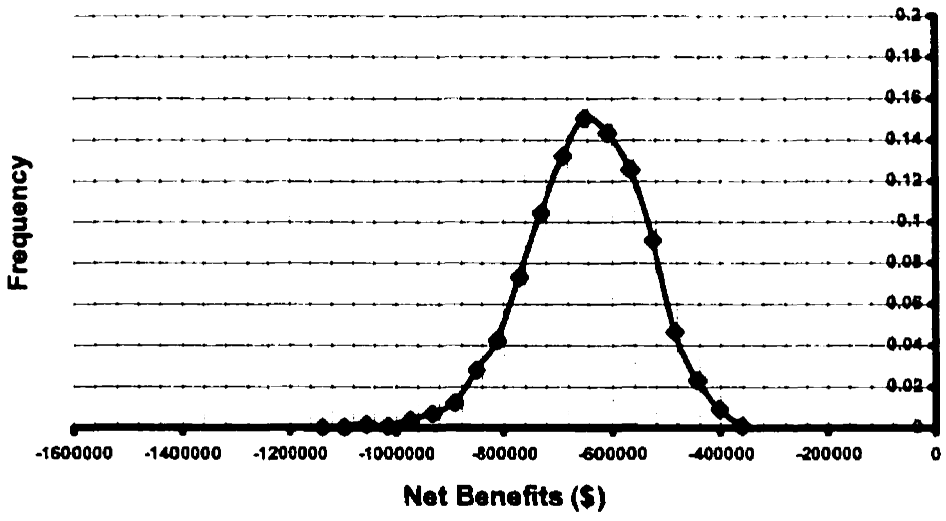
OWNER'S NET BENEFITS

Site Use: **SU0: None**
Remedial Action: **RA0: None**
Iterations to be Analyzed: **5000**

MaxNB	-341990	***NB Mean:***	**-648995.723**
MinNB	-1157868	***NB Std.Dev.:***	**108460.0903**
Range	815878.6	***NB Var:***	**11763591183**
Width	40793.93		

Division	*Init.Freq.*	*Ticks*	*Midpoints*	*Freq.*	*%Freq.*
1	0	-1157868	-1137471	1	0.0002
2	0	-1117074	-1096677	2	0.0004
3	0	-1076280	-1055883	9	0.0018
4	0	-1035486	-1015089	4	0.0008
5	0	-994692	-974295	20	0.004
6	0	-953899	-933502	36	0.0072
7	0	-913105	-892708	61	0.0122
8	0	-872311	-851914	142	0.0284
9	0	-831517	-811120	213	0.042599998
10	0	-790723	-770326	366	0.073200002
11	0	-749929	-729532	523	0.104599997
12	0	-709135	-688738	663	0.132599995
13	0	-668341	-647944	754	0.150800005
14	0	-627547	-607150	718	0.143600002
15	0	-586753	-566356	629	0.125799999
16	0	-545959	-525562	457	0.091399997
17	0	-505165	-484768	234	0.046799999
18	0	-464371	-443974	117	0.023399999
19	0	-423577	-403180	46	0.0092
20	0	-382784	-362387	5	0.001
		-341990			

DISTRIBUTION OF OWNER'S NET BENEFITS



Check Mean (B-C-L): **-648996**

Check Var's (B+C+L): **11719618106**

% Diff. Between Check/ Actual Var's: **0.4**

Iteration	*Benefits*	*Costs*	*Liability*	*NB's*
1	-41753.6	564272.9	68495.88396	-674522
2	-24201.4	478218.5	108505.1439	-610925
3	-26472.2	488278	0	-514750
4	-27835.4	510730	94177.42866	-632743
5	-18785.1	531090.4	65264.30608	-615140
6	-27558.9	455334.3	0	-482893
7	-26948.4	565998.2	82613.94258	-675561
8	-10947.9	555686.5	79374.46265	-646009
9	-32432.8	615772	91787.49114	-739992
10	-6661.02	431088.4	89884.46827	-527634
11	-36368	431883.1	81253.91	-549505
12	-28997.2	483121.5	53379.9943	-565499
13	-28061.6	542652.6	0	-570714
14	-24588.3	497106.4	0	-521695
15	-20733.1	505451.1	32176.59676	-558361
16	-17411.1	592053.4	113735.2692	-723200
17	-25039.3	468499.1	64486.19282	-558025
18	-20382.2	514368.4	108758.8605	-643509
19	-32282.8	572694.9	37538.44862	-642516
20	-22930.4	471006.8	0	-493937
21	-27344.1	443018.5	0	-470363
22	-35199.2	453003.2	122434.3394	-610637
23	-34185.2	668950	79994.90332	-783130
24	-15209.4	449871.6	51547.99444	-516629
25	-34524.1	472650.5	0	-507175
26	-45120	719085.1	80931.71141	-845137
27	-43807.6	618715.1	0	-662523
28	-28759.1	500524.1	91063.17618	-620346
29	-18028	434397.7	83931.14298	-536357
30	-36901.7	443704.7	61944.30253	-542551
31	-27612.2	642022	47256.24487	-716890
32	-48367.3	506404.7	85021.20914	-639793
33	-38611.3	625897	27120.56084	-691629
34	-33774.6	623688.4	121165.7065	-778629
35	-25153.6	444925.9	145931.3736	-616011
36	-40984	542427.8	168683.111	-752095
37	-44583.7	551777.3	65339.70159	-661701
38	-40015.5	439629.3	0	-479645
39	-12934.1	499357.7	140638.1877	-652930
40	-30313.6	414496	115390.7011	-560200
41	-26891	618837.1	128885.614	-774614
42	-18208.6	497590.2	104362.6163	-620161
43	-31966.8	470231.4	25999.16799	-528197
44	-13040.7	620283.3	123709.9419	-757034

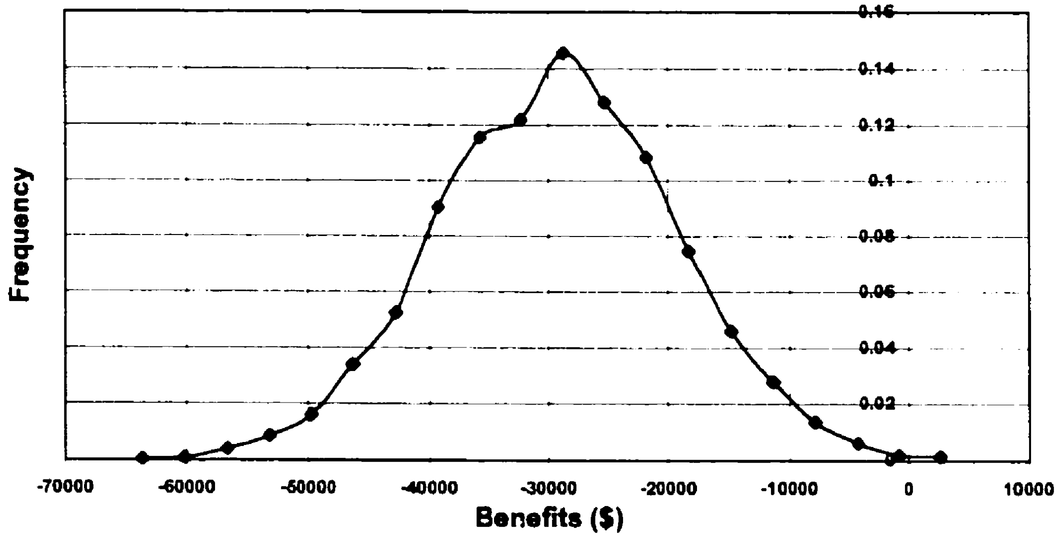
OWNER'S BENEFITS

Assumed Mean Benefits ($):	**-29500**	***Site Use:***	**SU0: None**
Assumed Std. Dev. ($):	**10000**	***Remedial Action:***	**SU0: None**
Iterations to be performed:	**5000**		

MaxBen	4374.552	***Actual Mean:***	**-29327.7**
MinBen	-65436.4	***Actual Std.Dev.:***	**9933.481**
Range	69810.95		
Width	3490.548		

Division	***Init.Freq.***	***Ticks***	***Midpoints***	***Freq.***	***%Freq.***
				2225	
1	0	-65436.4	-63691.1	2	0.0004
2	0	-61945.9	-60200.6	4	0.0008
3	0	-58455.3	-56710	20	0.004
4	0	-54964.8	-53219.5	44	0.0088
5	0	-51474.2	-49728.9	81	0.0162
6	0	-47983.7	-46238.4	170	0.034
7	0	-44493.1	-42747.8	263	0.0526
8	0	-41002.6	-39257.3	452	0.0904
9	0	-37512	-35766.7	579	0.1158
10	0	-34021.5	-32276.2	610	0.122
11	0	-30530.9	-28785.7	728	0.1456
12	0	-27040.4	-25295.1	641	0.1282
13	0	-23549.8	-21804.6	543	0.1086
14	0	-20059.3	-18314	373	0.0746
15	0	-16568.7	-14823.5	230	0.046
16	0	-13078.2	-11332.9	140	0.028
17	0	-9587.64	-7842.36	69	0.0138
18	0	-6097.09	-4351.82	32	0.0064
19	0	-2606.54	-861.269	10	0.002
20	0	884.0048	2629.279	8	0.0016
		4374.552			

DISTRIBUTION (NORMAL) OF OWNER'S BENEFITS



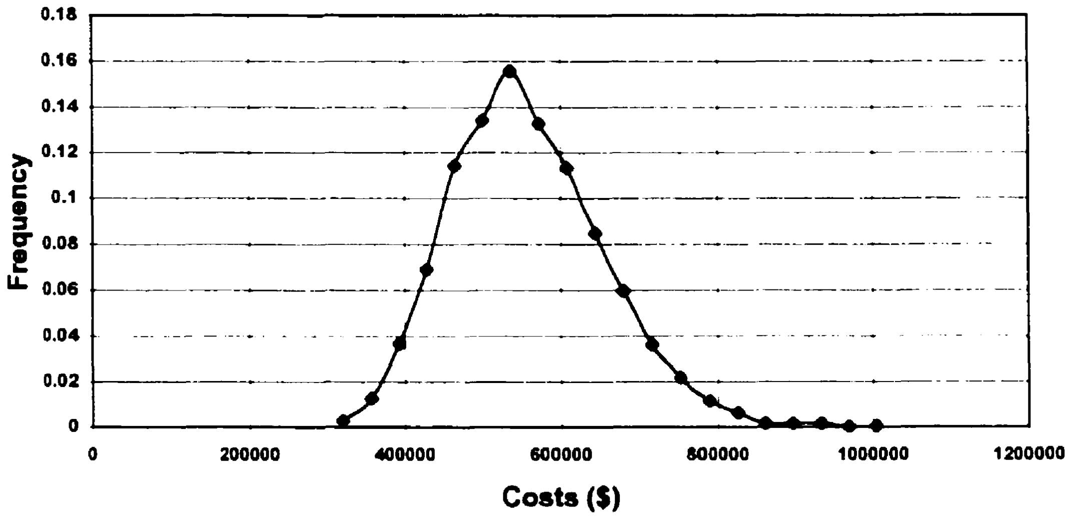
Iteration	*Rand1*	*Rand2*	*V1*	*V2*	*R2*	*Y*	*N1*	*N2*	*Benefits Using N1*
1	0.187252	0.603935	-0.6255	0.20787	0.434455	1.959018	-1.22536	0.407221	-41753.6
2	0.629476	0.795941	0.258952	0.591881	0.417379	2.046187	0.529864	1.2111	-24201.4
3	0.839057	0.163412	0.678115	-0.67318	0.913006	0.446509	0.302785	-0.30058	-26472.2
4	0.928553	0.251492	0.857106	-0.49702	0.981656	0.194217	0.166465	-0.09653	-27835.4
5	0.796332	0.669762	0.592664	0.339524	0.466527	1.80792	1.071489	0.613831	-18785.1
6	0.544025	0.80864	0.08805	0.61728	0.388788	2.204501	0.194107	1.360795	-27558.9
7	0.804422	0.871321	0.608845	0.742642	0.922209	0.419081	0.255155	0.311227	-26948.4
8	0.650209	0.423073	0.300417	-0.15385	0.113921	6.175427	1.855205	-0.95011	-10947.9
9	0.050387	0.311528	-0.89923	-0.37694	0.950694	0.326144	-0.29328	-0.12294	-32432.8
10	0.627179	0.475806	0.254357	-0.04839	0.067039	8.979097	2.283898	-0.43448	-6661.02
11	0.349464	0.76708	-0.30107	0.53416	0.375971	2.28119	-0.6868	1.218519	-36368
12	0.584453	0.982156	0.168907	0.964312	0.958427	0.297671	0.050279	0.287048	-28997.2
13	0.964936	0.324228	0.929872	-0.35154	0.988245	0.154693	0.143845	-0.05438	-28061.6
14	0.843298	0.208063	0.686596	-0.58387	0.812324	0.715372	0.491172	-0.41769	-24588.3
15	0.798324	0.721037	0.596648	0.442074	0.551418	1.46936	0.876691	0.649566	-20733.1
16	0.777791	0.35417	0.555581	-0.29166	0.393736	2.175896	1.208887	-0.63462	-17411.1
17	0.96518	0.594858	0.93036	0.189717	0.901562	0.479459	0.446069	0.090961	-25039.3
18	0.712873	0.733737	0.425747	0.467474	0.399792	2.1416	0.911779	1.001141	-20382.2
19	0.342052	0.097423	-0.3159	-0.80515	0.748065	0.880933	-0.27828	-0.70929	-32282.8
20	0.570711	0.69123	0.141421	0.382461	0.166276	4.64541	0.656961	1.776686	-22930.4
21	0.753301	0.907252	0.506603	0.814505	0.920064	0.425558	0.215589	0.346619	-27344.1
22	0.133784	0.249325	-0.73243	-0.50135	0.787809	0.778123	-0.56992	-0.39011	-35199.2
23	0.026971	0.515199	-0.94606	0.030398	0.895951	0.495237	-0.46852	0.015054	-34185.2
24	0.800072	0.501682	0.600144	0.003365	0.360184	2.3812	1.429062	0.008012	-15209.4
25	0.351456	0.818355	-0.29709	0.63671	0.493662	1.691116	-0.50241	1.076751	-34524.1
26	0.263635	0.58487	-0.47273	0.169739	0.252285	3.304205	-1.562	0.560853	-45120
27	0.207637	0.545954	-0.58473	0.091907	0.350351	2.446887	-1.43076	0.224887	-43807.6
28	0.562712	0.040421	0.125425	-0.91916	0.860583	0.590711	0.07409	-0.54296	-28759.1
29	0.831962	0.604985	0.663925	0.20997	0.484884	1.727904	1.147198	0.362808	-18028
30	0.438581	0.66025	-0.12284	0.3205	0.117809	6.025581	-0.74017	1.931199	-36901.7
31	0.844472	0.849927	0.688944	0.699854	0.964439	0.27402	0.188784	0.191774	-27612.2
32	0.347753	0.428097	-0.30449	-0.14381	0.113397	6.196264	-1.88673	-0.89106	-48367.3
33	0.411841	0.668573	-0.17632	0.337145	0.144755	5.167511	-0.91113	1.742202	-38611.3
34	0.485195	0.410669	-0.02961	-0.17866	0.032797	14.436	-0.42746	-2.57917	-33774.6
35	0.945907	0.3392	0.891815	-0.3216	0.89876	0.487367	0.434641	-0.15674	-25153.6
36	0.32639	0.681272	-0.34722	0.362545	0.252	3.307429	-1.1484	1.19909	-40984
37	0.220919	0.467657	-0.55816	-0.06469	0.31573	2.702385	-1.50837	-0.17481	-44583.7
38	0.122455	0.4713	-0.75509	-0.0574	0.573456	1.392616	-1.05155	-0.07994	-40015.5
39	0.540868	0.556026	0.081736	0.112053	0.019237	20.26751	1.656594	2.271029	-12934.1
40	0.138539	0.156813	-0.72292	-0.68637	0.993726	0.112548	-0.08136	-0.07725	-30313.6
41	0.511415	0.607642	0.022831	0.215284	0.046868	11.42786	0.260905	2.460234	-26891
42	0.771812	0.670323	0.543625	0.340646	0.411567	2.077055	1.129138	0.707539	-18208.6
43	0.177703	0.86	-0.64459	0.719999	0.933901	0.382689	-0.24668	0.275536	-31966.8
44	0.641235	0.604293	0.282469	0.208585	0.123297	5.826947	1.645933	1.215414	-13040.7

