AN ANALYTICAL BASIS FOR VALUING POTENTIAL AND REALIZED GROUNDWATER PROTECTION BENEFITS IN THE STATE OF WYOMING

Thomas D. Crocker
Bruce A. Forster
Jason F. Shogren

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Department of Economics
University of Wyoming
Laramie, Wyoming

and

Department of Economics
Appalachian State University
Boone, North Carolina

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EXECUTIVE SUMMARY

Groundwater is a valuable, renewable natural resource that, if contaminated by economic activities, may be rendered a nonrenewable, unusable, and mobile public hazard. Overall, 65 percent of Wyoming's population depends to some positive degree upon groundwater for its domestic water supply. This study surveys and synthesizes the existing literature about the economic value of groundwater contamination episodes, giving particular attention to extant knowledge about behavioral responses to parameter perturbations. Literature omissions are identified and an alternative ex ante valuation framework that incorporates risk attitudes, self-protection opportunities, and the use of market insurance to shift income to undesirable states is developed and its properties are derived. Finally, an empirical means to implement this framework by means of contingent valuation and hedonic property pricing methods is outlined.

Modern consumer economies create risks; they also reduce them. Other third parties often involuntarily bear the costs of these risks because of the nonexclusivity (inability to protect an asset) or commons problem and because commercial and industrial interests have neither a great incentive nor disincentive to account for environmental impacts in their decisions. Institutional designs for allocating the environment must often, therefore be created that substitute for simple private property forms. These designs will typically be developed in the legislative and the judicial arenas. Economic analysis helps the contestants in these political arenas to estimate the economic consequences to them of a given design or policy measure.

Assessments of the economic consequences of environmental change try to estimate those differences in wealth equivalents that will leave welfare

intact, given a change or the prospect of a change. A complete assessment of economic consequences requires three kinds of information: (1) the differential changes that pollution or its control causes in production and consumption opportunities; (2) the responses of input and output prices to these changes; and (3) the input, output, and consumption changes that affected individuals make to minimize losses or maximize gains from prospective or realized changes in production and consumption opportunities and in the prices of these opportunities. Accurate information on the economic consequences of environmental hazards can be achieved only if the reciprocal relations between physical and biological changes and the responses of individuals and institutions are explicitly recognized.

The individual who is involuntarily exposed to an environmental hazard can self-protect by reducing his exposures (prevention) or by moderating the severity of the consequences of these exposures (cure). Alternatively, he can purchase market insurance or passively await deterrent actions by nonmarket public policy institutions. Determination of the appropriate mix of collective deterrent policies requires knowledge of individual self-protection behaviors.

The sparse existing empirical economics literature, e.g., Raucher (1983, 1986a,b), Sharefkin, et al. (1984), Shechter (1985a, b), Main (1986), Spofford, et al. (1986), and Smith and Desvousges (1986a, b, 1987), on groundwater and soil contamination hazards generally is of quite limited use in helping to determine this appropriate policy mix. All of it assumes that the probabilities of contamination occurrence and detection are fixed and exogenous. Much of it assumes that if a public policy of deterrence is adopted that no contamination will occur, while if no such policy is put in place, contamination will occur with some positive probability. Study settings are typically site specific, thus disregarding the extent of regional contamination and the influence of this contamination upon the availability of substitute water sources for the specific site. From an ex ante perspective, the possibility of regional contamination implies that collective risk and individual risk are indistinguishable.

This existing literature also typically adopts an ex post perspective of value, thus neglecting the influence of attitudes toward risk upon behaviors and the valuations that they imply. In addition, it pays no attention to risks that are less than life-threatening, and it proceeds in terms of objective rather than perceived risks. Explanations of behavior require the use of perceived risk.

The literature also commonly employs a positive discount rate to define future value streams in terms of their present values. In some instances, the presence of risk is said to justify an upward adjustment of this rate; in others, the implicit assumption is made that a high rate is justified because the individual lacks opportunities to shift wealth across time. Since a high discount rate results in smaller present values of the future benefits from risk reduction, an unjustifiably high rate biases future risk reduction benefits downward. If the individual has opportunities to adapt to a risk by redistributing his consumption and investment opportunities across time, a discount rate lower than the riskless rate of time preference is analytically justified.

A correct treatment of the valuation of the risks from groundwater and soil contamination requires attention to preferences over the timing of and the means of resolving uncertainty. At the most fundamental level, an ex ante rather than an ex post perspective is necessary. Because the ex post representation establishes a number of contingent states and proceeds to treat each of them as if it were certain, it is incapable of accounting for the decisionmaker's attitude toward risk; that is, as it measures the economic consequences of each presumed certain state, it disregards the expenditures that the decisionmaker makes in preparing for states that go unrealized. The individual's planned rather than his realized outcomes properly explain his choices. The expenditures on these planned outcomes include a risk premium because the individual is required to make a decision before the state of nature or its associated outcome is revealed. Failure to account for this risk premium can cause risk reductions to be undervalued.

A correct model of individual behavior when confronted by risk of groundwater and soil contamination must also recognize that the individual can influence the probability of a feasible outcome as well as the severity of any realized outcome. For example, he can purchase bottled water and he can obtain medical treatment. We demonstrate that a failure to account for these self-protection activities can lead to substantial underestimates of the value of a risk reduction. We also demonstrate that the marginal value of a risk reduction can be increasing when an ex ante perspective is adopted and individual behavior can influence both the probability and the severity of a particular outcome. It is also shown that these conditions do not allow willingness-to-pay value expressions to be rid of unobservable total and marginal utility terms. Similarly, self-protection expenditures cannot be interpreted as a lower bound on the ex ante value of risk reduction. We conclude that the ex ante value an individual attaches to a risk reduction opportunity will be a function of the relative prices of his self-protection opportunities, collective protection efforts, wealth, the extent and the price of his insurance coverage, and his degree of risk aversion. A random utility [MacFadden (1973)] representation of this function is proposed for empirical implementation by means of a contingent valuation approach and a hedonic property pricing approach.

An Analytical Basis for Valuing Potential and Realized Groundwater Protection Benefits in the State of Wyoming

1. Introduction. Groundwater is a valuable, renewable natural resource that, if contaminated by economic activities, may be rendered a nonrenewable, unusable, and mobile public hazard. There are reasons to believe, given certain physical and technical aspects of groundwater contamination, that the straightforward piecemeal application of conventional benefit-cost analysis will lead to a cumulative loss of Wyoming's groundwater resources. Most Wyoming public water systems draw on groundwater although surface water constitutes the majority of the water sources in these systems. On the other hand, 90 percent of rural domestic water comes from groundwater. Overall, 65 percent of the State's population depends to some positive degree upon groundwater for domestic water supplies. Wyoming groundwater is also used for livestock, in power generation, oil recovery, uranium mining and processing, and for irrigation [Wyoming Department of Environmental Quality (1986)]. Groundwater is an important Wyoming natural resource.

The purpose of this study is to survey and synthesize the existing literature about the economic value of groundwater contamination episodes, giving particular attention to extant knowledge about behavioral responses to parameter perturbations. This study attempts to identify and resolve literature omissions. An alternative framework is developed for dealing with groundwater contamination episodes and empirical means for implementing it are proposed.

Background information is considered in Section 2 to set the stage for the remainder of the study. The literature review is in Section 3 and our proposed model development is contained in Section 4.

2• Background Information

2•1 Groundwater. Groundwater is water that occurs below ground-level in aquifers. Aquifers are permeable saturated strata of rock, gravel, or sand which may be either confined or unconfined. A confined aquifer (also known as an artesian aquifer) is one which is bounded above and below by impermeable layers called aquitards. This aquifer is saturated with water that is under pressure which is greater than atmospheric pressure. An unconfined aquifer does not have an upper aquitard. The water in an unconfined aquifer is under atmospheric pressure and the water level in the aquifer may rise or fall. The free water surface in an unconfined aquifer is called the water table. A "perched" aquifer is a special case of an unconfined aquifer that is temporarily formed by "ponding" on a restricted-flow layer. The perch is above the water table and exists because of the restricted-flow layer. A leaky aquifer is one which loses water in the downward direction. In this case the lower aquitard is only a partial aquitard.

2•2 Contamination of Groundwater Resources. The major sources of groundwater contamination are: landfill dumps; sludge lagoons or pits; disposal or injection wells; septic tanks or sewers; land spreading of agricultural chemicals or irrigation; and underground storage tanks [Burmaster (1982)]. With an estimated 4,000 petroleum injection wells, 350 in-site uranium injection wells, and 400 underground coal gasification wells, the Wyoming energy industry creates a variety of potential sources of groundwater contamination. Other recognized energy industry contamination sources include oil refineries and underground storage tanks for retail gasoline. According to the Wyoming

Department of Environmental Quality (1986) the most common contamination problem in all parts of the State is small difficult-to-detect leaks from underground storage tanks (mainly for gasoline).

Gasoline has been stored in underground storage tanks for roughly 75 years in the interest of public safety because of its flammable and explosive nature [Truax (1986)]. Unfortunately, this policy response created another problem since up to 90% of underground storage tanks leak at some point in their lifetime. In 1986, the State of Wyoming had 30 <u>known</u> sites with leaking underground storage tanks (referred to as LUST). In September 1987, the number of known sites had risen to 86. By February, 1988, the number had reached 110. An additional 10 were identified by June, 1988. Each site may have more than one LUST. One leakage in the town of Worland, Wyoming, spilled 43,000 gallons of gasoline.

2•3 <u>Mobility of the Contaminant Plume</u>. The contaminant burden in groundwater is mobile. Thus the contaminant may have impacts at locations distant from the contaminant source and at dates subsequent to the release of a slug of contaminant. Groundwater contamination episodes have <u>spatial</u> and <u>intertemporal</u> dimensions which make it difficult <u>ex ante</u> to predict the location of impact and the timing of the impact.

The movement of groundwater depends upon the geohydrologic properties of the aquifer. The velocity of the flow of groundwater is governed by Darcy's Law

$$q = -K \frac{\Delta H}{\Delta X} \tag{2.1}$$

where q is the Darcy velocity, K is the hydraulic conductivity and ΔH is the hydraulic lead-loss over the distance ΔX. Typically groundwater moves between

1 and 5 feet per day. As an example, a flow moving at 3.6 feet per day would take 12.2 years to move 16,000 feet - slightly more than 3 miles!

The Darcy Law (2.1) refers to movement through a homogeneous medium; if the soil properties are heterogeneous then the situation is more complicated.

The movement of contaminants in groundwater depends not only upon the properties of groundwater movement but also upon the movement of the chemicals in the groundwater. It is necessary to consider the processes of adsorption, desorption, precipitation, dissolution, ion exchange, biochemical reactions and chemical transformations. Consequently, the contaminant burden may move more slowly than the groundwater.

The contaminant burden as it spreads forms a moving <u>plume</u>. The towns of Powell and Worland in Wyoming have 8 and 14 plumes respectively as of the winter of 1988. In the Brookhurst subdivision of Casper, Wyoming, 110 homes have had their well-water contaminated from industrial sources. The Rawhide Village subdivision of Gillette has had 200 homes evacuated as a result of gas seepage into the homes creating a threat of explosion. While it is thought that this problem is created by natural processes in coal seams, the response to the episode still involves economic issues.

The following is a partial list of toxic chemicals that have been found in drinking water wells in the United States: trichloroethylene, tuolene; 1,1,1-trichloroethane, acetone, methylene chloride, dioxane, ethyl benzene, tetrachloroethylene, cyclohexane, chloroform, benzene, vinyl chloride [Burmaster 1982)].

2•4 Policy Measures for Protecting Groundwater Integrity. Groundwater integrity in the United States is protected under the U.S. Environmental Protection Agency's Ground-Water Protection Strategy issued in August 1984, and by groundwater provisions in the Safe Drinking Water Act (SDWA) Amendments of 1986 [Raucher (1986a)]. The following discussion is based upon Raucher's (1986a) analysis of these mechanisms.

EPA's Strategy identifies three categories of ground-water resources: "Special" groundwater resources (Class I); Current and potential drinking water sources (Class II); and those that are not potential sources of drinking water (Class III).

Class II resources are to receive protection roughly equal to the national uniform standards. Class I will receive more stringent protection while Class III will receive less stringent protection.

In Class I, the groundwater resources are deemed to be either irreplaceable or ecologically vital and vulnerable to contamination. Class III groundwater resources are those over which hazardous waste disposal and other contaminating activities may be located.

These guidelines focus on the activities that will be permitted at specific sites where those activities require either a federal EPA permit or are managed by EPA. Agricultural contaminating practices and petroleum-product storage tanks are not covered by the Strategy.

The Wellhead Protection and Sole Source Aquifer Demonstration clauses of the SDWA focus on points of use rather than the contaminating activities. States are to develop programs to protect areas around public drinking water wells, and programs that will prevent degradation around sole source aquifers.

The Wyoming State government failed to establish clean-up programs for LUST in its 1988 legislative session. The failed-bill would have provided a clean-up fund of $5 million by levying a 1¢ a gallon tax on gasoline and diesel fuel and by levying an annual registration fee of $250 per tank paid by tank owners. Federal regulations may require that station owners obtain insurance of $1 million in the absence of a State program. With a State program the station owners would only require an insurance package of $100 thousand [Casper Star-Tribune (various issues February-May 1988)].

2•5 Classifying Groundwater Contamination Episodes. Our thinking about groundwater contamination episodes suggests that there are 3 categories to be considered. Category I consists of known, currently existing, contamination of a given site. The Brookhurst situation, and the contaminant plumes in Powell and Worland fit into this category. In Category II there exists possible contamination episodes (now unknown but occurring or which may occur in the future) from existing facilities. Every underground storage tank in the State that is not now known to be leaking is in this category. Category III includes those proposed development sites which might introduce groundwater contaminants. This category includes an almost uncountable set of possibilities.

The assessment techniques and requirements for each of these three categories differ considerably. In the first category the economic issue is one of estimating the benefits and costs of alternative remedial actions in order to determine the appropriate responses to a known episode with specific attributes. The third category involves decisions about the appropriate degree of protection to be taken in designing and locating a future site. For the second category, the issues revolve around comparisons of prospective costs and benefits of avoiding damage.

2•6 Economic Analysis and Environmental Issues

2•6•1 Introduction. What is academically important in natural resource and environmental questions has become progressively less distinguishable from what is academically and societally urgent. Emotions run high. Environmentalists repeat again and again that too little is done to preserve and protect natural resources, especially environmental life support and amenity functions. Developers disagree and, with every downturn in the commercial and industrial economy, they find audiences more attuned to use the environment as a source of extractive raw materials and as a receptacle for the waste flows from consumption and fabrication activities. The developers identify with progress and assert that environmental regulation stifles it. Neither environmentalists nor developers provide coherent and reasonably comprehensive criteria for what is "too little" or what is "excessive". Factionalism and adversarial proceedings therefore rule. Unless realism is self-serving the factions ignore real-world data, assume worst-case scenarios, propose technology-forcing controls, and fail to validate supposed commercial or environmental improvements. For several academic disciplines, including economics, analytical constructs and empirical methods that took one hundred years or more to develop have recently been drawn tight in one-tenth that time across a practical problem spectrum at least ten times that wide. The common neglect of elementary but fundamental economic concepts such as supply, demand, and price accentuates this strain. This neglect often results in the wrong variables and the wrong problems, or the wrong versions of them, being thrown into prominence. Accurate visions of reality are compromised and, by socially meaningful criteria, excessive human and environmental costs follow.

2•6•2 Economic Analysis and Environmental Degradation. Modern consumer economies reduce risks; they also create them. The insecticide that increases food supplies simultaneously threatens human health; the underground storage tank that assures conveniently located transportation and heating energy upon demand also leaks, thus degrading groundwater and thereby endangering human health and property. The farmer, the gasoline station owner, and their customers capture risk reduction benefits in the form of increased profits and reduced expenditures of time and money. However, other third parties often involuntarily bear the costs of achieving these risk reductions.

The potential for abuse of the natural environments of third parties stems from two primary sources. The first is the so-called nonexclusivity or commons problem. Because natural resources such as air and water do not respect property lines, placing them under simple forms of private ownership is generally impossible: the owners would be unable to exclude others from using their property. Institutional designs must therefore be created that substitute for simple private property forms. Otherwise, nonowners will regard the resource as a free good, leading to its overuse and often its degradation or its ruin.

Second, the potential for abuse exists because of the wide range of commercial and industrial interests whose decisions affect what happens to the natural environment: they rarely benefit directly from actions that protect it and they infrequently suffer losses from actions that harm it. Consequently, they neither have a great incentive nor disincentive to account for environmental impacts in their decisions.

Economic analysis and its empirical tools can assist in two ways to generate information helpful in overcoming the environmental insults fostered by nonexclusivity and commercial and industrial detachment. First, knowledge about natural resource issues must ultimately be defined and refined in dimensions corresponding to those in which real-world decision agents operate. Because some human decision variables simultaneously influence and are influenced by the behavior of natural resource systems, economic analysis is often necessary to impart a policy-relevant form to research designs and results in disciplines other than economics.

Second, economic analysis and its empirical manifestations when applied to environmental issues (benefit-cost analyses) provide information useful to contestants in the political arena: they are informed about what a given change is likely to hold for them. Occasionally the bottom-line aggregates that any benefit-cost analysis can generate will be informative. More often, information that the analysis contains about market response and agent adaptations (allowing the beholder to draw inferences about the particulars of a change as it affects his immediate circumstances) will be of much more interest. He can then use this information to construct a political strategy.

2·6·3 <u>Benefit-Cost Analysis and Environmental Change</u>. Assessments of the economic consequences of environmental change try to estimate those differences in wealth equivalents that will leave welfare intact, given a change or the prospect of a change. The wealth equivalents are defined as differences in the sums of recipient surpluses and provider quasi-rents over two or more policy-relevant pollution levels. Recipient surplus portrays the difference between the maximum an individual would be willing to commit to pay for a secure property claim to a commodity unit and what he in fact has to pay. Similarly, provider quasi-rent is the difference between what one receives for supplying a secure property claim to a commodity unit and the minimum one must receive in order to be willing to commit to that supply. The sum of recipient surplus and provider quasi-rent is thus a measure of the prospective net benefits from the availability of a secure claim upon a commodity. The observable unit prices of secure claims to other commodities that could provide equal satisfaction set an upper bound to the recipient's maximum willingness-to-pay; the earnings his resources could obtain in other activities set a lower bound on the minimum reward the provider must receive. Maximum willingness-to-pay represents demand; the minimum necessary reward defines supply.

A complete assessment of economic consequences requires three kinds of information: (1) the differential changes that pollution or its control causes in production and consumption opportunities; (2) the responses of input and output prices to these changes; and (3) the input, output and consumption changes that affected individuals make to minimize losses or maximize gains from prospective or realized changes in production and consumption opportunities and in the prices of these opportunities. Natural science studies of dose-response functions are the primary source of information for the first requirement. Evaluation of the latter two requirements represents the economics portion of net benefits assessment. If an environmental change causes substantial changes in outputs and consumption, price and quality changes can occur which lead to further market-induced output and consumption changes. Moreover, even if prices remain constant, natural science information alone will still fail to provide accurate indications of output and consumption changes when individuals can alter their practices. Thus, accurate information on the economic consequences of environmental hazards can be achieved only if the reciprocal relations between physical and biological changes and the responses of individuals and institutions are explicitly recognized.