OWNER'S COSTS	*Lognorm*	*LN's - Normal*		
Assumed Mean Costs ($):	**560000**	**13.22**	***Site Use:***	**SU0: None**
Assumed Std. Dev. ($):	**100000**	**0.177172**	***Remedial Action:***	**SU0: None**
Iterations to be performed:	**5000**			

MaxCost	1022744	***Actual Mean:***	**557361.5**
MinCost	302479.8	***Actual Std.Dev.:***	**98339.85**
Range	720264.7		
Width	36013.23		

Division	*Init.Freq.*	*Ticks*	*Midpoints*	*Freq.*	*%Freq.*
1	0	302479.8	320486.4	14	0.0028
2	0	338493	356499.6	64	0.0128
3	0	374506.2	392512.9	184	0.0368
4	0	410519.5	428526.1	345	0.069
5	0	446532.7	464539.3	573	0.1146
6	0	482545.9	500552.6	673	0.1346
7	0	518559.2	536565.8	781	0.1562
8	0	554572.4	572579	665	0.133
9	0	590585.6	608592.2	567	0.1134
10	0	626598.9	644605.5	424	0.0848
11	0	662612.1	680618.7	298	0.0596
12	0	698625.3	716631.9	181	0.0362
13	0	734638.6	752645.2	110	0.022
14	0	770651.8	788658.4	58	0.0116
15	0	806665	824671.6	32	0.0064
16	0	842678.3	860684.9	8	0.0016
17	0	878691.5	896698.1	9	0.0018
18	0	914704.7	932711.3	9	0.0018
19	0	950718	968724.6	1	0.0002
20	0	986731.2	1004738	3	0.0006
		1022744			

DISTRIBUTION (LOGNORMAL) OF OWNER'S COSTS



Iteration	*Rand1*	*Rand2*	*V1*	*V2*	*R2*	*Y*	*N1*	*N2*	*LNCost*	*Cost*
1	0.727331	0.934139	0.454661	0.868278	0.960624	0.289202	0.131489	0.251108	13.24329	564272.9
2	0.082406	0.428607	-0.83519	-0.14279	0.717928	0.960818	-0.80246	-0.13719	13.07782	478218.5
3	0.149174	0.265532	-0.70165	-0.46894	0.712216	0.976222	-0.68497	-0.45779	13.09864	488278
4	0.162447	0.810797	-0.67511	0.621595	0.842149	0.638749	-0.43122	0.397043	13.1436	510730
5	0.422844	0.873478	-0.15431	0.746957	0.581756	1.364662	-0.21058	1.019344	13.18269	531090.4
6	0.167449	0.369399	-0.6651	-0.2612	0.510587	1.62266	-1.07923	-0.42384	13.02879	455334.3
7	0.621043	0.054761	0.242085	-0.89048	0.851557	0.614329	0.14872	-0.54705	13.24635	565998.2
8	0.593984	0.015941	0.187968	-0.96812	0.972584	0.239092	0.044942	-0.23147	13.22796	555686.5
9	0.828973	0.231017	0.657947	-0.53797	0.722301	0.949088	0.62445	-0.51058	13.33063	615772
10	0.209456	0.573089	-0.58109	0.146179	0.359031	2.388761	-1.38808	0.349186	12.97407	431088.4
11	0.374036	0.366947	-0.25193	-0.26611	0.13428	5.468569	-1.37768	-1.45521	12.97591	431883.1
12	0.068008	0.546873	-0.86398	0.093746	0.755257	0.862157	-0.74489	0.080824	13.08802	483121.5
13	0.423083	0.04134	-0.15383	-0.91732	0.86514	0.578699	-0.08902	-0.53085	13.20422	542652.6
14	0.318022	0.190628	-0.36396	-0.61874	0.515307	1.604118	-0.58383	-0.99254	13.11656	497106.4
15	0.065716	0.329507	-0.86857	-0.34099	0.870684	0.563992	-0.48987	-0.19231	13.13321	505451.1
16	0.591692	0.798575	0.183384	0.59715	0.390217	2.196183	0.402744	1.31145	13.29135	592053.4
17	0.097238	0.464799	-0.80552	-0.0704	0.653826	1.140077	-0.91836	-0.08026	13.05729	468499.1
18	0.379368	0.836425	-0.24126	0.672849	0.510934	1.621287	-0.39116	1.090882	13.15069	514368.4
19	0.544921	0.204145	0.089843	-0.59171	0.358193	2.394281	0.215109	-1.41672	13.25811	572694.9
20	0.223652	0.728624	-0.5527	0.457247	0.514549	1.607082	-0.88823	0.734833	13.06263	471006.8
21	0.338555	0.664308	-0.32289	0.328617	0.212247	3.821742	-1.234	1.255888	13.00137	443018.5
22	0.213217	0.666544	-0.57357	0.333088	0.439926	1.932129	-1.1082	0.643569	13.02365	453003.2
23	0.821806	0.639726	0.643612	0.279453	0.49233	1.696636	1.091976	0.474129	13.41346	668950
24	0.253105	0.677008	-0.49379	0.354016	0.369157	2.323569	-1.14736	0.82258	13.01672	449871.6
25	0.339779	0.269766	-0.32044	-0.46047	0.314713	2.710533	-0.86857	-1.24811	13.06611	472650.5
26	0.775887	0.4518	0.551774	-0.0964	0.313748	2.718298	1.499887	-0.26205	13.48574	719085.1
27	0.52358	0.590678	0.047161	0.181356	0.035114	13.81152	0.651362	2.504802	13.3354	618715.1
28	0.075503	0.326755	-0.84899	-0.34649	0.840845	0.642119	-0.54515	-0.22249	13.12341	500524.1
29	0.374042	0.362902	-0.25192	-0.2742	0.138645	5.338736	-1.34492	-1.46386	12.98172	434397.7
30	0.43813	0.603378	-0.12374	0.206755	0.058059	9.90189	-1.22527	2.047267	13.00291	443704.7
31	0.794554	0.272508	0.589108	-0.45498	0.55406	1.459957	0.860073	-0.66426	13.37238	642022
32	0.25126	0.157394	-0.49748	-0.68521	0.717001	0.963312	-0.47923	-0.66007	13.13509	506404.7
33	0.751829	0.778857	0.503658	0.557715	0.564717	1.422596	0.716501	0.793403	13.34694	625897
34	0.866732	0.714542	0.733465	0.429084	0.722084	0.94967	0.696549	0.407488	13.34341	623688.4
35	0.158218	0.54443	-0.68356	0.08886	0.475155	1.769773	-1.20975	0.157261	13.00566	444925.9
36	0.456642	0.088733	-0.08672	-0.82253	0.684081	1.053586	-0.09136	-0.86661	13.20381	542427.8
37	0.507434	0.01375	0.014869	-0.9725	0.945977	0.34266	0.005095	-0.33324	13.2209	551777.3
38	0.187018	0.581566	-0.62596	0.163133	0.418443	2.040606	-1.27735	0.332889	12.99369	439629.3
39	0.137802	0.242154	-0.7244	-0.51569	0.790688	0.770742	-0.55832	-0.39747	13.12108	499357.7
40	0.328466	0.607783	-0.34307	0.215565	0.164164	4.691833	-1.60961	1.011397	12.93482	414496
41	0.734357	0.79746	0.468714	0.594919	0.573622	1.392053	0.652475	0.828159	13.3356	618837.1
42	0.056943	0.386464	-0.88611	-0.22707	0.83676	0.652666	-0.57834	-0.1482	13.11753	497590.2
43	0.121031	0.626939	-0.75794	0.253878	0.638924	1.184173	-0.89753	0.300635	13.06098	470231.4
44	0.697823	0.791217	0.395646	0.582433	0.495764	1.682437	0.66565	0.979908	13.33793	620283.3

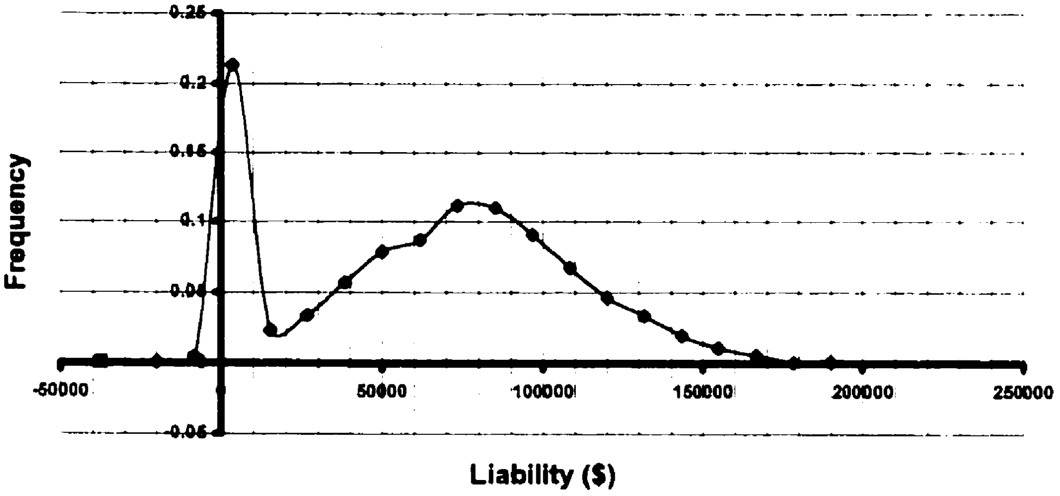
OWNER'S LIABILITY

Assumed Mean Liability ($):	**77800**	***Site Use:***	**SU0: None**
Assumed Std. Dev. ($):	**35000**	***Remedial Action:***	**SU0: None**
Iterations to be performed:	**5000**		

MaxLiab	195595	***Actual Mean:***	**62306.52**
MinLiabili	-37313.4	***Actual Std.Dev.:***	**44161.28**
Range	232908.4		
Width	11645.42		

Division	*Init.Freq.*	*Ticks*	*Midpoints*	*Freq.*	*%Freq.*
				3064	
1	0	-37313.4	-31490.7	4	0.0008
2	0	-25668	-19845.3	6	0.0012
3	0	-14022.6	-8199.84	24	0.0048
4	0	-2377.13	3445.579	1068	0.2136
5	0	9268.289	15091	115	0.023
6	0	20913.71	26736.42	170	0.034
7	0	32559.13	38381.84	285	0.057
8	0	44204.55	50027.26	394	0.0788
9	0	55849.97	61672.68	438	0.0876
10	0	67495.39	73318.1	560	0.112
11	0	79140.81	84963.52	550	0.11
12	0	90786.23	96608.94	455	0.091
13	0	102431.6	108254.4	338	0.0676
14	0	114077.1	119899.8	232	0.0464
15	0	125722.5	131545.2	168	0.0336
16	0	137367.9	143190.6	98	0.0196
17	0	149013.3	154836	55	0.011
18	0	160658.7	166481.5	28	0.0056
19	0	172304.2	178126.9	5	0.001
20	0	183949.6	189772.3	6	0.0012
		195595			

DISTRIBUTION OF OWNER'S LIABILITY



Prob.Liab = 0: **0.2**
Type of Distrib.: **normal** ***for "curve" distribution of liability***

Iteration	*Rand1*	*Rand2*	*V1*	*V2*	*R2*	*Y*	*N1*	*N2*	*Liability Using N1*	*From Uniform*
1	0.313091	0.910562	-0.37382	0.821123	0.813983	0.711127	-0.26583	0.583922	68495.88	0.259684
2	0.896103	0.403164	0.792206	-0.19367	0.6651	1.107401	0.87729	-0.21447	108505.1	0.633531
3	0.896103	0.403164	0.792206	-0.19367	0.6651	1.107401	0.87729	-0.21447	0	0.174234
4	0.899059	0.737314	0.798118	0.474628	0.862264	0.586288	0.467927	0.278269	94177.43	0.350266
5	0.453034	0.72584	-0.09393	0.451681	0.212839	3.812993	-0.35816	1.722255	65264.31	0.254134
6	0.453034	0.72584	-0.09393	0.451681	0.212839	3.812993	-0.35816	1.722255	0	0.115276
7	0.606618	0.054396	0.213235	-0.89121	0.839722	0.645021	0.137541	-0.57485	82613.94	0.869606
8	0.535893	0.041287	0.071787	-0.91743	0.846822	0.626641	0.044985	-0.5749	79374.46	0.559847
9	0.660428	0.14089	0.320855	-0.71822	0.618787	1.245554	0.399643	-0.89458	91787.49	0.325261
10	0.966141	0.369075	0.932282	-0.26185	0.937716	0.37035	0.345271	-0.09698	89884.47	0.468164
11	0.570932	0.05281	0.141864	-0.89438	0.82004	0.695619	0.098683	-0.62215	81253.91	0.688427
12	0.303899	0.217497	-0.3922	-0.56501	0.473056	1.778964	-0.69771	-1.00513	53379.99	0.865964
13	0.303899	0.217497	-0.3922	-0.56501	0.473056	1.778964	-0.69771	-1.00513	0	0.197085
14	0.303899	0.217497	-0.3922	-0.56501	0.473056	1.778964	-0.69771	-1.00513	0	0.044956
15	0.17684	0.536356	-0.64632	0.072712	0.423017	2.016842	-1.30353	0.146649	32176.6	0.952532
16	0.717641	0.291332	0.435283	-0.41734	0.36364	2.358748	1.026722	-0.98439	113735.3	0.788267
17	0.065981	0.701451	-0.86804	0.402902	0.915819	0.438224	-0.38039	0.176561	64486.19	0.499871
18	0.9105	0.519886	0.820999	0.039773	0.675621	1.077393	0.884539	0.042851	108758.9	0.728224
19	0.147109	0.448426	-0.70578	-0.10315	0.508769	1.629864	-1.15033	-0.16812	37538.45	0.781631
20	0.147109	0.448426	-0.70578	-0.10315	0.508769	1.629864	-1.15033	-0.16812	0	0.038036
21	0.147109	0.448426	-0.70578	-0.10315	0.508769	1.629864	-1.15033	-0.16812	0	0.168803
22	0.831171	0.474425	0.662341	-0.05115	0.441312	1.925392	1.275267	-0.09848	122434.3	0.30766
23	0.559967	0.033215	0.119934	-0.93357	0.885935	0.522885	0.062712	-0.48815	79994.9	0.50656
24	0.408643	0.700627	-0.18271	0.401253	0.194389	4.105092	-0.75006	1.647182	51547.99	0.880407
25	0.408643	0.700627	-0.18271	0.401253	0.194389	4.105092	-0.75006	1.647182	0	0.18901
26	0.544085	0.084584	0.08817	-0.83083	0.698057	1.014827	0.089477	-0.84315	80931.71	0.277052
27	0.544085	0.084584	0.08817	-0.83083	0.698057	1.014827	0.089477	-0.84315	0	0.146285
28	0.893978	0.235345	0.787956	-0.52931	0.901044	0.480925	0.378948	-0.25456	91063.18	0.405228
29	0.584219	0.906381	0.168439	0.812761	0.688953	1.039996	0.175176	0.845268	83931.14	0.419954
30	0.384623	0.191633	-0.23075	-0.61673	0.43361	1.963214	-0.45302	-1.21078	61944.3	0.366548
31	0.194182	0.717605	-0.61164	0.43521	0.563506	1.426796	-0.87268	0.620956	47256.24	0.688115
32	0.645389	0.072785	0.290779	-0.85443	0.814601	0.709544	0.20632	-0.60626	85021.21	0.292905
33	0.446489	0.578727	-0.10702	0.157453	0.036245	13.5298	-1.44798	2.130314	27120.56	0.760293
34	0.69216	0.667215	0.384319	0.334431	0.259545	3.223933	1.23902	1.078182	121165.7	0.766929
35	0.527895	0.465247	0.055789	-0.06951	0.007943	34.89223	1.946611	-2.42519	145931.4	0.243544
36	0.581292	0.519961	0.162584	0.039921	0.028027	15.97122	2.59666	0.637588	168683.1	0.934134
37	0.190486	0.152401	-0.61903	-0.6952	0.866497	0.575108	-0.35601	-0.39981	65339.7	0.820684
38	0.190486	0.152401	-0.61903	-0.6952	0.866497	0.575108	-0.35601	-0.39981	0	0.143715
39	0.660464	0.582553	0.320929	0.165106	0.130255	5.594319	1.795377	0.923657	140638.2	0.752551
40	0.735234	0.696441	0.470467	0.392882	0.375696	2.28288	1.07402	0.896902	115390.7	0.639102
41	0.716462	0.621469	0.432924	0.242938	0.246442	3.371467	1.459589	0.819058	128885.6	0.577605
42	0.580091	0.684695	0.160182	0.369391	0.162108	4.737924	0.758932	1.750145	104362.6	0.594818
43	0.229412	0.431374	-0.54118	-0.13725	0.31171	2.73483	-1.48002	-0.37536	25999.17	0.694995
44	0.609544	0.63308	0.219088	0.26616	0.118841	5.987144	1.311713	1.593536	123709.9	0.829807