2•6•4 Benefit-Cost Analysis and Environmental Protection. Our focus in this report is the individual who involuntarily bears risk from groundwater and soil contaminants that leak from underground storage tanks. Our concern is with the economic damages that he suffers from the prospect of being exposed to and having his health or his property thereby degraded. This involuntary risk-bearer has five general modes of protection available to him. He can draw upon his own resources ex ante to reduce his exposures to the risk or to insure against any undesirable consequences. Alternatively, he can expend his resources ex post to cure undesirable consequences. Whatever the combination of prevention and cure that he chooses the decision is his alone.

The remaining three protection modes are at least partly collective in that they involve some significant expenditure of societal resources via nonmarket public policy institutions. Deterrence of future risk-imposing behaviors rather than compensation of those upon whom involuntary risk is imposed is a major and often the sole object of these modes. The first, tort law, specifies the conditions and the magnitude of ex post compensation that the involuntary risk-bearer may collect. Burdens of proof reside with the involuntary risk-bearer. Quantity restrictions statutorily define behaviors to which risk-creators must conform under penalty of law. Adherence to these restrictions need not absolve the risk-creator from legal responsibility for any remaining third-party effects.[1] Finally, collectively mandated and monitored pecuniary incentives such as user charges and insurance requirements make risk-creators pay for prospective third-party effects.

Any individual who depends solely upon policies founded in the collective modes to secure his protection from the involuntary risks posed him by modern chemical and fossil fuel products will frequently suffer more than is necessary. In a medium such as groundwater the time interval between a toxin leak or spill and human exposure may be lengthy. Statutes of limitations can thus inhibit any appeal to tort law.[2] The use of tort law is also hindered by difficulties in identifying those who created the risks, delays between the time of a spill or leak and the appearance of a third party effect, and ambiguities about the etiology of an effect. These same sources of confusion also impede the application of quantity restrictions and pecuniary incentives.

In this report, we try to develop an analytical basis to guide an empirical grasp of the decision processes and resultant behaviors of those who involuntarily bear risks of exposure and harm from groundwater and soil contamination caused by potential or actual underground storage tank leaks. Determination of the appropriate mix of collective mode protection policies from these leaks requires knowledge of these risk-bearer behaviors. Any responsible policy implementation of the collective modes will involve some balancing of the benefits of controlling leaks against the costs of their control.[3] Risk-bearer behaviors influence collective control benefits, as earlier noted. Similarly, the exact structure of the collective modes that are adopted or expected will influence the risk-bearer behaviors. Our task then is to specify exactly how these behaviors affect control benefits and to demonstrate how the benefits can be measured while fully accounting for the self-protection behaviors of the involuntary bearers of risk. We do not try to deal with questions involving acceptable risk levels nor the allocation of risk. Prior understanding of the factors that influence control benefits is nevertheless necessary for informed treatment of these questions.

3• A review of the economic literature pertinent to groundwater contamination assessment.

In Section 3•1, those studies specific to groundwater are reviewed while Section 3•2 reviews studies concerned with the general problem of siting noxious facilities.

3•1 Groundwater Contamination Studies.

The discussion of these papers will be separated into analytical issues, and then applications of the analytical frameworks.

3•1•1 Analytical Frameworks.

The seminal contribution to the development of an analytical framework for analyzing groundwater contamination episodes and the benefits of protecting groundwater integrity is Raucher (1983). Raucher defines the expected net benefits of a protection policy i, $E(NB_i)$ as the difference between the expected benefits $E(B_i)$ net of protection costs X_i. Thus

$$E(NB_i) = E(B_i) - X_i \tag{3.1}$$

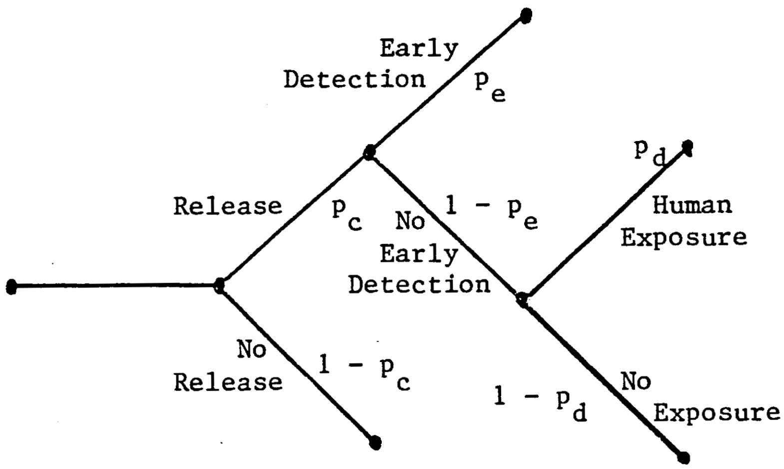
The expected benefits are defined to be the expected damages E(D) avoided as a result of the protection policy. The expected damages are defined by

$$E(D) = p_c[p_d C_r + (1 - p_d)C_u] \tag{3.2}$$

In (3.2) p_c is the probability that a contamination episode will occur in the absence of policy i. p_d is the conditional probability that contamination will be detected prior to the use of the contaminated water. C_r is the cost of the most economically efficient remedial response to the contamination episode and C_u is the cost imposed by continuing to use the contaminated water as before the episode occurred. Since continued use is one policy response it follows that $C_r \leq C_u$; that is, economically efficient remedial responses can be no more expensive than the passive response of continued use of the contaminated water.

Cast in the fashion of (3.1) and (3.2) this framework appears to portray a policy choice which is binary in nature. That is, if the policy i is used there will be no contamination while if the policy is not used, there is some positive probability that the contamination will occur. The probability of occurrence and the probability of detection appear as fixed and exogenous to the decision making process. It is unlikely that real world policy makers would be faced with such binary choices with exogenously determined probabilities. In fact, the policy-maker must decide on the degree of stringency of the protective policy. This stringency determines the probability of occurrence of an episode. The desired stringency in turn depends upon the benefits and costs of varying degrees of stringency. Similarly, the size of p_d depends upon the resources devoted to monitoring the groundwater or the facility likely to leak.

Main (1986) sets up a decision theoretic framework which allows for possible early detection of a leak. In this case, remedial action could take place prior to exposure. Let the probability of a spill be p_c; the conditional probability of early detection be p_e; and the conditional probability of no early detection and human exposure be p_d. The probability of late detection and no human exposure is $(1 - p_d)$. It is assumed that if there is no spill there is no cost. The cost of cleanup with early detection is C_r^1 the cost of clean-up with late detection is C_r^2 and the cost of clean-up and human exposure is $(C_r^2 + C_u)$. The decision tree for this timing sequence is:



It is presumed that $C_r^2 > C_r^1$. The expected damage in this case is given by:

$$E(D) = p_c p_e C_r^1 + p_c(1 - p_e)p_d(C_u + C_r^2) + p_c(1 - p_e)(1 - p_d)C_r^2$$

or

$$E(D) = p_c[p_e C_r^1 + (1 - p_e)\{p_d(C_u + C_r^2) + (1 - p_d)C_r^2\}] \qquad (3.2')$$

While (3.2') is more elaborate than (3.2) and captures the timing problem, it still considers the probabilities as exogenous. Main is aware of this issue however as he states: "Protective actions usually affect expected damages by influencing either the probability of a spill or the timing of the discovery of a spill". Thus the values of p_d and p_c are endogenous to the policy making process and as argued above and demonstrated by Adams et al. (1984), one of the determinants of these probabilities is the net benefits estimate.

Raucher (1983) tries to soften the binary nature of his formulation by suggesting that policies are likely to achieve changes in the relevant probabilities rather than eliminating the likelihood of occurrence altogether. For policies designed to reduce the probability of occurrence he defines the expected benefits as:

$$E(B_i) = -dp_c(i)[p_d C_r + (1 - p_d)C_u] \tag{3.3}$$

where it is presumed that $dp_c(i) < 0$ and hence $E(B_i) > 0$. For a policy i designed to increase the likelihood of detection given an occurring episode, the expected benefits are defined by:

$$E(B_j) = dp_d(j)[p_c(C_r - C_u)]. \tag{3.4}$$

Since $C_r \geq C_u$, the $E(B_j) \geq 0$ for any $dp_d(j)$.

While (3.3) and (3.4) allow for smoother variations in probabilities, the caveat concerning the dependence upon resource costs still applies to the dp_d and dp_c. The appropriate levels of these differentials are still endogenous to the decision making process.

The episode portrayed in (3.1) and (3.2) or (3.3) and (3.4) is also site specific and as such tend to reduce the expected benefits to a region. While there may be a small probability of a contamination episode at a given site, the probability of contamination occurring somewhere in the region is likely to be larger (once a spill has occurred). Indeed, there is reason to believe that the probability of contamination in a given region is governed by a Poisson distribution. This implies that at any particular site the policy alternatives are either elimination of the possibility of an episode or the assumption of the risk by individuals and firms.

The specification of C_r as the least-cost remedial measure at a particular site within a region generates a bias towards sacrificing regional groundwater integrity. The piecemeal approach fails to recognize that for technical or economic reasons the contamination of a groundwater resource can be irreversible. In these circumstances, the least cost remedial measure may be to substitute for use another regional groundwater source. However, the cost of resorting to this substitute will clearly depend upon its state of contamination. In effect therefore, neither the benefits of preventing contamination at a given regional site nor the costs of remedial actions at this site can be evaluated independently of the state of groundwater contamination throughout the entire region. In the <u>ex ante</u> case, the collective risk and the individual's risk may be indistinguishable.

Raucher (1983) does not refine the C_u measure. In his applications, C_u is taken to be either crop yield loss from irrigating with contaminated water, or health damage from drinking the contaminated water.

Shechter (1985a, b) formalizes the health impact by assuming:

$$C_u = (M_r)(L)Pop \tag{3.5}$$

where M_r is the incremental health risk, L is the monetary value of life, and Pop is the size of the exposed population. The monetary value of life, L, is taken to be the representative individual's maximum willingness-to-pay (WTP) for a small increment in safety and is given by Sharefkin et al. (1984) as:

$$L = \frac{U(W)}{(1 - M_r)U'(W)} \tag{3.6}$$

where W is the individuals' wealth or lifetime income and U(W) is the individual's utility function. In this formulation, L is the value of a "statistical life" rather than one which is individual-specific. Hazards that are less than life-threatening are disregarded.

The approach in (3.5) and (3.6) is also problematic in the case of groundwater contamination. The health risks imposed upon individual households are treated as strictly involuntary. For a given health risk, M_r, the control benefits depend upon the size of the exposed population and on the ex post monetary value of the realized health state.

As Weinstein and Quinn (1983) argue, a central source of difficulty in measuring the economic consequences of risky events is the divergence between "objective" or "scientific" measures of risk and the individual's perceptions of such a risk. Evidence available from perception studies undertaken by psychologists suggest that, if people have any perception of a hazardous waste problem at all, their risk perception is likely to be biased upwards. "New" risks with which the individuals are relatively unfamiliar and beyond their own control (such as groundwater contamination) as opposed to more familiar risks over which they have some degree of control (such as the risk of an automobile accident), seem to be especially feared. Objective damages (or benefits) are calculated as an objective probability of death (usually drawn from the best available scientific evidence) times a dollar value for safety (usually drawn from labor market studies). In contrast to such "damages", perceived damages for each individual are equal to a perceived (i.e. subjective) probability of death from the environmental risk at issue, times a perceived value of safety associated with a death brought about by the environmental risk at issue. The possible, if not probable, difference between these two measures of damages raises a fundamental policy problem, although Raucher (1986b) dismisses the subjective assessments as not relevant to the policy decision.

First, research in cognitive psychology repeatedly demonstrates the tendency of people to overestimate the odds of low probability events, especially for new or unfamiliar risks, and to underestimate the odds of relatively high probability events. Secondly, the perceived consequences of new or unfamiliar risks tend to be exaggerated, introducing dread until experience is accumulated with the new source of risk. Thirdly, perceived losses are valued much more highly than perceived gains (Smith and Desvousges, 1986). Thus, people will give up the opportunity to reap a substantial gain in order to prevent a small loss. Again such behavior appears inconsistent with general economic theories which predict that the value placed on giving something up should be similar to the value placed on an equivalent gain under most circumstances.

Characterization of the risk measure does not exhaust the analytical problems inherent in expression (3.3). In particular, estimates of the monetary value of life are based upon the expected utility axioms of von Neumann and Morgenstern (1947). One implication of the aforementioned psychological research results is that involuntary risks, risks with delayed effects, and risks not readily influenced by individual behavioral adjustments impose significant losses in excess of the losses inherent in risks lacking these features [Spence and Zeckhauser (1972)]. These three features frequently describe situations that challenge owners of assets threatened by groundwater contamination. Involuntary risks remove the <u>ex ante</u> opportunity to adapt. Lack of influence removes both <u>ex ante</u> and <u>ex post</u> opportunities to adapt. Delayed effects make subsequent as well as present decision-making risky. If the benefits of controlling groundwater contamination are to be fully evaluated, the conventional theory of choice under uncertainty must be extended to include preferences over the timing and the means of resolution of uncertainty.

Reliance on estimates of the value of life also overlooks other health impacts that occur short of death. As Shechter (1985b) points out individuals with cancer suffer while still alive and would be willing-to-pay some positive amount to avoid the suffering. There are also health effects short of cancer and death that impose losses on individuals. Exposure to chlorinated hydrocarbons for example can lead to nausea, dizziness, tremors and blindness [Burmaster (1982)]. Individuals would be willing-to-pay to avoid these discomforts.

It is important to consider non-health impacts as well as health impacts. For example, the contaminant plume could result in gases seeping into housing structures or other buildings, thus creating danger of explosion. The effects of these combined health and non-health threats effectively destroy large parts of individual and social wealth as a result of the consequent impacts on property values. In this respect it is interesting to note that a former deputy director of EPA's Office of Underground Storage Tanks sees the groundwater contamination issue as one of economics rather than health. Penelope Hansen is quoted as saying "If gas gets into your water, by and large you smell it and stop drinking it. So much for your health problem. On the other hand the economic cost in terms of clean-up, third party damages and long-term depletion of this increasingly precious resource, can be astronomic".

The size of the exposed population in (3.3) is not a trivial matter. It is not just the current population but also the future populations which matter. Shechter (1985a, b) acknowledges difficulties for intergenerational equity in groundwater contamination. However, his concern is for mutagenic impacts imposed upon future generations. However, there are subtle issues short of mutations appearing in future generations that need to be considered.

Since groundwater can move slowly, the timing of a contamination episode may be separated by decades from the original spill if not detected early [recall the framework of Main (1986)]. Housing developments may unknowingly be situated in the path of a contaminant plume that started from a leak in the past. A cost-benefit calculation that either ignored population projections or had faulty projections, would have underestimated the likely damages because the housing development that took place was not foreseen and hence not included.

The foregoing highlights the intertemporal nature of groundwater contamination episodes that is absent in a literal interpretation of the framework established in (3.1) through (3.4). Conventional cost-benefit analysis handles the intertemporal aspects by considering the Present Value of the stream of expected net benefits over some relevant time horizon:

$$P.V. = \sum_{t=1}^{T} \frac{E(N.B._i)_t}{(1 + r)^t} \qquad (3.7)$$

where r is the social rate of discount and T is the relevant time horizon.

Raucher (1983) recognizes the important influence which the selection of the time horizon has on the outcome of the analysis. The longer the time horizon the more benefits of protection to be included in the calculation. For example, if a 5 year horizon is used but it will take 10 years for the plume to reach a specific site, then there are no benefits to be included in the 5 year period. These impacts are discussed in Section 3•1. A longer time frame increases the likelihood of contamination. At this stage, Raucher (1983) introduces time-dependent probabilities.

A further issue with a long time horizon is that with positive discounting ($r > 0$), benefits that accrue 20-30 years into the future are likely to be negligible in Present Value terms. Hence, stringent protective measures that dictate high costs in the near term but benefits which accrue in the distant future are likely to be seen as <u>uneconomic</u>. Thus given the nature of groundwater movement, conventional cost-benefit analysis has a bias toward sacrificing groundwater integrity.

One method of getting around this difficulty is to consider using a zero discount rate. Raucher (1983) considered a zero discount rate as one method of dealing with intrinsic values, but seems to reject this technique as "tinkering" which "presents difficulties" since "using a zero discount rate to reflect concerns over the well-being of future generations would result in a failure to acknowledge other real opportunity costs and the positive rate of time preference that exists intragenerationally". This latter point is offered objectively rather than as an ethical issue open to debate. One is reminded of Ramsay's (1928) accusation that discounting is "a practice which is ethically indefensible and arises merely from the weakness of the imagination".

The use of a lower discount rate when there is the threat of environmental risk has been justified on economic-theoretic grounds by Brown (1983). In situations in which public projects are designed to produce favorable outcomes with uncertain benefits, it is usual to adjust the discount rate upwards. Brown's (1983) contribution was to show that when the uncertainty concerns a possible unfavorable outcome, the discount rate must be adjusted downwards in order to allow for this risk. Given the importance of this result to issues such as groundwater contamination which may involve long time periods, it is worth considering Brown's analysis in more detail.

Suppose an individual has a total (financial and property) wealth endowment of $\bar{W}$ a portion of which may be threatened by a contaminant plume. The loss D associated with the plume is uncertain but has a known distribution with mean E(C). The individual's expected wealth E(W) is then:

$$E(W) = \bar{W} - E(D). \tag{3.8}$$

Assuming the individual is risk-averse means that the individual would prefer a given wealth $\hat{W}$ with certainty than to face a lottery of high possible and low possible wealth which yields an average wealth of $\hat{W}$. In mathematical parlance, risk-aversion implies that, if the individual's utility function is $U = U(W)$

$$U(E(W)) > E(U(W)) \tag{3.9}$$

where W is the random variable. Thus with risk aversion there is a level of wealth $W^* < E(W)$ such that

$$U(W^*) = E(U(W)). \tag{3.10}$$

Hence the individual would be willing to pay up to $\bar{W} - W^*$ to avoid the expected loss E(D). It can be shown that

$$\bar{W} - W^* > \bar{W} - E(W) = E(D). \tag{3.11}$$

The individual's maximum willingness-to-pay to avoid the expected loss in fact exceeds the expected loss. The individual values the reduction in risk and this value of risk reduction needs to be taken into account in the Benefit-Cost calculus.

The present value of the individual's stream of maximum willingness-to-pay is

$$P.V. = \sum_{t=1}^{T} \frac{(\bar{W}_t - W_t^*)}{(1 + r)^t} \tag{3.12}$$

(3.12) accounts for the individual's valuation of risk reduction. An alternative approach characteristic of conventional treatments considers the present value of the stream of expected losses. Using the same discount rate produces different results and may generate opposite policy recommendations since using expected losses produces a lower present value which may fall short of the costs X_i. This may occur even though the individual would be willing to pay for the project costs! This may be remedied by choosing a risk-adjusted discount rate i_t for each t such that

$$\sum_{t=1}^{T} \frac{E(D_t)}{(1 + i_t)^t} = \sum_{t=1}^{T} \frac{(\bar{W}_t - W_t^*)}{(1 + r)^t}. \tag{3.13}$$

Given (3.11) it is clear that $i_t < r$ for (3.13) to hold. That is in the face of environmental risk, with risk averse individuals, the stream of expected losses should be discounted at a rate lower than the risk free rate of time preference.