OWNER'S NET BENEFITS

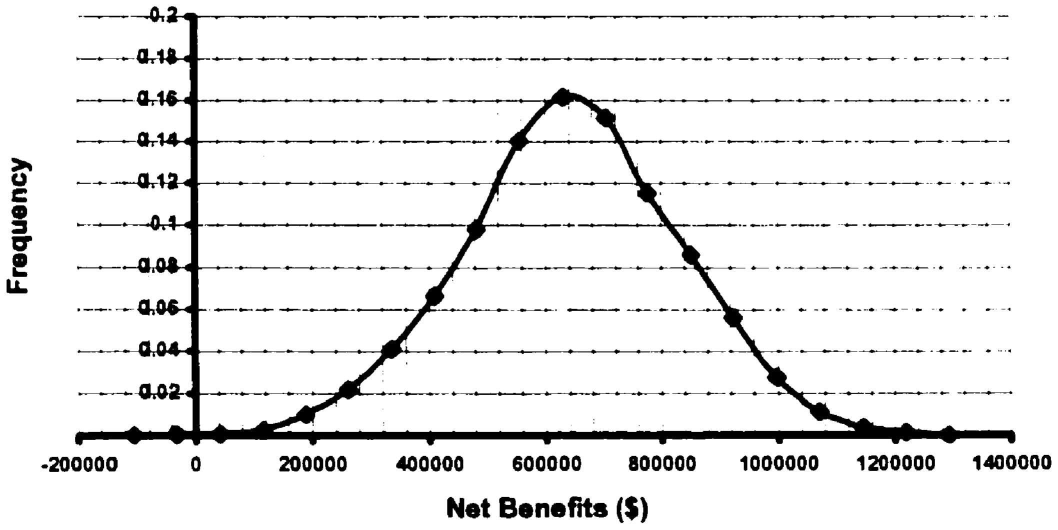
Site Use: **SU1: Service Station**

Remedial Action: **RA1: Containment**

Iterations to be Analyzed: **5000**

MaxNB	1328428	***NB Mean:***	**644774.5501**
MinNB	-142593	***NB Std.Dev.:***	**187763.6281**
Range	1471021	***NB Var:***	**35255180021**
Width	73551.06		

Division	*Init.Freq.*	*Ticks*	*Midpoints*	*Freq.*	*%Freq.*
1	0	-142593	-105818	1	0.0002
2	0	-69042.2	-32266.6	3	0.0006
3	0	4508.889	41284.42	4	0.0008
4	0	78059.95	114835.5	13	0.0026
5	0	151611	188386.5	52	0.0104
6	0	225162.1	261937.6	110	0.022
7	0	298713.1	335488.7	206	0.041200001
8	0	372264.2	409039.7	333	0.066600002
9	0	445815.2	482590.8	492	0.098399997
10	0	519366.3	556141.8	703	0.140599996
11	0	592917.4	629692.9	808	0.161599994
12	0	666468.4	703244	758	0.151600003
13	0	740019.5	776795	578	0.115599997
14	0	813570.5	850346.1	432	0.086400002
15	0	887121.6	923897.1	282	0.056400001
16	0	960672.7	997448.2	139	0.027799999
17	0	1034224	1070999	57	0.0114
18	0	1107775	1144550	20	0.004
19	0	1181326	1218101	8	0.0016
20	0	1254877	1291652	0	0
		1328428			



DISTRIBUTION OF OWNER'S NET BENEFITS

Check Mean (B-C-L): **644775**
Check Var's (B+C+L): **34895682875**
% Diff. Between Check/
Actual Var's: **1.0**

Iteration	*Benefits*	*Costs*	*Liability*	*NB's*
1	1120793	686735.1	125999.5717	308058.4
2	1353513	436834.5	0	916678.1
3	1189177	585596.6	0	603580.2
4	1483464	524891.5	0	958573
5	1238885	473241.2	48956.17158	716687.8
6	1150028	515274.2	0	634753.8
7	1243895	520441.2	92892.81972	630560.4
8	1079027	550102.8	76998.04668	451926.5
9	1251757	665607.6	72544.31866	513604.9
10	1370104	702403	55425.93134	612274.7
11	1069521	608816.5	0	460704
12	1073141	642828.2	59571.56006	370741.6
13	1176489	573644.6	0	602844.3
14	1435650	412182.1	7244.143323	1016224
15	1387040	699237.2	0	687802.7
16	1360406	453519.7	0	906886.2
17	1403210	471707.2	0	931502.7
18	1131260	535601.8	61618.44744	534039.4
19	1276938	456800.4	0	820138
20	988916.8	443024.9	94616.94907	451274.9
21	1241033	584014.9	0	657018.1
22	1087250	828264.7	94278.38974	164706.9
23	1021608	637047.4	161356.962	223204.1
24	1213164	478128.8	0	735035.1
25	1270936	771373.8	0	499562.1
26	1074483	535739.2	0	538743.8
27	1112882	522313.3	0	590568.3
28	1275510	613884.1	57633.43993	603992.9
29	1185414	625818.5	65513.6835	494082
30	1103059	504925.1	146569.6985	451564.7
31	1010064	579008.2	37009.42548	394046.8
32	1428726	502017.2	0	926708.5
33	1182229	535858.8	108532.2881	537838
34	1378870	697065.1	0	681804.5
35	1180114	442579	0	737535.3
36	1323244	538802.1	0	784441.8
37	1094003	519573.3	0	574429.6
38	1192620	502558.7	0	690061.5
39	1182097	660380.7	70015.96787	451699.9
40	1295869	751081.3	0	544788
41	1616258	578891.1	0	1037366
42	1087111	520977.4	0	566134
43	1410330	498373.2	0	911956.8
44	1614727	713921.8	0	900804.8

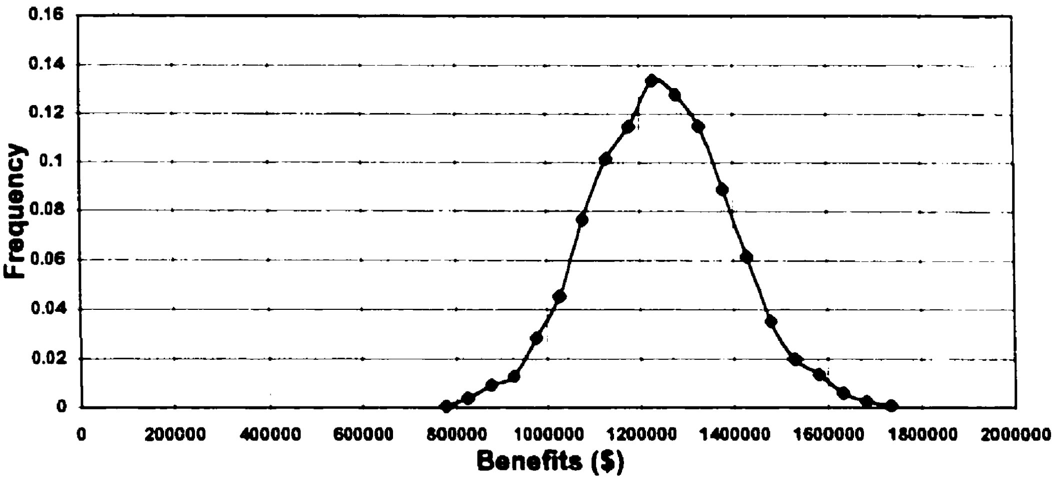
OWNER'S BENEFITS

Assumed Mean Benefits ($):	**1246000**	***Site Use:***	**SU1: Service Station**
Assumed Std. Dev. ($):	**150000**	***Remedial Action:***	**RA1: Containment**
Iterations to be performed:	**5000**		

MaxBen	1756261	***Actual Mean:***	**1242777**
MinBen	750012.3	***Actual Std.Dev.:***	**151389.6**
Range	1006249		
Width	50312.44		

Division	*Init.Freq.*	*Ticks*	*Midpoints*	*Freq.*	*%Freq.*
				2639	
1	0	750012.3	775168.5	3	0.0006
2	0	800324.7	825480.9	19	0.0038
3	0	850637.1	875793.3	46	0.0092
4	0	900949.6	926105.8	65	0.013
5	0	951262	976418.2	143	0.0286
6	0	1001574	1026731	227	0.0454
7	0	1051887	1077043	383	0.0766
8	0	1102199	1127356	509	0.1018
9	0	1152512	1177668	574	0.1148
10	0	1202824	1227980	670	0.134
11	0	1253137	1278293	640	0.128
12	0	1303449	1328605	576	0.1152
13	0	1353761	1378918	445	0.089
14	0	1404074	1429230	308	0.0616
15	0	1454386	1479543	177	0.0354
16	0	1504699	1529855	99	0.0198
17	0	1555011	1580167	68	0.0136
18	0	1605324	1630480	30	0.006
19	0	1655636	1680792	13	0.0026
20	0	1705949	1731105	4	0.0008
		1756261			

DISTRIBUTION (NORMAL) OF OWNER'S BENEFITS



Iteration	*Rand1*	*Rand2*	*V1*	*V2*	*R2*	*Y*	*N1*	*N2*	*Benefits Using N1*
1	0.401316	0.692578	-0.19737	0.385156	0.187299	4.22923	-0.83471	1.628912	1120793
2	0.72782	0.219048	0.45564	-0.5619	0.523345	1.573062	0.71675	-0.88391	1353513
3	0.475513	0.357926	-0.04897	-0.28415	0.083138	7.735244	-0.37882	-2.19795	1189177
4	0.73591	0.420607	0.471821	-0.15879	0.247828	3.355292	1.583096	-0.53277	1483464
5	0.40738	0.016671	-0.18524	-0.96666	0.968741	0.256059	-0.04743	-0.24752	1238885
6	0.369447	0.765359	-0.26111	0.530717	0.349837	2.450396	-0.63981	1.300467	1150028
7	0.433535	0.005834	-0.13293	-0.98833	0.994471	0.105594	-0.01404	-0.10436	1243895
8	0.26638	0.688207	-0.46724	0.376414	0.360001	2.382395	-1.11315	0.896767	1079027
9	0.967601	0.676461	0.935203	0.352923	0.999159	0.041038	0.038379	0.014483	1251757
10	0.511031	0.459503	0.022062	-0.08099	0.007047	37.50118	0.827358	-3.0374	1370104
11	0.279951	0.677279	-0.4401	0.354557	0.319397	2.673338	-1.17653	0.947851	1069521
12	0.187805	0.63072	-0.62439	0.261441	0.458215	1.845624	-1.15239	0.482521	1073141
13	0.412831	0.230299	-0.17434	-0.5394	0.321347	2.658093	-0.46341	-1.43378	1176489
14	0.834351	0.518595	0.668702	0.03719	0.448546	1.890729	1.264335	0.070316	1435650
15	0.582044	0.657473	0.164089	0.314947	0.126117	5.730225	0.940266	1.804715	1387040
16	0.842441	0.720154	0.684883	0.440308	0.662936	1.113629	0.762706	0.49034	1360406
17	0.71345	0.295726	0.426901	-0.40855	0.349156	2.455057	1.048066	-1.00301	1403210
18	0.157818	0.28025	-0.68436	-0.4395	0.661514	1.117733	-0.76494	-0.49124	1131260
19	0.538504	0.220345	0.077008	-0.55931	0.318757	2.678367	0.206256	-1.49804	1276938
20	0.260789	0.511619	-0.47842	0.023238	0.229427	3.582384	-1.71389	0.083248	988916.8
21	0.495779	0.726695	-0.00844	0.45339	0.205634	3.922144	-0.03311	1.778262	1241033
22	0.34344	0.307857	-0.31312	-0.38429	0.24572	3.379958	-1.05833	-1.29887	1087250
23	0.236627	0.573732	-0.52675	0.147464	0.299208	2.839967	-1.49594	0.418792	1021608
24	0.009728	0.560215	-0.98054	0.12043	0.975972	0.223251	-0.21891	0.026886	1213164
25	0.561112	0.876888	0.122223	0.753776	0.583117	1.360129	0.166239	1.025232	1270936
26	0.257989	0.320557	-0.48402	-0.35889	0.363076	2.362389	-1.14345	-0.84783	1074483
27	0.201991	0.281641	-0.59602	-0.43672	0.545959	1.488979	-0.88746	-0.65026	1112882
28	0.538222	0.785767	0.076444	0.571534	0.332495	2.573605	0.196736	1.470903	1275510
29	0.140422	0.79765	-0.71916	0.595299	0.871567	0.561637	-0.40391	0.334342	1185414
30	0.153694	0.342915	-0.69261	-0.31417	0.578414	1.375859	-0.95294	-0.43225	1103059
31	0.414091	0.405596	-0.17182	-0.18881	0.06517	9.154481	-1.5729	-1.72844	1010064
32	0.819982	0.595273	0.639963	0.190546	0.445861	1.903503	1.218172	0.362705	1428726
33	0.471334	0.35423	-0.05733	-0.29154	0.088283	7.415314	-0.42514	-2.16187	1182229
34	0.535422	0.594705	0.070843	0.18941	0.040895	12.50361	0.885797	2.368305	1378870
35	0.112214	0.758983	-0.77557	0.517965	0.869801	0.56634	-0.43924	0.293345	1180114
36	0.692962	0.83241	0.385925	0.66482	0.590923	1.334353	0.51496	0.887104	1323244
37	0.449971	0.607404	-0.10006	0.214809	0.056154	10.12727	-1.01331	2.175429	1094003
38	0.343158	0.873279	-0.31368	0.746558	0.655747	1.13447	-0.35587	0.846948	1192620
39	0.393877	0.808157	-0.21225	0.616314	0.424891	2.007212	-0.42602	1.237073	1182097
40	0.87366	0.202059	0.747321	-0.59588	0.913564	0.444872	0.332462	-0.26509	1295869
41	0.586141	0.529583	0.172282	0.059166	0.033182	14.32757	2.468383	0.847701	1616258
42	0.296861	0.298178	-0.40628	-0.40364	0.327989	2.607229	-1.05926	-1.05239	1087111
43	0.817085	0.643879	0.63417	0.287759	0.484977	1.727507	1.095534	0.497105	1410330
44	0.6044	0.517409	0.208799	0.034819	0.04481	11.77291	2.458177	0.409917	1614727