This result is of direct relevance to the applied groundwater studies. Raucher (1986b) claims that Superfund guidelines and the Office of Management and Budget stipulate a 10% discount rate be used in evaluating the benefits and costs of the relevant programs. Sharefkin et al. (1984) use a 10% discount rate. If one believes that the risk-free, long-run discount rate is around 5%, then these procedures are adjusting the discount rate in the wrong direction! Thus will cause the protection of groundwater integrity to be less beneficial. Raucher (1986b) calculates his estimates using 0%, 2% and 10%. This approach at least serves to bracket the appropriate estimate and we endorse this approach.

Some researchers have expressed concern that welfare criteria such as (3.7) may not provide accurate rankings aside from problems with discounting. Blackorby et al. (1984) identify situations in which the present value is negative but the project is nonetheless desirable. Their general conclusion is that "there do not exist intertemporal preferences for which the sum of discounted instantaneous surpluses is an exact measure of welfare change". As a positive note, if the discounted value of compensating variations is positive, then lifetime welfare has increased; and, if the discounted sum of equivalent variations is negative then welfare has decreased.

Wildasin and Harris (1985) have shown (in a non-intertemporal setting) that when redistribution is not possible between (groups of) agents that the condition for social welfare maximization is the maximum condition. That is policies should be selected which maximize the welfare of the least well-off (groups of) agents. This rule was also determined by Rawls (1971) in his theory of justice. Invoking this criterion requires expected net benefits to be equal in all generations. In an intertemporal context, this allocation rule is inconsistent with the expression (3.7). In the absence of insurance markets for groundwater contamination events, it is not possible for future agents to gain compensation from those who were responsible for the episode. Wildasin and Harris (1985) also show that if complete redistribution is possible, then an unweighted sum of benefits should be used. In an intertemporal context, this implies a zero discount rate. Thus if there is complete insurability the time periods should be treated equally. This becomes relevant with the insurance scheme being proposed by EPA at the present time.

The framework established in (3.1), (3.2), (3.5), (3.6) and the various modifications presumes that the relevant outcomes of a contamination spill and their associated probabilities are known. Spofford et al. (1986) modify the usual classification of types of uncertainty in economics for considering groundwater issues. The first classification is the classical case of "risk" which refers to situations in which relevant outcomes can be described by objective probabilities. This is the case considered above. The second classical case is "uncertainty" and it is this case that Spofford et al. (1986) extend. In the classical treatment, "uncertainty" refers to situations for which the relevant outcomes cannot be described by objective probabilities. Spofford et al. (1986) identify two sub-categories of this "uncertainty". Both categories consider situations for which either the relevant outcomes are not known completely a priori (and hence neither are the probabilities) or the outcomes are known but the relevant objective probabilities are unknown. The difference is that Spofford et al. split the situations into those for which the events or the objective probabilities may be made known through the collection of information. Thus for this sub-category "uncertainty" may be converted into "risk". The other category of uncertainty they term "true uncertainty". For this category no objective information exists or can be made available to convert the uncertainty to risk.

As examples of events that are not known a priori, they suggest diseases caused by as yet unidentified contaminants in groundwater and damages to ecosystems that have not been experienced. As examples of unknown probabilities, they offer projections of future exposure levels to groundwater contaminants and future population levels that may be exposed.

Spofford et al. (1986) consider the uncertainties that exist at the various stages of analysis of groundwater contamination. The uncertainties in a sense compound since early stages of analysis serve as inputs to subsequent stages. At the economic loss stage they see the major uncertainties being attributable to the fact that potential use of groundwater resources depends upon future demands for water, costs of extraction and distribution, and the costs of alternative sources of supply.

Whether it is worth obtaining more information to resolve uncertainty (or convert it to risk) depends upon the maximum ex ante expected loss associated with the strategy compared to the cost of acquiring the information. And of course in some cases the information is simply not available as Spofford et al. (1986) caution.

3•1•2 Applications of the Analytical Framework. The previous section has critiqued the general analytical framework for assessing groundwater contamination. In this section we consider the applications found in the literature.

In his seminal contribution, Raucher (1983) did not apply his framework to a real world episode but rather to a set of hypothetical cases designed to highlight the sensitivity of results to changes in key parametric assumptions. He considered the impact of different plume characteristics, by considering two sizes: a small one (65 feet deep, 100 feet wide and 500 feet long) and a large one (65 feet deep, 2000 feet wide and 10,000 feet long). The plumes were assumed to grow either slowly at 360 feet per year or rapidly at 3600 feet per year.

The water was assumed to have two alternative uses: drinking or agricultural crop irrigation. The contaminants in the groundwater are not specified but are assumed to have a lifetime excess risk of fatality of 1×10^{-3}. This produces an expected number of annual fatalities for the exposed population of 100,000 of 1.43. For the crop irrigation case it is assumed that the contaminated water causes an 80% crop yield reduction. There are 400 acres of sugar beets to be irrigated. The non-contaminant value is $800 per acre.

Three responses are considered: treatment, containment, and alternate sources. For the treatment case the cost is assumed to be $740,000 in capital expenditures with annual operating costs running at $234,000. This treatment eliminates crop yield reductions completely and in the case of drinking water reduces the excess risk of fatality to 1×10^{-5}. For containment, the capital cost of slurry wall varies from $520,000 for the small plume to $21.6 million for the large one. The annual operating costs also vary with plume size being $10,000 and $20,000 respectively. For an alternate source the best alternative is assumed to be a new well 10 miles from the site. The capital costs run $5000 for the new well and $1.73 million for the pipeline conveyance. The annual operating costs are assumed to be $80,000.

The losses C_u of continued use of the contaminated water amount to $256,000 per year for the irrigation use and $1.43 million per year in the drinking water scenario (assuming a value of $1 million per statistical life).

With a small, slow-growing plume the water quality at the site is not impacted for 10 years indicating that if the planning horizon is 10 years or less the "optimal" strategy is to do nothing. For a 20 year time horizon and a zero discount rate Raucher (1983) shows that a reduction in the probability of contamination of 0.2 due to containment would produce expected benefits of $217,600 for the irrigation scenario and $686,000 in the drinking water scenario. Employing a 5% discount rate cuts these estimates to $146,600 and $369,100 respectively. These calculations show the importance of the economic information inputs to the analysis. In particular, the importance of the discount rate is highlighted.

When the plume is large but still slow-growing, changes in the rate of discount influence the best response. With a zero discount rate the cost efficient response is containment regardless of the water usage, while with a 5% discount rate the efficient solution in the irrigation scenario is to suffer the crop losses. In the drinking water scenario, an alternate source of drinking water is the appropriate response mode.

The rate of growth of the plume was shown to influence the expected prevention benefits with more rapidly growing plumes increasing prevention benefits over a given time horizon.

Shechter (1985a, b) applies his framework to the Price Landfill contamination episode. This landfill operated between 1968 and 1976 receiving chemical and liquid wastes (illegally) as well as trash. The 22 acre landfill was located over the Cohansey aquifer which supplies water to Atlantic City. 12 wells supply 13.7 million gallons of water per day. The demand in Atlantic City matched the capacity of the system by 1982 and hence removal of any wells due to contamination would create shortages year round.

Groundwater quality was predicted using groundwater quality modelling techniques. It was inferred that the plume was spreading at an average rate of 0.70 to 0.80 feet per day.

The excess cancer risk is assumed proportional to the intake of drinking water contaminated by a particular compound j

$$r_j = \alpha_j d_j, \qquad \alpha_j \geq 0 \tag{3.14}$$

where d_j is the daily intake and r_j is the excess risk due to compound j. With J compounds the excess risk R is assumed to be the sum of individual risks

$$R(d) = \sum_{j=1}^{J} r_j, \qquad (d \equiv d_1, d_2, \cdots, d_J) \tag{3.15}$$

The mortality risk M_r is given by

$$M_r = R(d) \cdot \text{prob } (M/S) \tag{3.16}$$

where prob(M/S) is the conditional probability of death M, given that a person has contracted disease S. Shechter (1985a, b) points out that this approach to calculating M_r ignores synergistic effects, nonlinear effects, and morbidity or mortality risks associated with noncarcinogenic compounds.

The mortality risk measures calculated range from a low of 8.98×10^{-4} to a high of 1.34×10^{-1}. The two most significant compounds in the calculations are hexachlorobenzene and PCBs and if these are withdrawn, the upper figure drops to 1.75×10^{-3}. Shechter (1985a, b) provides the following mortality risks in the U.S. for comparison:

Motor Vehicle accidents	2.7×10^{-5}
Lung Cancer	3.7×10^{-5}
All Cancer	1.6×10^{-4}
Heart Disease	3.5×10^{-4}

which shows the mortality risks from drinking water contaminated from the Price Landfill are quite high. The assumed value for p_d was 0.5 while p_c took on values between 0.01 and 1.0.

Various estimated costs of remedial action were considered. It costs $5-8 million for plume containment and management with water treatment and an additional $10 million if excavation and reburial is also undertaken. The cost of alternate water source was taken to be $2 million (once allowance for demand growth was allowed for). Empirical estimates were drawn from the literature and range between $100,000 and $10 million (1980 dollars).

Shechter (1985a, b) found that despite the high mortality risks associated with the contamination they translated into relatively low measures of damage except when PCBs and hexachlorobenzene were included. The variation in results obtained were attributed to variations in the risk factor caused by variations in the probability of contamination p_c and the range in mortality risks M_r since p_d was held constant.

In this analysis of the Price Landfill site, Sharefkin et al. (1984) calculate low and high aggregate incremental risk over all wells and all chemicals of $0.176 \times 10^{+3}$ and $0.202 \times 10^{+3}$ respectively. They then choose a range for the value of changing mortality risk of $\$10^5$ to $\$10^6$. Simply multiplying lower and upper ranges together, they report the benefit range <u>incorrectly</u> as <u>$176 million</u> to $1.76 <u>billion</u>. As Main (1986) points out, the correct range, given their assumptions, is <u>$17.6 million</u> to $202 <u>million</u>. The cost of plume containment and management, and alternate water supply in Sharefkin et al. (1986) is the same as in Shechter (1985a, b) above.