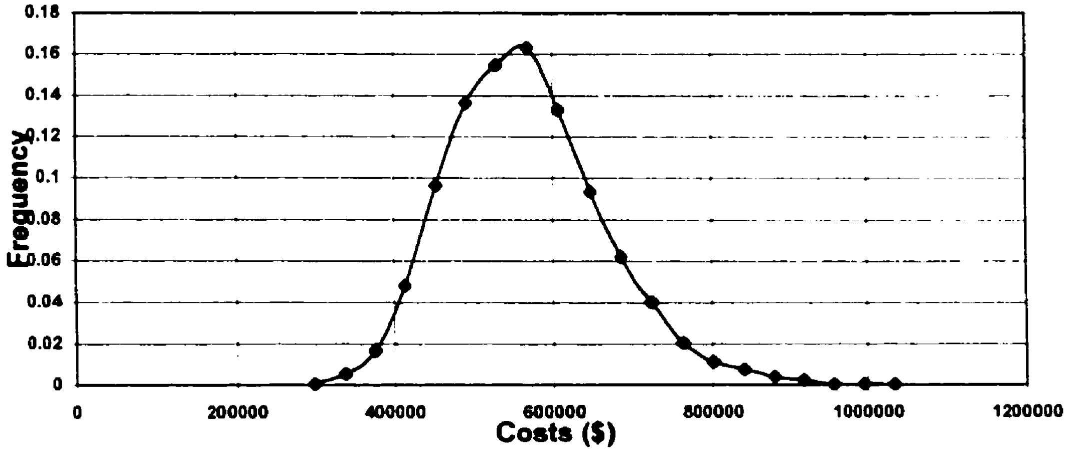
OWNER'S COSTS

	Lognorm	*LN's - Normal*		
Assumed Mean Costs ($):	**570000**	**13.23823**	***Site Use:***	**SU1: Service Station**
Assumed Std. Dev. ($):	**100000**	**0.174111**	***Remedial Action:***	**RA1: Containment**
Iterations to be performed:	**5000**			

MaxCost	1052694	***Actual Mean:***	**566201.5**
MinCost	278444.4	***Actual Std.Dev.:***	**98955.25**
Range	774249.9		
Width	38712.5		

Division	*Init.Freq.*	*Ticks*	*Midpoints*	*Freq.*	*%Freq.*
1	0	278444.4	297800.7	3	0.0006
2	0	317156.9	336513.2	28	0.0056
3	0	355869.4	375225.7	84	0.0168
4	0	394581.9	413938.2	242	0.0484
5	0	433294.4	452650.6	484	0.0968
6	0	472006.9	491363.1	683	0.1366
7	0	510719.4	530075.6	774	0.1548
8	0	549431.9	568788.1	817	0.1634
9	0	588144.4	607500.6	666	0.1332
10	0	626856.9	646213.1	469	0.0938
11	0	665569.4	684925.6	310	0.062
12	0	704281.9	723638.1	202	0.0404
13	0	742994.4	762350.6	102	0.0204
14	0	781706.9	801063.1	57	0.0114
15	0	820419.4	839775.6	39	0.0078
16	0	859131.8	878488.1	20	0.004
17	0	897844.3	917200.6	13	0.0026
18	0	936556.8	955913.1	2	0.0004
19	0	975269.3	994625.6	3	0.0006
20	0	1013982	1033338	2	0.0004
		1052694			

DISTRIBUTION (LOGNORMAL) OF OWNER'S COSTS



Iteration	*Rand1*	*Rand2*	*V1*	*V2*	*R2*	*Y*	*N1*	*N2*	*LNCost*	*Cost*
1	0.832766	0.599278	0.665532	0.198557	0.482358	1.738661	1.157135	0.345223	13.4397	686735.1
2	0.338834	0.632953	-0.32233	0.265906	0.174604	4.471112	-1.44118	1.188897	12.98731	436834.5
3	0.573824	0.848029	0.147647	0.696059	0.506297	1.639715	0.242099	1.141337	13.28039	585596.6
4	0.231925	0.138496	-0.53615	-0.72301	0.810197	0.720813	-0.38646	-0.52115	13.17095	524891.5
5	0.125112	0.404371	-0.74978	-0.19126	0.598745	1.308936	-0.98141	-0.25035	13.06736	473241.2
6	0.163792	0.797241	-0.67242	0.594482	0.805553	0.732692	-0.49267	0.435573	13.15245	515274.2
7	0.449597	0.707527	-0.10081	0.415054	0.182432	4.318827	-0.43537	1.792545	13.16243	520441.2
8	0.146474	0.151196	-0.70705	-0.69761	0.98658	0.1655	-0.11702	-0.11545	13.21786	550102.8
9	0.571494	0.359902	0.142988	-0.2802	0.098956	6.837385	0.977661	-1.91581	13.40846	665607.6
10	0.652836	0.654084	0.305671	0.308168	0.188402	4.209424	1.2867	1.297209	13.46226	702403
11	0.913233	0.716765	0.826465	0.43353	0.870993	0.563168	0.465439	0.24415	13.31927	608816.5
12	0.584703	0.312829	0.169405	-0.37434	0.16883	4.590515	0.777657	-1.71842	13.37363	642828.2
13	0.503297	0.426308	0.006594	-0.14738	0.021765	18.75366	0.123663	-2.76398	13.25977	573644.6
14	0.423907	0.425344	-0.15219	-0.14931	0.045455	11.66207	-1.77481	-1.74129	12.92922	412182.1
15	0.835975	0.495046	0.67195	-0.00991	0.451616	1.876261	1.260755	-0.01859	13.45775	699237.2
16	0.432404	0.609323	-0.13519	0.218647	0.066083	9.067811	-1.22589	1.982645	13.02479	453519.7
17	0.231643	0.703918	-0.53671	0.407836	0.454393	1.863293	-1.00006	0.759917	13.06411	471707.2
18	0.270323	0.096788	-0.45935	-0.80642	0.861325	0.588759	-0.27045	-0.47479	13.19115	535601.8
19	0.14794	0.497263	-0.70412	-0.00547	0.495815	1.682228	-1.18449	-0.00921	13.032	456800.4
20	0.198536	0.435683	-0.60293	-0.12863	0.380068	2.256257	-1.36036	-0.29023	13.00138	443024.9
21	0.636411	0.916247	0.272823	0.832494	0.767479	0.830449	0.226565	0.691344	13.27768	584014.9
22	0.604243	0.545222	0.208487	0.090445	0.051647	10.71229	2.23337	0.968869	13.62709	828264.7
23	0.609828	0.725855	0.219656	0.451711	0.252292	3.304131	0.725773	1.492512	13.3646	637047.4
24	0.139035	0.352226	-0.72193	-0.29555	0.608533	1.277678	-0.9224	-0.37762	13.07764	478128.8
25	0.715826	0.516503	0.431653	0.033006	0.187414	4.227161	1.824666	0.139523	13.55593	771373.8
26	0.438112	0.807777	-0.12378	0.615554	0.394227	2.173084	-0.26898	1.33765	13.1914	535739.2
27	0.434962	0.252041	-0.13008	-0.49592	0.262855	3.188488	-0.41475	-1.58123	13.16602	522313.3
28	0.946771	0.6308	0.893541	0.261599	0.86685	0.574173	0.513047	0.150203	13.32756	613884.1
29	0.876947	0.276184	0.753893	-0.44763	0.768729	0.827218	0.623634	-0.37029	13.34682	625818.5
30	0.168926	0.771463	-0.66215	0.542927	0.73321	0.920042	-0.6092	0.499515	13.13217	504925.1
31	0.524001	0.265931	0.048001	-0.46814	0.221458	3.689786	0.177115	-1.72733	13.26907	579008.2
32	0.1262	0.277813	-0.7476	-0.44437	0.756373	0.859253	-0.64238	-0.38183	13.12639	502017.2
33	0.139473	0.823079	-0.72105	0.646158	0.937439	0.371254	-0.26769	0.239888	13.19163	535858.8
34	0.818113	0.412279	0.636227	-0.17544	0.435564	1.953527	1.242886	-0.34273	13.45463	697065.1
35	0.224004	0.601956	-0.55199	0.203913	0.346276	2.474931	-1.36614	0.50467	13.00037	442579
36	0.408178	0.121823	-0.18364	-0.75635	0.605797	1.286357	-0.23623	-0.97294	13.1971	538802.1
37	0.472266	0.362298	-0.05547	-0.2754	0.078924	8.02168	-0.44495	-2.2092	13.16076	519573.3
38	0.049057	0.526576	-0.90189	0.053152	0.816222	0.705395	-0.63619	0.037493	13.12747	502558.7
39	0.795028	0.291837	0.590057	-0.41633	0.521495	1.580154	0.932381	-0.65786	13.40057	660380.7
40	0.666173	0.599424	0.332346	0.198848	0.149994	5.029555	1.67155	1.000118	13.52927	751081.3
41	0.559359	0.865299	0.118719	0.730597	0.547867	1.482095	0.175953	1.082815	13.26887	578891.1
42	0.33246	0.851782	-0.33508	0.703564	0.60728	1.281648	-0.42945	0.901721	13.16346	520977.4
43	0.392446	0.266918	-0.21511	-0.46616	0.26358	3.180815	-0.68422	-1.48278	13.1191	498373.2
44	0.514027	0.530348	0.028055	0.060696	0.004471	49.19422	1.380124	2.985887	13.47853	713921.8

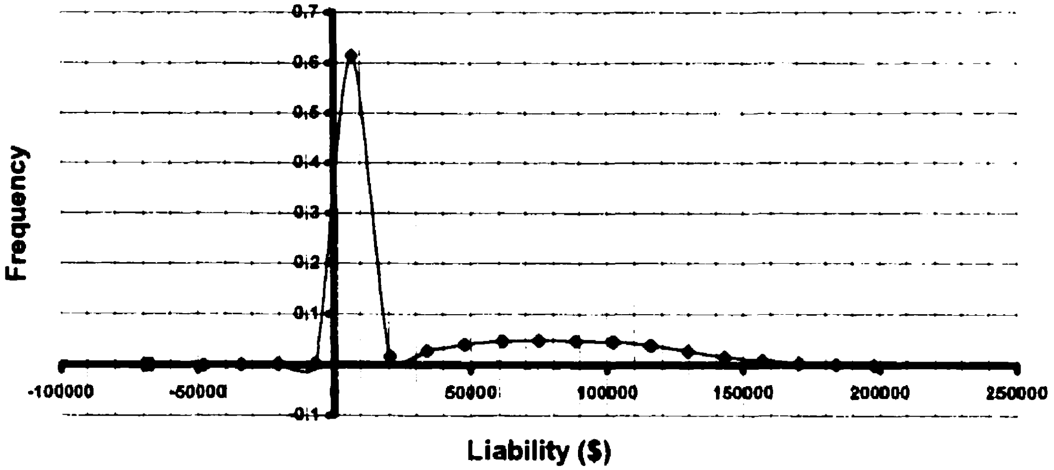
OWNER'S LIABILITY

Assumed Mean Liability ($):	**81000**	***Site Use:***	**SU1: Service Station**
Assumed Std. Dev. ($):	**40000**	***Remedial Action:***	**RA1: Containment**
Iterations to be performed:	**5000**		

MaxLiab	204440.8	***Actual Mean:***	**31800.44**
MinLiabili	-68474.6	***Actual Std.Dev.:***	**46740.97**
Range	272915.4		
Width	13645.77		

Division	*Init.Freq.*	*Ticks*	*Midpoints*	*Freq.*	*%Freq.*
				3788	
1	0	-68474.6	-61651.7	2	0.0004
2	0	-54828.8	-48006	1	0.0002
3	0	-41183.1	-34360.2	6	0.0012
4	0	-27537.3	-20714.4	11	0.0022
5	0	-13891.5	-7068.66	20	0.004
6	0	-245.772	6577.113	3075	0.615
7	0	13400	20222.88	87	0.0174
8	0	27045.77	33868.65	143	0.0286
9	0	40691.54	47514.42	205	0.041
10	0	54337.3	61160.19	238	0.0476
11	0	67983.07	74805.96	245	0.049
12	0	81628.84	88451.73	238	0.0476
13	0	95274.61	102097.5	235	0.047
14	0	108920.4	115743.3	195	0.039
15	0	122566.2	129389	140	0.028
16	0	136211.9	143034.8	84	0.0168
17	0	149857.7	156680.6	43	0.0086
18	0	163503.5	170326.3	18	0.0036
19	0	177149.2	183972.1	10	0.002
20	0	190795	197617.9	3	0.0006
		204440.8			

DISTRIBUTION OF OWNER'S LIABILITY



Prob.Liab = 0: **0.6**

Type of Distrib.: **normal** ***for "curve" distribution of liability***

Iteration	*Rand1*	*Rand2*	*V1*	*V2*	*R2*	*Y*	*N1*	*N2*	*Liability Using N1*	*From Uniform*
1	0.864055	0.487894	0.72811	-0.02421	0.530731	1.545081	1.124989	-0.03741	125999.6	0.614339
2	0.864055	0.487894	0.72811	-0.02421	0.530731	1.545081	1.124989	-0.03741	0	0.159087
3	0.864055	0.487894	0.72811	-0.02421	0.530731	1.545081	1.124989	-0.03741	0	0.229811
4	0.864055	0.487894	0.72811	-0.02421	0.530731	1.545081	1.124989	-0.03741	0	0.283218
5	0.223724	0.750806	-0.55255	0.501612	0.556929	1.449811	-0.8011	0.727243	48956.17	0.691373
6	0.223724	0.750806	-0.55255	0.501612	0.556929	1.449811	-0.8011	0.727243	0	0.107945
7	0.819203	0.146865	0.638406	-0.70627	0.90638	0.465723	0.29732	-0.32893	92892.82	0.656738
8	0.361706	0.035287	-0.27659	-0.92943	0.940335	0.361724	-0.10005	-0.3362	76998.05	0.872955
9	0.051947	0.706323	-0.89611	0.412645	0.973282	0.235901	-0.21139	0.097343	72544.32	0.887682
10	0.318826	0.206284	-0.36235	-0.58743	0.476372	1.764468	-0.63935	-1.0365	55425.93	0.940934
11	0.318826	0.206284	-0.36235	-0.58743	0.476372	1.764468	-0.63935	-1.0365	0	0.382914
12	0.247879	0.173398	-0.50424	-0.6532	0.680935	1.062407	-0.53571	-0.69397	59571.56	0.727308
13	0.247879	0.173398	-0.50424	-0.6532	0.680935	1.062407	-0.53571	-0.69397	0	0.18256
14	0.297463	0.459459	-0.40507	-0.08108	0.170659	4.552004	-1.8439	-0.36909	7244.143	0.859529
15	0.297463	0.459459	-0.40507	-0.08108	0.170659	4.552004	-1.8439	-0.36909	0	0.470008
16	0.297463	0.459459	-0.40507	-0.08108	0.170659	4.552004	-1.8439	-0.36909	0	0.583457
17	0.297463	0.459459	-0.40507	-0.08108	0.170659	4.552004	-1.8439	-0.36909	0	0.508688
18	0.060072	0.659303	-0.87986	0.318607	0.875656	0.550703	-0.48454	0.175457	61618.45	0.732996
19	0.060072	0.659303	-0.87986	0.318607	0.875656	0.550703	-0.48454	0.175457	0	0.49137
20	0.932245	0.713928	0.864489	0.427856	0.930403	0.393786	0.340424	0.168484	94616.95	0.750662
21	0.932245	0.713928	0.864489	0.427856	0.930403	0.393786	0.340424	0.168484	0	0.28732
22	0.889519	0.220278	0.779039	-0.55944	0.919879	0.426115	0.33196	-0.23839	94278.39	0.85343
23	0.662468	0.454837	0.324937	-0.09033	0.113743	6.18251	2.008924	-0.55844	161357	0.637213
24	0.662468	0.454837	0.324937	-0.09033	0.113743	6.18251	2.008924	-0.55844	0	0.476993
25	0.662468	0.454837	0.324937	-0.09033	0.113743	6.18251	2.008924	-0.55844	0	0.126361
26	0.662468	0.454837	0.324937	-0.09033	0.113743	6.18251	2.008924	-0.55844	0	0.094317
27	0.662468	0.454837	0.324937	-0.09033	0.113743	6.18251	2.008924	-0.55844	0	0.190449
28	0.332101	0.196121	-0.3358	-0.60776	0.48213	1.739633	-0.58416	-1.05728	57633.44	0.902053
29	0.299853	0.127398	-0.40029	-0.7452	0.715563	0.967186	-0.38716	-0.72075	65513.68	0.990095
30	0.603379	0.403161	0.206758	-0.19368	0.08026	7.9283	1.639242	-1.53553	146569.7	0.763599
31	0.23328	0.319795	-0.53344	-0.36041	0.414454	2.061644	-1.09976	-0.74304	37009.43	0.642059
32	0.23328	0.319795	-0.53344	-0.36041	0.414454	2.061644	-1.09976	-0.74304	0	0.019951
33	0.656786	0.770224	0.313572	0.540448	0.390412	2.195055	0.688307	1.186314	108532.3	0.834323
34	0.656786	0.770224	0.313572	0.540448	0.390412	2.195055	0.688307	1.186314	0	0.122719
35	0.656786	0.770224	0.313572	0.540448	0.390412	2.195055	0.688307	1.186314	0	0.572421
36	0.656786	0.770224	0.313572	0.540448	0.390412	2.195055	0.688307	1.186314	0	0.565785
37	0.656786	0.770224	0.313572	0.540448	0.390412	2.195055	0.688307	1.186314	0	0.320114
38	0.656786	0.770224	0.313572	0.540448	0.390412	2.195055	0.688307	1.186314	0	0.322705
39	0.163014	0.156569	-0.67397	-0.68686	0.926018	0.407437	-0.2746	-0.27985	70015.97	0.84609
40	0.163014	0.156569	-0.67397	-0.68686	0.926018	0.407437	-0.2746	-0.27985	0	0.308885
41	0.163014	0.156569	-0.67397	-0.68686	0.926018	0.407437	-0.2746	-0.27985	0	0.541283
42	0.163014	0.156569	-0.67397	-0.68686	0.926018	0.407437	-0.2746	-0.27985	0	0.31293
43	0.163014	0.156569	-0.67397	-0.68686	0.926018	0.407437	-0.2746	-0.27985	0	0.263568
44	0.163014	0.156569	-0.67397	-0.68686	0.926018	0.407437	-0.2746	-0.27985	0	0.146074

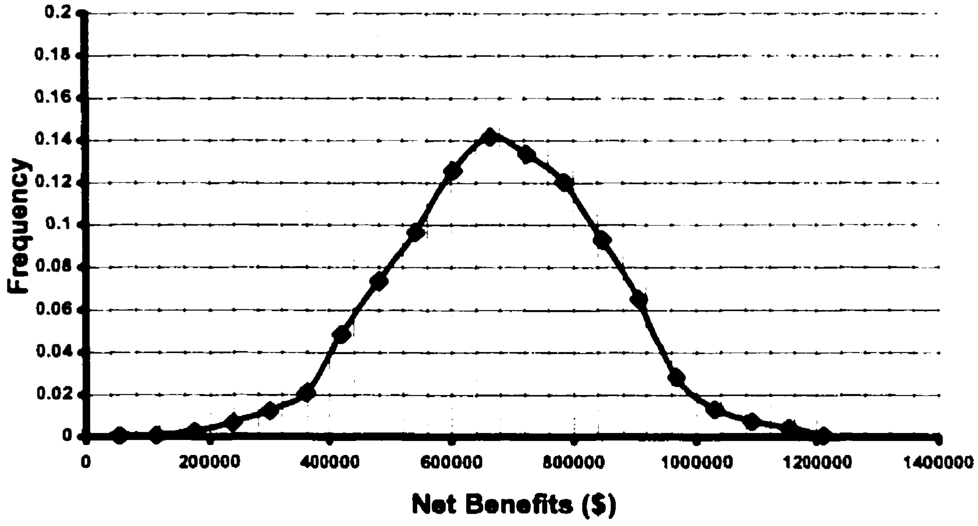
OWNER'S NET BENEFITS

Site Use:	**SU1: Service Station**
Remedial Action:	**RA2a: Moderate Pump and Treat w/ SVE**
Iterations to be Analyzed:	**5000**

MaxNB	1241980	***NB Mean:***	**677639.6314**
MinNB	23997.88	***NB Std.Dev.:***	**170875.3004**
Range	1217982	***NB Var:***	**29198368272**
Width	60899.11		

Division	*Init.Freq.*	*Ticks*	*Midpoints*	*Freq.*	*%Freq.*
1	0	23997.88	54447.44	3	0.0006
2	0	84896.99	115346.5	4	0.0008
3	0	145796.1	176245.7	13	0.0026
4	0	206695.2	237144.8	35	0.007
5	0	267594.3	298043.9	63	0.0126
6	0	328493.4	358943	106	0.021199999
7	0	389392.5	419842.1	244	0.048799999
8	0	450291.6	480741.2	368	0.073600002
9	0	511190.7	541640.3	483	0.096600004
10	0	572089.9	602539.4	630	0.126000002
11	0	632989	663438.5	710	0.142000005
12	0	693888.1	724337.6	669	0.1338
13	0	754787.2	785236.7	604	0.120800003
14	0	815686.3	846135.8	465	0.093000002
15	0	876585.4	907035	327	0.065399997
16	0	937484.5	967934.1	144	0.0288
17	0	998383.6	1028833	67	0.0134
18	0	1059283	1089732	37	0.0074
19	0	1120182	1150631	22	0.0044
20	0	1181081	1211530	5	0.001
		1241980			

DISTRIBUTION OF OWNER'S NET BENEFITS



Check Mean (B-C-L):	**677640**
Check Var's (B+C+L):	**29306506071**
% Diff. Between Check/ Actual Var's:	**0.4**

Iteration	*Benefits*	*Costs*	*Liability*	*NB's*
1	1176716	519352.9	0	657362.9
2	1206967	550513.7	0	656452.8
3	961443.9	590789.8	0	370654.1
4	1100464	512048.2	0	588415.5
5	1219674	418747.1	0	800926.6
6	1307299	551696.6	0	755602.6
7	1125876	358767.4	0	767109
8	1370535	608341.8	0	762193.3
9	1460110	591480.4	0	868629.4
10	1367876	507701	92387.45391	767787.4
11	1214355	519433.3	62667.52475	632254
12	1308974	573985.5	0	734988
13	1157243	591961.5	0	565281.4
14	1180128	460270.4	0	719857.2
15	1245533	564583.2	10702.17744	670248
16	1130677	485730.2	43670.95652	601276.3
17	1269494	512379.1	0	757114.7
18	1077384	506470.5	0	570913.2
19	1170328	534996.4	0	635331.9
20	1066146	570683	80712.65856	414749.9
21	1306660	440503.8	0	866156.2
22	1268266	518275.9	0	749989.9
23	1141876	596772.6	0	545103.4
24	1532898	616137.8	0	916760.3
25	1367933	514793.7	0	853138.8
26	1133728	531148.6	0	602579.8
27	1219021	443957.4	87157.2734	687906.1
28	1594434	472007.6	0	1122427
29	1059623	572373.4	0	487249.9
30	1304239	500327.5	7546.085081	796365.2
31	1060980	470498.4	0	590481.1
32	1310698	571562.7	0	739135.2
33	1404511	538519.1	0	865991.8
34	1375074	490652.8	0	884421.1
35	1223164	610491.6	0	612672
36	1570536	380584.2	66438.27362	1123514
37	1334210	617803.5	0	716406.2
38	1210055	511140.2	0	698915.2
39	1112511	540908.9	0	571602
40	1366821	453986.7	0	912834.2
41	1155154	752401.8	0	402752
42	1346760	485136.5	0	861623.6
43	1377961	481871.9	40383.45456	855705.6
44	1184670	464917.5	145481.3054	574271.5

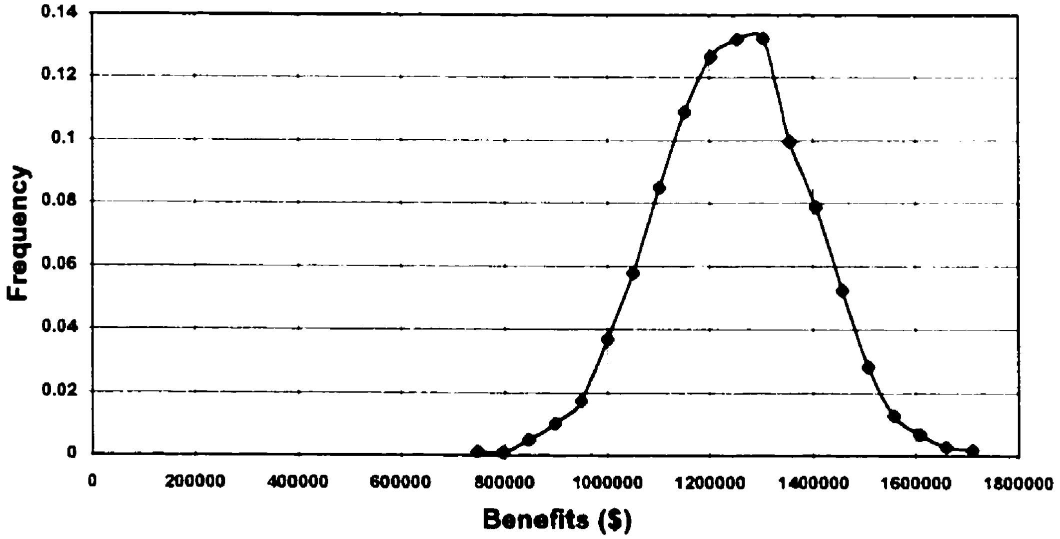
OWNER'S BENEFITS

Assumed Mean Benefits ($):	**1246000**	***Site Use:***	**SU1: Service Station**
Assumed Std. Dev. ($):	**150000**	***Remedial Action:***	**RA2a: Mod. Pump and Treat**
Iterations to be performed:	**5000**		

MaxBen	1734799	***Actual Mean:***	**1244212**
MinBen	720755.3	***Actual Std.Dev.:***	**149249.2**
Range	1014044		
Width	50702.19		

Division	***Init.Freq.***	***Ticks***	***Midpoints***	***Freq.***	***%Freq.***
				2255	
1	0	720755.3	746106.4	6	0.0012
2	0	771457.5	796808.6	5	0.001
3	0	822159.7	847510.8	25	0.005
4	0	872861.9	898213	51	0.0102
5	0	923564.1	948915.2	88	0.0176
6	0	974266.3	999617.4	185	0.037
7	0	1024968	1050320	290	0.058
8	0	1075671	1101022	425	0.085
9	0	1126373	1151724	546	0.1092
10	0	1177075	1202426	634	0.1268
11	0	1227777	1253128	662	0.1324
12	0	1278479	1303831	663	0.1326
13	0	1329182	1354533	499	0.0998
14	0	1379884	1405235	394	0.0788
15	0	1430586	1455937	263	0.0526
16	0	1481288	1506639	142	0.0284
17	0	1531990	1557341	64	0.0128
18	0	1582693	1608044	34	0.0068
19	0	1633395	1658746	14	0.0028
20	0	1684097	1709448	9	0.0018
		1734799			