Raucher (1986b) considers three episodes from the EPA Superfund list. We outline these studies in turn.

The first is the 58th Street municipal waste landfill in Miami, Florida. This landfill, covering one square mile operated for 30 years starting in 1952. 15 toxic compounds have been detected in leachate from the landfill since contamination was first discovered in 1974. The landfill is situated over the Biscayne aquifer. One well-field has been closed due to contamination and two others, two miles away from the landfill are threatened by the approaching plume.

The second is the Davie landfill, near Fort Lauderdale, Florida, which is also situated over the Biscayne aquifer. The site which opened in 1974 has a 5.6 acre, 9-foot deep unlined sludge lagoon which accepted grease-trap and septic-tank pumpings, municipal sewer sludges as well as unauthorized industrial wastes until 1981 when groundwater contamination was discovered. There is also a 70 acre area of trash and garbage landfill. The main concern is a plume, from the sludge lagoon, containing metals and organic compounds. The plume may reach a residential area in about 5 years and an agricultural area prior to then.

At the third episode, the Gilson Road landfill Nashua, New Hampshire, contaminated groundwater enters the Nashua River which is a source of municipal drinking water. This site spans a 7 acre area and contamination enters an underlying glacial aquifer. A plume of organics is moving at a speed of 1.5 feet per day while a plume of organics is moving more slowly. Since the contaminated water reaches surface waters there is the risk of exposure from

TABLE 1

PRESENT VALUE COSTS OF SEVERAL REMEDIAL RESPONSE OPTIONS
($1982 x 10^6, Time Horizon of 120 Years)

Site and Remedial Response Option:	Discount Rate		
58TH STREET	0%	2%	10%
Isolate (counterpump) and deep well inject	$ 65.4	$ 26.8	$ 8.1
Close (final cover), isolate (counterpump), and deep well inject	43.2	24.0	9.8
Close (final cover), isolate (counterpump), treat, and dispose (surface water)	99.8	55.4	20.5
Open new drinking water wellfield	50.0	48.1	41.3
Treat affected municipal water	465.0	182.0	46.5
DAVIE			
Provide bottled water (private wells no longer used for drinking water or cooking)	1.2	0.4	0.02
Isolate (counterpump) and deep well inject	15.4	6.5	2.2
Connect to municipal water system (close private wells)	27.4	13.7	6.8
Close (sludge removal), isolate (counterpump), treat, and reinject	16.5	14.2	9.3
GILSON ROAD			
Partially isolate (7.5-acre slurry wall), partially treat (arsenic removal only), and recirculate (inject within wall)	6.1	5.7	4.5
Partially isolate (7.5-acre slurry wall), treat (organics and inorganics), and recirculate	7.6	7.1	5.5
Isolate (20-acre slurry wall), treat (organics and inorganics), and recirculate	12.1	11.3	8.7
Same as directly above, plus treat plume beyond slurry wall, and recirculate	34.5	27.8	14.5

inhalation of organic compounds which have volatized from those waters as well as the risk of ingesting inorganic and organic contaminants.

For the various cases Raucher (1986b) assumes a 120 year time horizon and a range of interest rates (0%, 2%, 10%). The following table shows Raucher's (1986b) calculations for a range of remedial actions at the various sites. These estimates identify the least-cost response C_r to be used in the benefits calculations.

For the 58th Street landfill site the cost-effective response is closure, isolate (counterpump) and deep-well inject for low discount-rates but when the 10% discount rate is used the cost-efficient solution is counter-pump and deep well injection. For the Davie site the least-cost remedy is discontinuation of use of well water for drinking or cooking and supply the area with bottled water. For Gilson Road the cost-effective option is to partially isolate using a 7.5 acre slurry wall; remove the arsenic and recirculate. This does not isolate all of the contaminants however and hence has not completely solved the problem.

Raucher (1986b) compares these remedial costs with the cost of strategies that would have prevented the contamination from occurring in the first place at each site. For the 58th Street site the assumed prevention policy is to keep wastes above the water table and to cover the site when filled with an impermeable cover to prevent the leaching of wastes down to the water table. For the Davie site proper lines and covers for the sludge pond is assumed. For Gilson Road, there are three alternative strategies considered: send the wastes elsewhere to a proper facility; use a single liner on-site; or operate the site as a proper hazardous waste facility with high standards. The costs of "prevention" are compared to the remedial response costs in Table 2 for 58th Street and Davie and Table 3 for Gilson Road.

TABLE 2

COSTS OF PREVENTIVE AND CORRECTIVE MEASURES
AT BISCAYNE SITES
($\$1982 \times 10^6$)

	Costs (X_i)	"Benefits" (C_r)	
Rate Discount	PV Cost of "Prevention"	PV Cost of Most Economical Remedial Response	
58TH STREET:		Time Horizon of 30 Years	Time Horizon of 120 Years
0%	50.8	18.7	43.2
2%	67.5	14.7	24.0
10%	267.5	7.8	8.1
DAVIE:			
0%	0.91	0.10	1.24
2%	0.93	0.07	0.36
10%	2.68	0.02	0.02

TABLE 3

COSTS OF PREVENTIVE AND CORRECTIVE MEASURES
AT GILSON ROAD SITE
($\$1982 \times 10^6$)

Scenario	Discount Rate		
Preventive Options ("Costs" X_j):	0%	2%	10%
Send Waste Elsewhere	\$ 1.6	\$ 1.7	\$ 2.4
On-site: Single Liner	8.8	5.5	4.7
On-site: High Standard	4.3	4.4	5.3
Response Options ("Benefits" C_i):			
Small Slurry Wall, Partial Treatment	\$ 6.1	\$ 5.7	\$ 4.5
Small Slurry Wall, Full Treatment	7.6	7.1	5.5
Large Slurry Wall, Full Treatment	12.1	11.3	8.7

For the 58th Street and Davie landfills the respective cost-effective remedial responses are cheaper than the respective prevention strategies for all discount rates and time horizons considered. In the Gilson Road case the results depend on the various strategies both at the prevention stage and the remedial response. The option to send the wastes elsewhere dominates all other prevention strategies and is definitely cheaper than any of the remedial responses. The high standard hazardous waste facility option is preferred to the large slurry wall and full treatment response at any discount rate considered. However, the high standard facility is preferred to the single-liner, partial treatment at low discount rates but not at the 10% case.

The above comparisons essentially presume that once contamination occurs it is detected and remedial response eliminates the problem so that there are no health threats (or other adverse impacts). To decide if remedial action is warranted Raucher (1986b) considers the health costs that would be incurred in the absence of such action.

For the 58th Street episode Raucher (1986b) calculates a cost per statistical excess cancer avoided of roughly \$0.6 million while for the Davie episode the cost is roughly \$100 million. Citing a range of individual willingness-to-pay to reduce risk of a statistical death of \$0.4 - \$7 million, Raucher (1986b) concludes that remedial action is desirable for the 58th Street episode but not for the Davie episode. The factor that is causing the major difference between these episodes is population size. The 58th Street incident exposes 500,000 people to risk, while the Davie site exposes only 280.

For Gilson Road, prevention is less expensive than remedial action, however, the cheapest prevention strategy of sending wastes elsewhere still results in a cost of \$6 million per statistical excess cancer avoided when a zero discount rate is employed. All other estimates provided for the Gilson Road episode are well outside the range of individual willingness-to-pay.

It will be noticed that the approach followed by Raucher (1986b) does not conform to the analytical framework that we adopt.

3•2 Studies of Siting Hazardous and Noxious Facilities. There is a surprisingly small published literature dealing specifically with the economic aspects of groundwater quality protection. The literature that does exist deals almost exclusively with existing episodes (Category I in section 2•5) and then only the attendant health risks in most cases. According to a Wyoming DEQ spokesperson there are no government studies on the economic aspects since their response to an episode is dictated (under current regulations) by human health threat considerations only, given a contamination episode. For example, the Rawhide Village was denied federal assistance initially because the gases, methane and hydrogen sulfide, which were present were "not life-threatening". The discovery of a third gas, hydrogen selenide, and high methane concentrations leading to the threat of fire and explosion led the Federal Emergency Management Agency to reverse their decision and provide disaster relief of up to one year's housing cost.

We believe that the existing studies of groundwater contamination are deficient in terms of their usefulness to the ex ante design of regulations and their appropriate stringency (Category III) and the ex ante benefits of monitoring existing sites (Category II). The studies ignore non-life threatening health impacts and the anxiety cost of the possible consequences of an approaching plume or one that could change direction due to geological structure. They ignore the potentially large loss in wealth that households may experience if the threat of explosion requires evacuation of house and home (witness the Rawhide problem).

Having identified this significant omission in the groundwater literature leads us to consider the literature on the problem of siting hazardous waste disposal, and other noxious, facilities. These studies deal with ex ante decision making and the possible impacts may include groundwater contamination but are generally of a broader nature.

3•2•1 Contingent Valuation and Option Price for Risk Reduction. Smith and Desvousges (1986a, 1987) propose using a Contingent Valuation Method (CVM) to determine the option price that individuals would be willing to pay for regulations that reduce risk. The theoretical framework is cast in simple fashion as follows. The individual faces two separate risks. First, a risk R of exposure to hazardous compounds during a specified time interval, and second, a separate risk, q, of premature death given exposure (although it is straightforward to consider deleterious effects short of death in this framework). The individual's utility function, V is state-dependant and depends upon income, y, and a vector of socioeconomic characteristics, Z. V_L and V_D represent the utility given life and death respectively.