DISTRIBUTION (NORMAL) OF OWNER'S BENEFITS



Iteration	*Rand1*	*Rand2*	*V1*	*V2*	*R2*	*Y*	*N1*	*N2*	*Benefits Using N1*
1	0.424664	0.751075	-0.15067	0.502151	0.274858	3.065552	-0.46189	1.539369	1176716
2	0.121541	0.194744	-0.75692	-0.61051	0.945648	0.343793	-0.26022	-0.20989	1206967
3	0.331123	0.562216	-0.33775	0.124431	0.129561	5.616629	-1.89704	0.698885	961443.9
4	0.420619	0.650296	-0.15876	0.300591	0.115561	6.111265	-0.97024	1.836994	1100464
5	0.288397	0.068565	-0.42321	-0.86287	0.923645	0.414712	-0.17551	-0.35784	1219674
6	0.941547	0.678574	0.883094	0.357149	0.907411	0.462761	0.408661	0.165274	1307299
7	0.201944	0.741255	-0.59611	0.48251	0.588165	1.343413	-0.80082	0.648211	1125876
8	0.873414	0.337319	0.746828	-0.32536	0.663612	1.111681	0.830234	-0.3617	1370535
9	0.792009	0.450799	0.584017	-0.0984	0.350759	2.444104	1.427399	-0.24051	1460110
10	0.856097	0.691274	0.712193	0.382548	0.653562	1.14085	0.812505	0.43643	1367876
11	0.432888	0.855552	-0.13422	0.711103	0.523684	1.571767	-0.21097	1.117689	1214355
12	0.822685	0.175542	0.64537	-0.64892	0.837593	0.650517	0.419824	-0.42213	1308974
13	0.057674	0.390618	-0.88465	-0.21876	0.830466	0.668867	-0.59171	-0.14632	1157243
14	0.438157	0.732691	-0.12369	0.465381	0.231878	3.550515	-0.43915	1.652343	1180128
15	0.498266	0.930658	-0.00347	0.861316	0.741877	0.897167	-0.00311	0.772744	1245533
16	0.352706	0.74539	-0.29459	0.49078	0.327647	2.609808	-0.76882	1.280842	1130677
17	0.562288	0.112862	0.124575	-0.77428	0.615024	1.257272	0.156625	-0.97348	1269494
18	0.136143	0.482237	-0.72771	-0.03553	0.530829	1.544713	-1.12411	-0.05488	1077384
19	0.191648	0.813037	-0.6167	0.626073	0.772291	0.818023	-0.50448	0.512143	1170328
20	0.15948	0.442012	-0.68104	-0.11598	0.477266	1.760587	-1.19903	-0.20419	1066146
21	0.602077	0.81161	0.204153	0.62322	0.430081	1.980863	0.4044	1.234513	1306660
22	0.666165	0.052085	0.332329	-0.89583	0.912954	0.446662	0.148439	-0.40013	1268266
23	0.242957	0.216363	-0.51409	-0.56727	0.586085	1.350277	-0.69416	-0.76598	1141876
24	0.651994	0.431755	0.303989	-0.13649	0.111039	6.291862	1.912654	-0.85878	1532898
25	0.886984	0.646831	0.773967	0.293661	0.685262	1.050282	0.812884	0.308427	1367933
26	0.414376	0.306108	-0.17125	-0.38778	0.179702	4.370731	-0.74848	-1.6949	1133728
27	0.153641	0.8493	-0.69272	0.6986	0.9679	0.259646	-0.17986	0.181389	1219021
28	0.607234	0.534662	0.214469	0.069324	0.050803	10.83092	2.322895	0.750846	1594434
29	0.481093	0.457154	-0.03781	-0.08569	0.008773	32.85849	-1.24251	-2.81572	1059623
30	0.635826	0.849644	0.271652	0.699289	0.5628	1.429251	0.388259	0.999459	1304239
31	0.243177	0.652712	-0.51365	0.305424	0.357116	2.401403	-1.23347	0.733447	1060980
32	0.649068	0.842389	0.298136	0.684778	0.557806	1.44672	0.431319	0.990682	1310698
33	0.833242	0.362256	0.666483	-0.27549	0.520094	1.585545	1.056739	-0.4368	1404511
34	0.89733	0.602731	0.794659	0.205462	0.673698	1.082845	0.860493	0.222483	1375074
35	0.474122	0.767009	-0.05176	0.534017	0.287853	2.941488	-0.15224	1.570806	1223164
36	0.610454	0.550516	0.220908	0.101031	0.059008	9.794	2.163576	0.989501	1570536
37	0.845443	0.765592	0.690887	0.531183	0.759481	0.851174	0.588065	0.452129	1334210
38	0.225926	0.107664	-0.54815	-0.78467	0.916176	0.437164	-0.23963	-0.34303	1210055
39	0.119113	0.373538	-0.76177	-0.25292	0.64427	1.16823	-0.88993	-0.29547	1112511
40	0.892214	0.360022	0.784428	-0.27996	0.693703	1.026828	0.805472	-0.28747	1366821
41	0.443598	0.676695	-0.1128	0.353389	0.137609	5.368972	-0.60564	1.897336	1155154
42	0.93262	0.400179	0.865241	-0.19964	0.788498	0.776356	0.671735	-0.15499	1346760
43	0.876623	0.361263	0.753245	-0.27747	0.64437	1.167933	0.87974	-0.32407	1377961
44	0.231698	0.855731	-0.5366	0.711461	0.794122	0.761947	-0.40886	0.542096	1184670

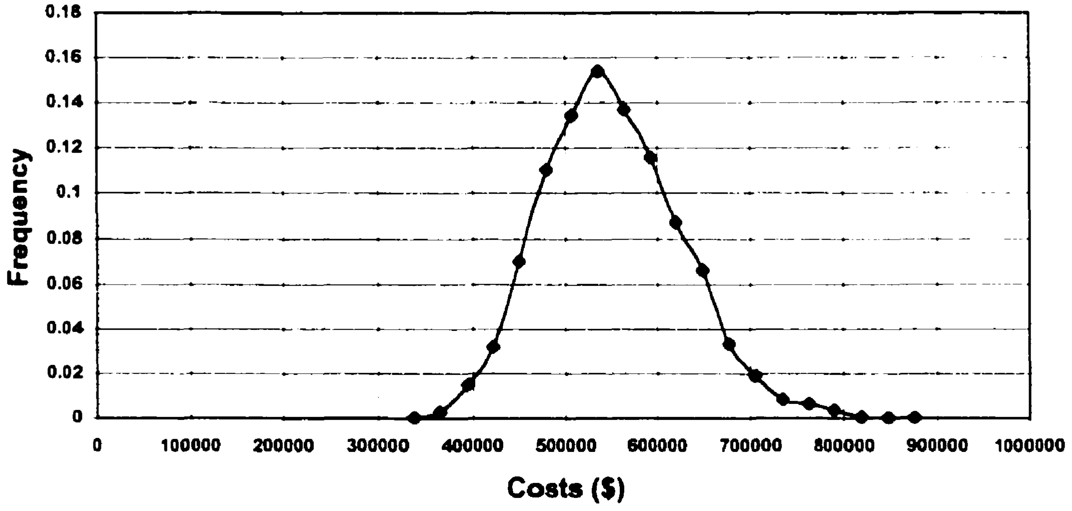
OWNER'S COSTS

	Lognorm	LN's - Normal		
Assumed Mean Costs ($):	550000	13.20846	*Site Use:*	SU1: Service Station
Assumed Std. Dev. ($):	75000	0.135736	*Remedial Action:*	RA2a: Mod. Pump and Treat
Iterations to be performed:	5000			

MaxCost	889177.2	*Actual Mean:*	550760.3
MinCost	323028.8	*Actual Std.Dev.:*	75588.12
Range	566148.3		
Width	28307.42		

Division	*Init.Freq.*	*Ticks*	*Midpoints*	*Freq.*	*%Freq.*
1	0	323028.8	337182.6	2	0.0004
2	0	351336.3	365490	14	0.0028
3	0	379643.7	393797.4	76	0.0152
4	0	407951.1	422104.8	161	0.0322
5	0	436258.5	450412.2	352	0.0704
6	0	464565.9	478719.6	552	0.1104
7	0	492873.3	507027.1	674	0.1348
8	0	521180.8	535334.5	771	0.1542
9	0	549488.2	563641.9	686	0.1372
10	0	577795.6	591949.3	580	0.116
11	0	606103	620256.7	437	0.0874
12	0	634410.4	648564.1	332	0.0664
13	0	662717.8	676871.5	168	0.0336
14	0	691025.3	705179	96	0.0192
15	0	719332.7	733486.4	42	0.0084
16	0	747640.1	761793.8	32	0.0064
17	0	775947.5	790101.2	18	0.0036
18	0	804254.9	818408.6	3	0.0006
19	0	832562.3	846716	1	0.0002
20	0	860869.8	875023.5	2	0.0004
		889177.2			

DISTRIBUTION (LOGNORMAL) OF OWNER'S COSTS



Iteration	***Rand1***	***Rand2***	***V1***	***V2***	***R2***	***Y***	***N1***	***N2***	***LNCost***	***Cost***
1	0.382703	0.151858	-0.23459	-0.69628	0.539844	1.511258	-0.35453	-1.05226	13.16034	519352.9
2	0.996737	0.449528	0.993475	-0.10094	0.997182	0.075237	0.074746	-0.00759	13.21861	550513.7
3	0.889924	0.715402	0.779848	0.430804	0.793755	0.762886	0.594935	0.328654	13.28922	590789.8
4	0.265535	0.149483	-0.46893	-0.70103	0.711345	0.97858	-0.45889	-0.68602	13.14617	512048.2
5	0.313986	0.466286	-0.37203	-0.06743	0.142951	5.21687	-1.94082	-0.35176	12.94502	418747.1
6	0.669189	0.038617	0.338379	-0.92277	0.965998	0.267625	0.090559	-0.24696	13.22075	551696.6
7	0.453482	0.498362	-0.09304	-0.00328	0.008667	33.1024	-3.07974	-0.10845	12.79043	358767.4
8	0.859372	0.688039	0.718744	0.376078	0.658028	1.127833	0.810623	0.424153	13.31849	608341.8
9	0.777967	0.801518	0.555933	0.603036	0.672715	1.085638	0.603543	0.654679	13.29038	591480.4
10	0.424538	0.267321	-0.15792	-0.46536	0.239335	3.456711	-0.5217	-1.6086	13.13765	507701
11	0.434742	0.772966	-0.13052	0.545932	0.315076	2.707616	-0.35339	1.478174	13.16049	519433.3
12	0.674161	0.130148	0.348322	-0.7397	0.668491	1.09768	0.382346	-0.81196	13.26036	573985.5
13	0.9434	0.595989	0.886801	0.191977	0.823271	0.687338	0.609532	0.131953	13.2912	591961.5
14	0.233111	0.644094	-0.53378	0.288188	0.367972	2.331056	-1.24427	0.671783	13.03957	460270.4
15	0.964763	0.342814	0.929526	-0.31437	0.962849	0.280428	0.260665	-0.08816	13.24384	564583.2
16	0.174344	0.710285	-0.65131	0.42057	0.601085	1.301409	-0.84762	0.547334	13.09341	485730.2
17	0.424424	0.754115	-0.15115	0.508229	0.281144	3.004431	-0.45413	1.52694	13.14682	512379.1
18	0.292203	0.172384	-0.41559	-0.65523	0.602047	1.298325	-0.53958	-0.8507	13.13522	506470.5
19	0.039896	0.311263	-0.92021	-0.37747	0.98927	0.14768	-0.1359	-0.05575	13.19002	534996.4
20	0.565872	0.780331	0.131744	0.560662	0.331698	2.579498	0.339834	1.446226	13.25459	570683
21	0.439079	0.577948	-0.12184	0.155896	0.039149	12.86618	-1.56765	2.005792	12.99567	440503.8
22	0.372689	0.850482	-0.25462	0.700964	0.556184	1.452438	-0.36982	1.018107	13.15826	518275.9
23	0.746107	0.208011	0.492213	-0.58398	0.583304	1.359505	0.669167	-0.79392	13.29929	596772.6
24	0.906755	0.52111	0.81351	0.042219	0.663581	1.111769	0.904436	0.046938	13.33123	616137.8
25	0.287238	0.863182	-0.42552	0.726364	0.708675	0.985818	-0.41949	0.716062	13.15152	514793.7
26	0.180425	0.129056	-0.63915	-0.74189	0.95891	0.295822	-0.18908	-0.21947	13.1828	531148.6
27	0.219105	0.521927	-0.56179	0.043854	0.317532	2.688048	-1.51012	0.117881	13.00348	443957.4
28	0.294445	0.297981	-0.41111	-0.40404	0.332258	2.575356	-1.05875	-1.04054	13.06475	472007.6
29	0.883186	0.218527	0.766372	-0.56295	0.904234	0.471865	0.361624	-0.26563	13.25755	572373.4
30	0.2904	0.197201	-0.4192	-0.6056	0.542477	1.501626	-0.62948	-0.90938	13.12302	500327.5
31	0.158179	0.615471	-0.68364	0.230942	0.520701	1.583207	-1.08235	0.365629	13.06155	470498.4
32	0.905872	0.754349	0.811744	0.508699	0.917703	0.432626	0.351181	0.220076	13.25613	571562.7
33	0.459879	0.092451	-0.08024	-0.8151	0.670822	1.091024	-0.08755	-0.88929	13.19658	538519.1
34	0.131349	0.688516	-0.7373	0.377031	0.685768	1.04887	-0.77333	0.395457	13.10349	490652.8
35	0.608151	0.298514	0.216302	-0.40297	0.209173	3.867798	0.836612	-1.55861	13.32202	610491.6
36	0.413108	0.498022	-0.17378	-0.00396	0.030216	15.21914	-2.64483	-0.06022	12.84946	380584.2
37	0.648098	0.713098	0.296195	0.426195	0.269374	3.120661	0.924325	1.330011	13.33393	617803.5
38	0.166747	0.19548	-0.66651	-0.60904	0.81516	0.708113	-0.47196	-0.43127	13.1444	511140.2
39	0.003523	0.444063	-0.99295	-0.11187	0.998474	0.055315	-0.05493	-0.00619	13.20101	540908.9
40	0.289328	0.354349	-0.42134	-0.2913	0.262388	3.193446	-1.34554	-0.93026	13.02582	453986.7
41	0.591035	0.464119	0.182071	-0.07176	0.0383	13.05213	2.376409	-0.93665	13.53103	752401.8
42	0.285283	0.253569	-0.42943	-0.49286	0.427327	1.994789	-0.85663	-0.98316	13.09219	485136.5
43	0.153062	0.671839	-0.69388	0.343678	0.59958	1.306248	-0.90638	0.448929	13.08543	481871.9
44	0.413069	0.633151	-0.17386	0.266302	0.101145	6.730926	-1.17026	1.792457	13.04962	464917.5

OWNER'S LIABILITY

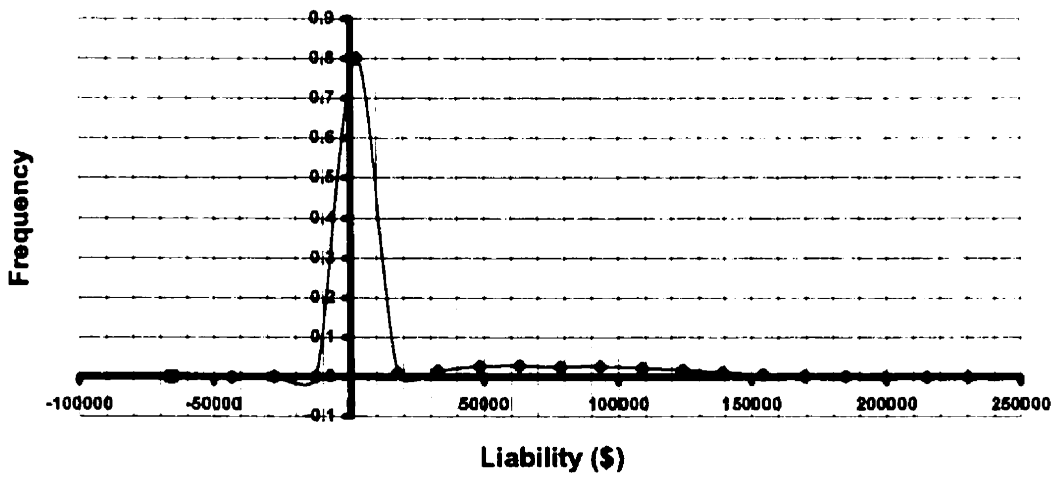
Assumed Mean Liability ($): **81000**
Assumed Std. Dev. ($): **40000**
Iterations to be performed: **5000**

Site Use: **SU1: Service Station**
Remedial Action: **RA2a: Mod. Pump and Treat**

MaxLiab	237682.9	***Actual Mean:***	**15811.88**
MinLiabili	-65869.3	***Actual Std.Dev.:***	**36298.87**
Range	303552.2		
Width	15177.61		

Division	*Init.Freq.*	*Ticks*	*Midpoints*	*Freq.*	*%Freq.*
				4568	
1	0	-65869.3	-58280.5	2	0.0004
2	0	-50691.7	-43102.9	3	0.0006
3	0	-35514.1	-27925.3	5	0.001
4	0	-20336.5	-12747.6	5	0.001
5	0	-5158.85	2429.959	4012	0.8024
6	0	10018.76	17607.57	53	0.0106
7	0	25196.37	32785.18	81	0.0162
8	0	40373.98	47962.79	136	0.0272
9	0	55551.59	63140.4	143	0.0286
10	0	70729.2	78318.01	128	0.0256
11	0	85906.81	93495.62	134	0.0268
12	0	101084.4	108673.2	111	0.0222
13	0	116262	123850.8	85	0.017
14	0	131439.6	139028.4	56	0.0112
15	0	146617.2	154206.1	34	0.0068
16	0	161794.9	169383.7	7	0.0014
17	0	176972.5	184561.3	4	0.0008
18	0	192150.1	199738.9	0	0
19	0	207327.7	214916.5	0	0
20	0	222505.3	230094.1	0	0
		237682.9			

DISTRIBUTION OF OWNER'S LIABILITY



Prob.Liab = 0: **0.8**
Type of Distrib.: **normal** ***for "curve" distribution of liability***

Iteration	*Rand1*	*Rand2*	*V1*	*V2*	*R2*	*Y*	*N1*	*N2*	*Liability Using N1*	*From Uniform*
1	0.50766	0.595593	0.01532	0.191186	0.036787	13.39982	0.205281	2.561855	0	0.724509
2	0.50766	0.595593	0.01532	0.191186	0.036787	13.39982	0.205281	2.561855	0	0.632422
3	0.50766	0.595593	0.01532	0.191186	0.036787	13.39982	0.205281	2.561855	0	0.568992
4	0.50766	0.595593	0.01532	0.191186	0.036787	13.39982	0.205281	2.561855	0	0.536948
5	0.50766	0.595593	0.01532	0.191186	0.036787	13.39982	0.205281	2.561855	0	0.63308
6	0.50766	0.595593	0.01532	0.191186	0.036787	13.39982	0.205281	2.561855	0	0.344684
7	0.50766	0.595593	0.01532	0.191186	0.036787	13.39982	0.205281	2.561855	0	0.209872
8	0.50766	0.595593	0.01532	0.191186	0.036787	13.39982	0.205281	2.561855	0	0.766972
9	0.50766	0.595593	0.01532	0.191186	0.036787	13.39982	0.205281	2.561855	0	0.350401
10	0.58539	0.157081	0.17078	-0.68584	0.49954	1.666981	0.284686	-1.14328	92387.45	0.865695
11	0.321683	0.15395	-0.35663	-0.6921	0.60619	1.285106	-0.45831	-0.88942	62667.52	0.965873
12	0.321683	0.15395	-0.35663	-0.6921	0.60619	1.285106	-0.45831	-0.88942	0	0.489258
13	0.321683	0.15395	-0.35663	-0.6921	0.60619	1.285106	-0.45831	-0.88942	0	0.183544
14	0.321683	0.15395	-0.35663	-0.6921	0.60619	1.285106	-0.45831	-0.88942	0	0.124916
15	0.299862	0.567924	-0.40028	0.135848	0.178675	4.390588	-1.75745	0.596452	10702.18	0.904653
16	0.20373	0.707211	-0.59254	0.414422	0.522849	1.57496	-0.93323	0.652698	43670.96	0.936697
17	0.20373	0.707211	-0.59254	0.414422	0.522849	1.57496	-0.93323	0.652698	0	0.071509
18	0.20373	0.707211	-0.59254	0.414422	0.522849	1.57496	-0.93323	0.652698	0	0.064873
19	0.20373	0.707211	-0.59254	0.414422	0.522849	1.57496	-0.93323	0.652698	0	0.237446
20	0.497843	0.85356	-0.00431	0.70712	0.500037	1.664959	-0.00718	1.177325	80712.66	0.974458
21	0.497843	0.85356	-0.00431	0.70712	0.500037	1.664959	-0.00718	1.177325	0	0.169313
22	0.497843	0.85356	-0.00431	0.70712	0.500037	1.664959	-0.00718	1.177325	0	0.444436
23	0.497843	0.85356	-0.00431	0.70712	0.500037	1.664959	-0.00718	1.177325	0	0.087907
24	0.497843	0.85356	-0.00431	0.70712	0.500037	1.664959	-0.00718	1.177325	0	0.423073
25	0.497843	0.85356	-0.00431	0.70712	0.500037	1.664959	-0.00718	1.177325	0	0.259524
26	0.497843	0.85356	-0.00431	0.70712	0.500037	1.664959	-0.00718	1.177325	0	0.338338
27	0.607962	0.062202	0.215925	-0.8756	0.813292	0.712895	0.153932	-0.62421	87157.27	0.836316
28	0.607962	0.062202	0.215925	-0.8756	0.813292	0.712895	0.153932	-0.62421	0	0.441106
29	0.607962	0.062202	0.215925	-0.8756	0.813292	0.712895	0.153932	-0.62421	0	0.79359
30	0.325471	0.430124	-0.34906	-0.13975	0.141372	5.26086	-1.83635	-0.73522	7546.085	0.887536
31	0.325471	0.430124	-0.34906	-0.13975	0.141372	5.26086	-1.83635	-0.73522	0	0.218657
32	0.325471	0.430124	-0.34906	-0.13975	0.141372	5.26086	-1.83635	-0.73522	0	0.332107
33	0.325471	0.430124	-0.34906	-0.13975	0.141372	5.26086	-1.83635	-0.73522	0	0.257338
34	0.325471	0.430124	-0.34906	-0.13975	0.141372	5.26086	-1.83635	-0.73522	0	0.481646
35	0.325471	0.430124	-0.34906	-0.13975	0.141372	5.26086	-1.83635	-0.73522	0	0.543142
36	0.300674	0.120238	-0.39865	-0.75952	0.735802	0.913184	-0.36404	-0.69359	66438.27	0.888147
37	0.300674	0.120238	-0.39865	-0.75952	0.735802	0.913184	-0.36404	-0.69359	0	0.510255
38	0.300674	0.120238	-0.39865	-0.75952	0.735802	0.913184	-0.36404	-0.69359	0	0.699928
39	0.300674	0.120238	-0.39865	-0.75952	0.735802	0.913184	-0.36404	-0.69359	0	0.599751
40	0.300674	0.120238	-0.39865	-0.75952	0.735802	0.913184	-0.36404	-0.69359	0	0.165862
41	0.300674	0.120238	-0.39865	-0.75952	0.735802	0.913184	-0.36404	-0.69359	0	0.098618
42	0.300674	0.120238	-0.39865	-0.75952	0.735802	0.913184	-0.36404	-0.69359	0	0.459192
43	0.216113	0.692707	-0.56777	0.385414	0.470912	1.788411	-1.01541	0.689279	40383.45	0.846311
44	0.512599	0.476405	0.025198	-0.04719	0.002862	63.97437	1.612033	-3.01893	145481.3	0.903763

E.1 EXCEL 97 VISUAL BASIC PROGRAMS FOR PROBABILISTIC ANALYSIS

This appendix shows the Excel 97 Visual Basic programs that were written to derive the owner's net benefits, site use benefits, costs, and liability distributions for the probabilistic analysis of the illustrative example.

The programs are shown in the following order:

- Subroutine to return a normally distributed random number for other subroutines that need such a value.
- Subroutine to derive the distribution of the owner's site use benefits.
- Subroutine to derive the distribution of the owner's costs of remediation.
- Subroutine to derive the distribution of the owner's liability.
- Subroutine to calculate the distribution of the owner's net benefits.

SUBROUTINE TO RETURN A NORMALLY DISTRIBUTED RANDOM NUMBER

```
'This subroutine returns the FIRST of
'two normally distributed random numbers
'with mean 0, variance 1 [N(0,1)] using the Polar-Marsaglia Method.

'Declare following variables as "Public" BEFORE Sub or Function
'so that they can be used in other subroutines. Do not redeclare
'them in the next subroutine or else the value will be "cleared".

Public Rand1 As Double
Public Rand2 As Double
Public V1 As Double
Public V2 As Double
Public R2 As Double
Public Y As Double
Public N1 As Double
Public N2 As Double

Public Sub Normal1()

'Initialize random number generator.
Randomize

10: Rand1 = Rnd
  Rand2 = Rnd
  Let V1 = 2 * Rand1 - 1
  Let V2 = 2 * Rand2 - 1
  Let R2 = (V1 * V1) + (V2 * V2)
    If R2 > 1 Then GoTo 10 Else _
    Y = Sqr(((-1 * 2) * Log(R2)) / R2)
  N1 = V1 * Y
  N2 = V2 * Y

End Sub
```

SUBROUTINE TO DERIVE THE OWNER'S SITE USE BENEFITS

```
Public BenArray() As Double

Sub Benefits()

'This subroutine calculates the benefits for the owner based on
'the normal values from the Normall Function.

Dim I As Integer
Dim J As Integer
Dim K As Integer
Dim L As Integer
Dim M As Integer
Dim N As Integer
Dim C As Integer
Dim W As Double
Dim BEN As Double
Dim BenSum As Double
Dim BenSum2 As Double
Dim BenMean As Double
Dim DiffSqd As Double
Dim BenSD As Double
Dim Freq() As Integer
Dim BenTicks() As Double
Dim BenMidpoints() As Double

'Clear Worksheets("Benefits").Cells A13 to Z15000 if there are previous values on the
spreadsheet.

Worksheets("Benefits").Range("A13:Z15000").Clear

'SU = InputBox("Site use description? (none;commercial;residential)")
'Worksheets("Benefits").Range("H2").Font.Bold = True
'Worksheets("Benefits").Range("H2").Value = SU

'RA = InputBox("Remedial action used? (none;contain;pump-treat)")
'Worksheets("Benefits").Range("H3").Font.Bold = True
'Worksheets("Benefits").Range("H3").Value = RA

Mean = InputBox("Expected mean of the benefits?", "BENEFITS")
Worksheets("Benefits").Range("D2").Font.Bold = True
Worksheets("Benefits").Range("D2").Value = Mean

StdDev = InputBox("Expected standard deviation of the benefits?", "BENEFITS")
Worksheets("Benefits").Range("D3").Font.Bold = True
```

```
Worksheets("Benefits").Range("D3").Value = StdDev

M = InputBox("Number of iterations for random number generation?", "ITERATIONS")
Worksheets("Benefits").Range("D4").Font.Bold = True
Worksheets("Benefits").Range("D4").Value = M

D = InputBox("How many benefits divisions do you want to divide the benefits into for the
frequency histogram? (10 is default.)", "INTERVALS", 10)

BenSum = 0

For I = 1 To M
   Call Normal1
   BEN = N1 * StdDev + Mean
   BenSum = BenSum + BEN

   'Note! ReDim wipes out the dynamic array... and since I am interating
   'it M times, nothing is stored from the previous iterations. Use the
   'Preserve command.
   ReDim Preserve BenArray(M)
   BenArray(I) = BEN

   'Output SELECTED random numbers and benefits to the worksheet.

   Row = 12 + I
      With Worksheets("Benefits")
         .Cells(Row, 11) = I
         .Cells(Row, 12) = Rand1
         .Cells(Row, 13) = Rand2
         .Cells(Row, 14) = V1
         .Cells(Row, 15) = V2
         .Cells(Row, 16) = R2
         .Cells(Row, 17) = Y
         .Cells(Row, 18) = N1
         .Cells(Row, 19) = N2
         .Cells(Row, 20) = BEN
      End With

   'The following was used to double check the benefits array.
      'Row = 20 + I
      'Worksheets("Benefits").Cells(Row, 10) = BenArray(I)

 Next I
```

```
'Calculate the actual mean and standard deviation.

BenMean = BenSum / M
Worksheets("Benefits").Range("F6").Value = BenMean
Worksheets("Benefits").Range("F6").Font.Bold = True

BenSum2 = 0
For C = 1 To M
   DiffSqd = (BenArray(C) - BenMean) ^ 2
   BenSum2 = BenSum2 + DiffSqd
Next C

BenSD = Sqr(BenSum2 / M)
Worksheets("Benefits").Range("F7").Value = BenSD
Worksheets("Benefits").Range("F7").Font.Bold = True

'Find the maximum and minimum benefits and their range.

Let MaxBen = BenArray(1)
Let MinBen = BenArray(1)

For K = 2 To M
   If BenArray(K) > MaxBen Then MaxBen = BenArray(K)
   If BenArray(K) < MinBen Then MinBen = BenArray(K)
Next K

RangeBen = MaxBen - MinBen

Worksheets("Benefits").Range("B6").Value = MaxBen
Worksheets("Benefits").Range("B7").Value = MinBen
Worksheets("Benefits").Range("B8").Value = RangeBen

'Develop an array that shows the frequency of occurence of the
'benefits.

W = RangeBen / D
Worksheets("Benefits").Range("B9").Value = W

'Set the Freq array values to zero - the initial counter value of all
'array elements.
```

```
ReDim Preserve Freq(D)
  For L = 1 To D
    Freq(L) = 0
    Row = 12 + L
      With Worksheets("Benefits")
        .Cells(Row, 1) = L
        .Cells(Row, 2) = Freq(L)
      End With
  Next L

'Set the values for the division "BenTicks" and calculate BenMidpoints for each
'interval.

ReDim Preserve BenTicks(D)
BenTicks(0) = MinBen
BenTicks(D) = MaxBen

For N = 1 To D
  BenTicks(N) = BenTicks(N - 1) + W
  ReDim Preserve BenMidpoints(D)
  BenMidpoints(N) = BenTicks(N - 1) + W / 2

  For K = 1 To M
    If (BenArray(K) >= BenTicks(N - 1)) And (BenArray(K) < BenTicks(N)) Then
      Freq(N) = Freq(N) + 1
    End If
  Next K

Next N

For J = 0 To D
  Row = 12 + 1 + J
    Worksheets("Benefits").Cells(Row, 3) = BenTicks(J)
Next J

For L = 1 To D
  Row = 12 + L
    With Worksheets("Benefits")
      .Cells(Row, 4) = BenMidpoints(L)
      .Cells(Row, 5) = Freq(L)
      .Cells(Row, 6) = Freq(L) / M  'Gives percent frequency.
    End With
Next L

End Sub
```