The individual's expected utility given the risks R and q is given by:

$$E(V) = R_q V_D(y, Z) + (1 - R_q) V_L(y, Z) \tag{3.17}$$

Suppose now that there is a policy that will reduce the risk of exposure from R to $\bar{R}$. The household will place a higher value on the more favorable policy. Option price is defined as the largest amount P, that the household would be willing to pay to have the more favorable policy rather than no policy (i.e. a passive policy of no action). P is defined algebraically by:

$$\bar{R}_q V_D(y - P, Z) + 1 - \bar{R}_q)V_L(y - P, Z)$$
$$= R_q V_D(y, Z) + (1 - R_q)V_L(y, Z). \quad (3.18)$$

P may be interpreted as the individual household's value of risk reduction.

Smith and Desvousges (1986a, 1987) apply this framework to a hypothetical regulation case for a hazardous waste facility in Boston, Massachusetts. They asked individuals how much they would pay for (1) a 50 percent reduction in R and (2) a further 40 percent reduction in R. The risk of exposure occurs over a 30 year period. Another question asked willingness to pay to avoid an increase in R (equal in size to the sum of the two decreases) caused by an increase in the volume of wastes to be disposed. The risks were portrayed using shaded areas of disks.

The results indicated that marginal values declined with increases in the baseline risk specification. The marginal valuation was lower for the case of avoiding a risk increase, than for obtaining a risk decrease which may be related to the perceived property right entitlements.

3•2•2 Hedonic Property Value Approach. Smith and Desvousges (1986b) employ a hedonic property value model to determine the hedonic property value model to determine the demand for distance from a hazardous waste facility in Boston. In this approach the individual is assumed to maximize a utility function.

$$U = U(Z, x) \quad (3.19)$$

where Z is a vector of property specific characteristics, and x is a composite good which has a normalized price of unity. The optimization is performed subject to an equilibrium locus that relates the relevant commodity price to the characteristics. The budget constraint is:

$$y = x + P(Z) \quad (3.20)$$

where y is consumer income and P(X) denotes the hedonic price function. The first-order equilibrium condition is:

$$\frac{\frac{\partial U}{\partial Z_i}}{\frac{\partial U}{\partial x}} = \frac{\partial P(Z)}{\partial Z_i} \tag{3.21}$$

where Z_i is the ith component of the Z vector.

The key component of interest in this study was the distance between the individual's residence and a landfill containing hazardous wastes. The individuals chose between two residences that had identical characteristics except for the distance from the landfill. The price of the closer residence corresponded to the average price of houses in the respondent's neighborhood, while the more distant home had a higher price. The price was increased a constant amount per mile. The constant marginal cost was taken to be one of four values ($250, $600, $1000, $1300) assigned randomly. Thus $\partial P/\partial Z_i$ in this case is a constant.

The authors determined annual values of consumer surplus per mile further away from the facility of between $330 and $495. This is the additional price per mile that individuals would be willing to pay annually to live further away from the facility. In their calculations the authors use a discount rate of 13% without justification. Following the arguments in Section 3•1, this rate may be excessively high.

3•2•3 Auction Mechanisms. Kunreuther and Kleindorfer (1986) and Kunreuther et al. (1987) propose a low-bid auction with a compensation mechanism for siting noxious facilities. It is assumed that there are N possible communities in which the facility may be placed. The problem is to select which community will host the facility given that there is a natural reluctance on the part of any community to fight the establishment of such a facility in their area.

The low-bid auction with compensation is designed to create an incentive for communities not to mis-state their preferences. In this proposed procedure each community is asked to specify a bid that is the smallest compensation that they would accept to host the facility. The planner selects the lowest bid community (assuming it is unique) and that community receives as compensation, its own stated bid. The remaining (N-1) communities must pay (1/(N-1)) times their own bids to finance the compensation. This mechanism limits the incentive to misrepresent their true preferences but is not fully incentive compatible.

The authors argue that if each community knows its own preferences but is ignorant of all other preferences, they will all pursue a maxi-min bidding strategy. This hypothesis was confirmed by experimental results when there was sufficient time for learning by the participants.

The mechanism generates a surplus of tax revenue that will finance the compensation and it is coalition-free. This latter point means that no two communities can gain by strategically linking their bids in any fashion.

In the development of the most basic mechanism, it is presumed that the externality associated with the facility is known with certainty at least for each community. If the externalities are stochastic then Kunreuther et al. (1987) suggest two alternative compensation schemes that can be used. In one case ex ante compensation is used. The low-bid community receives its low bid, say X_i. If a loss of L_i occurs then the net return to the community is $X_i - L_i$ which could be negative or non-negative. The ex post compensation mechanism pays compensation only when the event occurs. In this case Kunreuther et al.

(1987) propose a community or regional self-insurance program into which the participants pay a premium. When the accident occurs the victims are compensated from the fund. This proposal is similar to the insurance schemes being proposed for the underground storage tanks.

3•2•4 Referenda. Kunreuther and Kleindorfer (1986) and Kunreuther et al. (1987) emphasize the importance of public participation by all residents in determining the community bid. They suggest a referendum as a collective choice mechanism for selecting the final bid. This appears to open the possibility of information being made available to allow strategic behavior. There may be advantages to being the last community to hold a referendum.

Mitchell and Carson (1986) suggest that a major problem in trying to find an acceptable site for noxious facilities is that no one has clear property rights. As a solution they propose a collective property right that is enforced by using a referendum to decide local approval or rejection of a facility. They believe that this provides developers with incentives to develop strong proposals and to select potential sites where voters are more likely to be agreeable.

4• An Alternative Formulation for Assessing the Benefits of Protecting Groundwater Integrity.

4•1 An Ex Ante Perspective. Leaking underground storage tanks have several features in common with a wide variety of environmental problems. Most thinking about and modelling of the underground storage tank issue presumes routine releases that are small relative to the assimilative capacity of the environment and which only slowly vary and accumulate contaminant stocks. Cleary (1984), for example, suggests that transport and dispersion can be modelled adequately with rough average times of release and of geohydrological conditions. Our view is that it is generally insufficient to depict decisionmakers as working with a best estimate of a natural or an economic parameter and then proceeding as though the estimate were certain.

A very common alternative has decisionmakers pursuing a range of estimates, which could be based upon Bayesian calculations of full posterior probability distributions rather than simply working with a set of classical point estimates or expected values.[4/] Whether some summary measure such as an average or a range of estimates is employed, the estimates are ex post measures; that is, the values that they take on depend upon the realization of one or more states of the world. For example, a decisionmaker who adopts an ex post measure would estimate his economic consequences if realized contamination effects prove to be large and if realized effects turn out to be small. He might then strike an average of the two outcomes but in doing so he implicitly asks what the consequences would be if he knew the effects in each contingent state with certainty. The alternative, ex ante representation of this decisionmaker has him asking about the consequences when he is unsure whether the contamination effects will prove large or small. He recognizes that outcomes are stochastically related to actions, implying that his behaviors and the relative values which motivate them depend not only on preference orderings over outcomes, but also on preference orderings of lotteries over outcomes.

Because the ex post representation establishes a number of contingent states and proceeds to treat each of them as if it were certain, it is incapable of accounting for the decisionmaker's attitude toward risk; that is, as it measures the economic consequences of each presumed certain state, it disregards the expenditures that the decisionmaker makes in preparing for states that go unrealized. The ex post perspective disregards the degree to which the decisionmaker is willing to bear risk, i.e., the degree to which he is willing to take the chance of "wasting" his resources on eventualities that do not occur or of disregarding consequences, possibly severe, that could in fact be realized.

In a world of complete contingent claims (insurance and futures) markets the risk attitude-induced discrepancy between ex ante and ex post measures of economic value would not exist. Exchange would occur among the better and the less well-informed and among the more and the less risk averse until the magnitudes of all relevant dimensions of scarcity were made equal at the margin. Complete markets enable individuals to redistribute income and associated consumption and production opportunities toward undesirable prospective states. Ehrlich and Becker (1972) have shown, given insurance prices that are actuarially fair and individuals who are risk averse such that the marginal utility of income is decreasing, that insurance or futures claims would be acquired in those amounts that make the individual indifferent as to which of a set of feasible states of nature ultimately is realized. No matter what the realized state of nature the ex ante premium payments and the ex post compensation that the insurance supplies maintains the ex ante utility level. The opportunities that complete markets provide the individual to make actuarially fair option payments perfect the efficiency with which he can allocate his wealth among states of nature [Cook and Graham (1977)].[8]
Questions of ex ante versus ex post valuation therefore become irrelevant.

However, because of moral hazard, adverse selection, and nonindependence of risks, contingent claims markets are incomplete [Arrow (1971), Shavell (1979)]. Since fair contingent claims markets rarely if ever exist especially for environmental goods, ex ante measures of value are particularly appropriate for these goods. Policymakers must perform their tasks ex ante. Rarely do individuals have the opportunity to shift current resources toward undesirable future environmental states, and seldom is compensation for undesirable realized environmental outcomes an admissable public policy. Complete markets make anticipated and realized utility levels synonymous, implying that ex ante and ex post behaviors correspond, given that insurance prices are actuarially fair. The standard analysis of consumer behavior under certainty can then be applied without modification. One simply works with contingent Arrow-Debreu prices rather than with ex post prices. With incomplete markets, prospective outcomes are inherently uncertain, implying that the individual's planned rather than his realized outcomes explain his choices [Brookshire and Crocker (1981), Gallagher and Smith (1985)][6]

The valuation consequences of adopting an ex ante rather than an ex post perspective of the individual's decision problem can be formally demonstrated in a manner similar to Schmalensee (1972), Graham (1981), Chavas, et al. (1986), and others.