SUBROUTINE TO DERIVE THE OWNER'S COSTS

```
Public CostArray() As Double
'If getting a variable from a previous subroutine/function, DO NOT
'publicly redeclare it in the subroutine you want it used, otherwise
'it will be reset to nothing. eg. NO... Public RA As String

Sub Costs()

'This subroutine calculates the costs of remediation to the owner based on
'lognormal values calculated from the normal values returned from the Normal1 Function.

Dim I As Integer
Dim J As Integer
Dim K As Integer
Dim L As Integer
Dim M As Integer
Dim D As Integer
Dim C As Integer
Dim W As Double
Dim LNStdDev As Double
Dim LNMean As Double
Dim COST As Double
Dim CostSum As Double
Dim CostSum2 As Double
Dim CostMean As Double
Dim DiffSqd As Double
Dim CostSD As Double
Dim Freq() As Integer
Dim CostTicks() As Double
Dim CostMidpoints() As Double

'Clear Worksheets("Costs").Cells A13 to Z15000 if there are previous values on the
spreadsheet.

Worksheets("Costs").Range("A13:Z15000").Clear

'Worksheets("Costs").Range("H2").Font.Bold = True
'Worksheets("Costs").Range("H2").Value = SU

'Worksheets("Costs").Range("H3").Font.Bold = True
'Worksheets("Costs").Range("H3").Value = RA

Mean = InputBox("Expected mean of the costs?", "COSTS")
Worksheets("Costs").Range("D2").Font.Bold = True
Worksheets("Costs").Range("D2").Value = Mean
```

```
StdDev = InputBox("Expected standard deviation of the costs?", "COSTS")
Worksheets("Costs").Range("D3").Font.Bold = True
Worksheets("Costs").Range("D3").Value = StdDev

M = InputBox("Number of iterations for random number generation?", "ITERATIONS")
Worksheets("Costs").Range("D4").Font.Bold = True
Worksheets("Costs").Range("D4").Value = M

D = InputBox("How many cost intervals for the frequency histogram? (10 is default.)",
"INTERVALS", 10)

'Calculate standard deviation and mean for the logs of the costs
'based on the inputed cost data.

   LNStdDev = Sqr(Log(1 + StdDev ^ 2 / Mean ^ 2))
   Worksheets("Costs").Range("E3").Font.Bold = True
   Worksheets("Costs").Range("E3").Value = LNStdDev
   LNMean = Log(Mean) - LNStdDev ^ 2 / 2
   Worksheets("Costs").Range("E2").Font.Bold = True
   Worksheets("Costs").Range("E2").Value = LNMean

CostSum = 0

For I = 1 To M
   Call Normal1
   LNCost = N1 * LNStdDev + LNMean
   COST = Exp(LNCost)
   CostSum = CostSum + COST

   ReDim Preserve CostArray(M)
   CostArray(I) = COST

   'Output SELECTED random numbers and benefits to the worksheet.

   Row = 12 + I
      With Worksheets("Costs")
         .Cells(Row, 11) = I
         .Cells(Row, 12) = Rand1
         .Cells(Row, 13) = Rand2
         .Cells(Row, 14) = V1
         .Cells(Row, 15) = V2
         .Cells(Row, 16) = R2
         .Cells(Row, 17) = Y
         .Cells(Row, 18) = N1
         .Cells(Row, 19) = N2
         .Cells(Row, 20) = LNCost
         .Cells(Row, 21) = COST
      End With
```

```
Next I

'Calculate the actual mean and standard deviation.

CostMean = CostSum / M
Worksheets("Costs").Range("F6").Value = CostMean
Worksheets("Costs").Range("F6").Font.Bold = True

CostSum2 = 0
For C = 1 To M
   DiffSqd = (CostArray(C) - CostMean) ^ 2
   CostSum2 = CostSum2 + DiffSqd
Next C

CostSD = Sqr(CostSum2 / M)
Worksheets("Costs").Range("F7").Value = CostSD
Worksheets("Costs").Range("F7").Font.Bold = True

'Find the maximum and minimum costs and their range.

Let MaxCost = CostArray(1)
Let MinCost = CostArray(1)

For K = 2 To M
   If CostArray(K) > MaxCost Then MaxCost = CostArray(K)
   If CostArray(K) < MinCost Then MinCost = CostArray(K)
Next K

RangeCost = MaxCost - MinCost

Worksheets("Costs").Range("B6").Value = MaxCost
Worksheets("Costs").Range("B7").Value = MinCost
Worksheets("Costs").Range("B8").Value = RangeCost

'Develop an array that shows the frequency of occurence of the
'costs.

W = RangeCost / D
Worksheets("Costs").Range("B9").Value = W

'Set the Freq array values to zero - the initial counter value of all
'array elements.

ReDim Preserve Freq(D)
   For L = 1 To D
      Freq(L) = 0
      Row = 12 + L
         With Worksheets("Costs")
```

```
            .Cells(Row, 1) = L
            .Cells(Row, 2) = Freq(L)
        End With
    Next L

'Set the values for the division "CostTicks" and calculate CostMidpoints for each
'interval.

ReDim Preserve CostTicks(D)
CostTicks(0) = MinCost
CostTicks(D) = MaxCost

For N = 1 To D
    CostTicks(N) = CostTicks(N - 1) + W
    ReDim Preserve CostMidpoints(D)
    CostMidpoints(N) = CostTicks(N - 1) + W / 2

    For K = 1 To M
        If (CostArray(K) >= CostTicks(N - 1)) And (CostArray(K) < CostTicks(N)) Then
            Freq(N) = Freq(N) + 1
        End If
    Next K

Next N

For J = 0 To D
    Row = 12 + 1 + J
        Worksheets("Costs").Cells(Row, 3) = CostTicks(J)
Next J

For L = 1 To D
    Row = 12 + L
        With Worksheets("Costs")
            .Cells(Row, 4) = CostMidpoints(L)
            .Cells(Row, 5) = Freq(L)
            .Cells(Row, 6) = Freq(L) / M  'Gives percent frequency.
        End With
Next L

End Sub
```

SUBROUTINE TO DERIVE THE OWNER'S LIABILITY

```
Public LiabArray() As Double

Sub Liability()

'This subroutine calculates the liability to the owner. There will
'be two components: a probability that liability is ZERO, and a
'probability that the financial cost of liability will be distributed
'according to some other function (assumed to be a normal distribution).

'Note that if liability is equal to zero, it is not shown separately but
'included in the range that includes zero.

Dim I As Integer
Dim J As Integer
Dim K As Integer
Dim L As Integer
Dim M As Integer
Dim D As Integer
Dim C As Integer
Dim Freq() As Integer
Dim Distb As Integer
Dim Distribution As String * 20
Dim LiabSum As Double
Dim LiabSum2 As Double
Dim LiabMean As Double
Dim LiabSD As Double
Dim DiffSqd As Double
Dim Prob As Double
Dim ProbLiab As Double
Dim W As Double
Dim LIAB As Double
Dim MaxLiab As Double
Dim MinLiab As Double
Dim RangeLiab As Double
Dim LiabTicks() As Double
Dim LiabMidpoints() As Double

'Clear Worksheets("Liability").Cells A13 to Z15000 if there are previous values on the spreadsheet.

Worksheets("Liability").Range("A13:Z15000").Clear

'Worksheets("Liability").Range("H2").Font.Bold = True
'Worksheets("Liability").Range("H2").Value = SU
```

```
'Worksheets("Liability").Range("H3").Font.Bold = True
'Worksheets("Liability").Range("H3").Value = RA

Prob = InputBox("Probability that liability will equal ZERO?(Between 0 and 1.)", "LIABILITY")
Worksheets("Liability").Range("M2").Font.Bold = True
Worksheets("Liability").Range("M2").Value = Prob

Distb = InputBox("Type of distribution for liability for that portion? [1=norm] or [2=lognorm]", "LIABILITY")
If Distb = 1 Then Distribution = "normal"
If Distb = 2 Then Distribution = "lognormal"
Worksheets("Liability").Range("M3").Font.Bold = True
Worksheets("Liability").Range("M3").Value = Distribution

Mean = InputBox("Expected mean of the liability for the distribution portion?", "LIABILITY")
Worksheets("Liability").Range("D2").Font.Bold = True
Worksheets("Liability").Range("D2").Value = Mean

StdDev = InputBox("Expected standard deviation of the liability for the distribution portion?", "LIABILITY")
Worksheets("Liability").Range("D3").Font.Bold = True
Worksheets("Liability").Range("D3").Value = StdDev

M = InputBox("Number of iterations for random number generation?", "ITERATIONS")
Worksheets("Liability").Range("D4").Font.Bold = True
Worksheets("Liability").Range("D4").Value = M

D = InputBox("How many Liab intervals for the frequency histogram? (10 is default.)", "INTERVALS", 10)

LiabSum = 0

For I = 1 To M
  'Generate a uniformly distributed random number between 0 and 1.
  'If randomly selected ProbLiab is less than Prob specified by user,
  'then liability equals zero.

  Randomize
  ProbLiab = Rnd
  If ProbLiab <= Prob Then
    LIAB = 0
  ElseIf (ProbLiab > Prob) And (Distb = 1) Then
    Call Normal1
    LIAB = N1 * StdDev + Mean
  End If
```

```
  LiabSum = LiabSum + LIAB

  ReDim Preserve LiabArray(M)
  LiabArray(I) = LIAB

  'Output SELECTED random numbers and benefits to the worksheet.

  Row = 12 + I
    With Worksheets("Liability")
      .Cells(Row, 11) = I
      .Cells(Row, 12) = Rand1
      .Cells(Row, 13) = Rand2
      .Cells(Row, 14) = V1
      .Cells(Row, 15) = V2
      .Cells(Row, 16) = R2
      .Cells(Row, 17) = Y
      .Cells(Row, 18) = N1
      .Cells(Row, 19) = N2
      .Cells(Row, 20) = LIAB
      .Cells(Row, 21) = ProbLiab
    End With
Next I

'Calculate the mean and standard deviation of the ENTIRE
'liability distribution.

LiabMean = LiabSum / M
Worksheets("Liability").Range("F6").Font.Bold = True
Worksheets("Liability").Range("F6").Value = LiabMean

LiabSum2 = 0
For C = 1 To M
  DiffSqd = (LiabArray(C) - LiabMean) ^ 2
  LiabSum2 = LiabSum2 + DiffSqd
Next C

LiabSD = Sqr(LiabSum2 / M)
Worksheets("Liability").Range("F7").Font.Bold = True
Worksheets("Liability").Range("F7").Value = LiabSD

'Find the maximum and minimum Liability and their range.

Let MaxLiab = LiabArray(1)
Let MinLiab = LiabArray(1)

For K = 2 To M
  If LiabArray(K) > MaxLiab Then MaxLiab = LiabArray(K)
  If LiabArray(K) < MinLiab Then MinLiab = LiabArray(K)
```

```
Next K

RangeLiab = MaxLiab - MinLiab

Worksheets("Liability").Range("B6").Value = MaxLiab
Worksheets("Liability").Range("B7").Value = MinLiab
Worksheets("Liability").Range("B8").Value = RangeLiab

'Develop an array that shows the frequency of occurence of the
'Liability.

W = RangeLiab / D
Worksheets("Liability").Range("B9").Value = W

'Set the Freq array values to zero - the initial counter value of all
'array elements.

ReDim Preserve Freq(D)
  For L = 1 To D
    Freq(L) = 0
    Row = 12 + L
      With Worksheets("Liability")
        .Cells(Row, 1) = L
        .Cells(Row, 2) = Freq(L)
      End With
  Next L

'Set the values for the division "LiabTicks" and calculate LiabMidpoints for each
'interval.

ReDim Preserve LiabTicks(D)
LiabTicks(0) = MinLiab
LiabTicks(D) = MaxLiab

For N = 1 To D
  LiabTicks(N) = LiabTicks(N - 1) + W
  ReDim Preserve LiabMidpoints(D)
  LiabMidpoints(N) = LiabTicks(N - 1) + W / 2

  For K = 1 To M
    If (LiabArray(K) >= LiabTicks(N - 1)) And (LiabArray(K) < LiabTicks(N)) Then
      Freq(N) = Freq(N) + 1
    End If
  Next K

Next N

For J = 0 To D
```

```
  Row = 12 + 1 + J
    Worksheets("Liability").Cells(Row, 3) = LiabTicks(J)
Next J

For L = 1 To D
  Row = 12 + L
    With Worksheets("Liability")
      .Cells(Row, 4) = LiabMidpoints(L)
      .Cells(Row, 5) = Freq(L)
      .Cells(Row, 6) = Freq(L) / M  'Gives percent frequency.
    End With
Next L

End Sub
```

SUBROUTINE TO CALCULATE THE OWNER'S NET BENEFITS

```
Public NetBenArray() As Double
Public SU As String
Public RA As String

Sub NET()

'This subroutine calculates the net benefits for every iteration of
'benefits, costs, and liability calculated.

Dim I As Integer
Dim J As Integer
Dim K As Integer
Dim L As Integer
Dim B As Integer
Dim N As Integer
Dim C As Integer
Dim Freq() As Integer
Dim NBSum As Double
Dim NBSum2 As Double
Dim NBMean As Double
Dim NBSD As Double
Dim DiffSqd As Double
Dim W As Double
Dim RangeNetBen As Double
Dim MinNetBen As Double
Dim MaxNetBen As Double
Dim BEN As Double
Dim COST As Double
Dim NetBenTicks() As Double
Dim NetBenMidpoints() As Double

'Clear Worksheets("NetBens").Cells A13 to Z15000 if there are previous values on the
spreadsheet.
Worksheets("NetBens").Range("A13:Z15000").Clear

SU = InputBox("Site use description? (none;commercial;residential)", "SITE USE")
With Worksheets("NetBens").Range("D2")
   .Font.Bold = True
   .Font.Size = 14
   .Value = SU
End With

RA = InputBox("Remedial action used? (none;contain;pump-treat)", "REMEDIAL ACTION")
With Worksheets("NetBens").Range("D3")
```

```
  .Font.Bold = True
  .Font.Size = 14
  .Value = RA
End With

Call Benefits
Call Costs
Call Liability

B = InputBox("Number of net benefits iterations to look at?", "ITERATIONS")
With Worksheets("NetBens").Range("D4")
  .Font.Bold = True
  .Value = B
End With

D = InputBox("How many NetBens divisions do you want to divide the NetBens into for the
frequency histogram? (10 is default.)", "INTERVALS", 10)

NBSum = 0

For I = 1 To B

  BEN = BenArray(I)
  COST = CostArray(I)
  LIAB = LiabArray(I)

  ReDim Preserve NetBenArray(B)
  NetBenArray(I) = BEN - COST - LIAB
  NBSum = NBSum + NetBenArray(I)

  'Output net benefits to the worksheet.

  Row = 12 + I
    With Worksheets("NetBens")
      .Cells(Row, 11) = I
      .Cells(Row, 12) = BenArray(I)
      .Cells(Row, 13) = CostArray(I)
      .Cells(Row, 14) = LiabArray(I)
      .Cells(Row, 15) = NetBenArray(I)
    End With
Next I

'Calculate the mean and standard deviation of the ENTIRE
'net benefits distribution.

NBMean = NBSum / B
Worksheets("NetBens").Range("F6").Font.Bold = True
Worksheets("NetBens").Range("F6").Value = NBMean
```

```
NBSum2 = 0
For C = 1 To B
  DiffSqd = (NetBenArray(C) - NBMean) ^ 2
  NBSum2 = NBSum2 + DiffSqd
Next C

NBSD = Sqr(NBSum2 / B)
Worksheets("NetBens").Range("F7").Font.Bold = True
Worksheets("NetBens").Range("F7").Value = NBSD

'Find the maximum and minimum net benefits and their range.

Let MaxNetBen = NetBenArray(1)
Let MinNetBen = NetBenArray(1)

For K = 2 To B
  If NetBenArray(K) > MaxNetBen Then MaxNetBen = NetBenArray(K)
  If NetBenArray(K) < MinNetBen Then MinNetBen = NetBenArray(K)
Next K

RangeNetBen = MaxNetBen - MinNetBen

Worksheets("NetBens").Range("B6").Value = MaxNetBen
Worksheets("NetBens").Range("B7").Value = MinNetBen
Worksheets("NetBens").Range("B8").Value = RangeNetBen

'Develop an array that shows the frequency of occurence of the
'NetBens.

W = RangeNetBen / D
Worksheets("NetBens").Range("B9").Value = W

'Set the Freq array values to zero - the initial counter value of all
'array elements.

ReDim Preserve Freq(D)
  For L = 1 To D
    Freq(L) = 0
    Row = 12 + L
      With Worksheets("NetBens")
        .Cells(Row, 1) = L
        .Cells(Row, 2) = Freq(L)
      End With
  Next L

'Set the values for the division "NetBenTicks" and calculate NetBenMidpoints for each
'interval.
```

```
ReDim Preserve NetBenTicks(D)
NetBenTicks(0) = MinNetBen
NetBenTicks(D) = MaxNetBen

For N = 1 To D
   NetBenTicks(N) = NetBenTicks(N - 1) + W
   ReDim Preserve NetBenMidpoints(D)
   NetBenMidpoints(N) = NetBenTicks(N - 1) + W / 2

   For K = 1 To B
      If (NetBenArray(K) >= NetBenTicks(N - 1)) And (NetBenArray(K) < NetBenTicks(N))
Then
         Freq(N) = Freq(N) + 1
      End If
   Next K

Next N

For J = 0 To D
   Row = 12 + 1 + J
      Worksheets("NetBens").Cells(Row, 3) = NetBenTicks(J)
Next J

For L = 1 To D
   Row = 12 + L
      With Worksheets("NetBens")
         .Cells(Row, 4) = NetBenMidpoints(L)
         .Cells(Row, 5) = Freq(L)
         .Cells(Row, 6) = Freq(L) / B 'Gives percent frequency.
      End With
Next L

End Sub
```