Assume that an individual faces the prospect of an exogenously determined pollution increase with probability π and a continuance of the status quo with probability $(1 - \pi)$. Further assume that he has a twice continuously differentiable, quasi-concave, state dependent, atemporal von Neumann-Morgenstern indirect utility function [Karni (1985)]:

$$\nu = V(A,y) = \pi V_1(A_1,y) + (1 - \pi)V_0(A_0,y) \tag{4.1}$$

where, in accordance with Becker (1965), y is "full" income. The subscripts on A, the pollution variable ($A_1 < A_0$), respectively denote the pollution increase and the status quo. Expression (4.1) represents the solution to the Lagrangian of the individual's constrained utility maximization problem; that is:

$$V(A,y) = U(x^*,Q^*) - \lambda(y - x^* - s(Q^*,A)), \tag{4.2}$$

where x^* and Q^* are respectively utility-maximizing quantities of a numeraire commodity and environmental quality, and $s(\cdot)$ is a self-protection function showing the minimum self-protection expenditures the individual must make in order to attain Q^* for any exogenous pollution level, A, and λ is the Lagrangian multiplier. Levels of market insurance and self-insurance are predetermined and are inadequate to make the individual indifferent between the occurrence or the nonoccurrence of the prospective pollution increase. Let y be independent of whether or not the pollution increase occurs.

Allow the pollution increase to occur. The ex post consumer surplus, w, gained in order to attain the individual's status quo utility level, V_0, must then be given by:

$$V_0(A_1,y - w) = V_1(A_1,y). \tag{4.3}$$

If self-protection is useful only for its contribution to attaining the status quo utility level, then the Le Chatelier principle implies that:

$$V_0(A_1,y - s) \geq V_1(A_1,y), \tag{4.4}$$

and it then follows that $w \geq s$; that is, because ex post compensatory full income can be used in any manner the individual wishes, it must at least be equal to self-protection expenditures.

Now presume that the pollution increase will never be realized. The individual's ex ante willingness-to-pay for this realization is z, where:

$$V_0(A_0,y - z) = (1 - \pi)V_0(A_0,y) + \pi V_1(A_1,y) \tag{4.5}$$

Let πw be the expected ex post surplus from this realization. It is then easy to show that $z > \pi w$. To do so, substitute (4.1) into (4.5) to obtain:

$$V_0(A_0, y - z) = (1 - \pi)V_0(A_0, y) + \pi V_0(A_1, y - w). \tag{4.6}$$

Assuming risk aversion, it follows from Jensen's inequality that:

$$V_0(A_0, y - \pi w) > (1 - \pi)V_0(A_0, y) + \pi V_0(A_1, y - w), \tag{4.7}$$

which directly yields the desired result.

Expressions (4.1) through (4.7) imply that the individual's ex ante value of preventing the pollution increase is the sum of three components: the individual's self-protection expenditures, πs; the probable loss in consumer surplus, $\pi(w - s)$, he would otherwise suffer; and $z - \pi w$, which is the difference between the willingness-to-pay to assure that the pollution increase does not occur and the expected value of the ex post consumer's surplus thereby derived. Basically, $z - \pi w$ is a risk premium. If the individual is risk averse, the term will be positive because, by the definition of risk aversion, he will pay more than the expected value of a loss in order to avoid a risk.

The amount $z - \pi w$ is typically referred to as option value, the difference between the maximum a risk averse individual would be willing to pay to retain the option of using a future good (option price) and the expected value of ex post consumer surplus. The latter, πw, is a traditional Marshallian or Hicksian measure while the former, z, includes a risk premium because the individual is required to make a decision before the state of nature or its associated outcome is revealed. Most of the abundant environmental economics literature on option value has sought to establish whether it is negative, positive, or zero, which would respectively imply that the traditional measures of environmental protection are positively, negatively, or not at all biased. It is generally agreed that the sign of option value is indeterminant for a risk-averse individual who confronts an exogenous probability of an environmental event. For example, if the exogenous probability of an undesirable event is reduced rather than eliminated, any insurance payment the individual has made reduces his income should the event occur. If his marginal utility of income differs with the occurrence or the nonoccurrence of the event (e.g., the state of being healthy or of being ill), then the expected value of ex post consumer surplus may exceed the ex ante willingness-to-pay such that $z < \pi w$.

The sole exception to the supposed ambiguity of the sign of the risk premium, as Bishop (1982) and Smith (1983) have shown, is that it will be positive when demand is certain and exogenous supply uncertainty is eliminated. At least superficially, this case would appear to describe the setting for leaking underground storage tanks.

The option value literature, however, invariably assumes that the individual treats the probability of provision of a desired good as exogenous, i.e., his private influence over an uncertain outcome is assumed to be predetermined or nonexistent. Exogeneity is by no means an obvious assumption and it is not difficult to find perfectly reasonable, everyday counter - examples. For example, when a potable water supply is uncertain, individuals often choose to provide self-protection in the form of bottled water, water filters, or both [Smith and Johnson (1988)]. Other examples of self-protection include purchases of air purifiers and conditioners to increase the likelihood of acceptable air quality, and the construction of air vents and isolation panels to reduce the chances of radon contamination [Smith and Johnson (1988)]. These and similar examples of environmental quality issues conform to what Mohring and Boyd (1971) and Cornes and Sandler (1986, Chap. 7) term impure public goods that have benefits which are only partially rivalrous or excludable.

It is easy to demonstrate that the prospective removal of supply uncertainty does not necessitate a positive option value, given that the level of this uncertainty is at least partially dependent on the individual's choice of actions. Here and throughout this report, we assume that demand is state independent. We therefore disregard demand uncertainty. We justify this neglect on the intuitive grounds that the price, money income, and preference-ordering sources of demand uncertainty are much less susceptible to immediate and direct manipulation by individuals. Since an individual who is an efficient provider of self-protection will have a wider variety of ex ante and ex post choices [Spence and Zeckhauser (1972)], the likelihood of a small option price, and consequently, a trivial or negative option value is increased. Therefore, any concept of ex ante valuation must include both self-protection expenditures and option price payments in order to avoid misestimating actual economic benefits of collective supply of a nonmarketed environmental good like the prevention of groundwater and soil contamination from leaking underground storage tanks.[7/] Similarly, savings in self-protection expenditures constitute a benefit of collective risk reduction efforts.

For simplicity, consider an individual who is uncertain about which of two mutually exclusive and jointly exhaustive states of nature will occur. Given that option price is defined in terms of an expected compensating variation, this binary assumption, which is standard in the option value literature, avoids the integrability problems raised by Chipman and Moore (1980) with respect to possible inconsistencies in using compensating measures to rank more than two alternatives.

Conrad (1986) makes a similar point. The following development differs from his, however, in that (a) we directly address the impact of self-protection upon the individual's ex ante risk premium (option value); and (b) the individual influences through his option price payment the optimal level of collectively-supplied reduction. Conrad's (1986) result nevertheless supports our view that accurate ex ante benefit estimation requires attention to both self-protecting expenditures and collective option price payments.

This individual, whose preferences and income are independent of these states, makes an atemporal choice in a von Neumann-Morgenstern framework where his expected utility is an increasing, strictly concave, and differentiable function of his certain income full income y, and an environmental good, Q. Thus, in the absence of self-protection or an option payment, expected utility, EU, is:

$$EU = \pi_0 U(y,Q_0) + (1 - \pi_0)U(y,Q_1), \tag{4.8}$$

where E is an expectations operator, $\pi_0 (0 \leq \pi_0 \leq 1)$ is the individual's initial degree of belief that level Q_1 of the environmental good will occur, $1 - \pi_0$ is his degree of belief in the occurrence of Q_1 and $U(y, Q_0) > U(y, Q_1)$. Given concavity of the utility function, option price, z, is then that ex ante sure payment, given nonstrategic revelation of preferences, which holds expected utility constant when the probability of Q_0 being realized has changed; that is, following Freeman (1985):

$$\pi U(y - z,Q_0) + (1 - \pi)U(y - z,Q_1) = \pi_0 U(y,Q_0) + (1 - \pi_0)U(y,Q_1), \tag{4.9}$$

where $\pi \gtrless \pi_0$. In accordance with the standard option value literature the payment of z "secures" access to the benefits of the predetermined probability of the desirable state, Q_0 [Smith (1985), p. 304)]. Typically the desirable state is represented as a pure public good which is independent of any individual's actions, and which the appropriate collective agency funds by sure payments from everyone.

More realistically, one might view the individual as one of a collection of potential beneficiaries, any one of whom by increasing the size of a voluntary option payment can enhance the probability of Q_0. Similarly the individual might improve his chances of privately commanding Q_0 by adopting assorted self-protection strategies. The collective and private alternatives are unlikely to be perfect ex ante substitutes for him, if only because of differences in his ability to influence the probability of the desirable state. For example, contributions to the construction of a public water treatment plant might make it more likely that everyone will get "safe" drinking water. Alternatively, an individual could accomplish the same end for himself alone by purchasing a water filter for his home.

With the singular exception of Conrad (1986) the current theoretical and empirical option value literature has not explicitly recognized the implications of substitution possibilities between self-protection and collective risk reduction. Weinstein, et al (1980) do discuss ex ante prevention expenditures in terms of preventive health practices relative to ex post curative expenditures. However, they do not allow for substitution between public and private prevention and cure, nor do they formally, consider endogenous states of the world. The empirical literature universally estimates maximum option payments by framing the payment mechanism in terms of government action as the only possible way to finance increased probability of provision.[8] No framework for incorporating self-protection or substitute activities is evident in these analyses.

When opportunities are available to make a probability - influencing option payment, z, or to engage in self-protection, s, the left-hand-side of (4.9) can be rewritten as:

$$\pi(s,z)U(y - s - z,Q_0) + [1 - \pi(s,z)]U(y - s - z,Q_1), \tag{4.10}$$

where π is differentiable and monotonically increasing in s and in z. Both self-protection, s and option price, z, are ex ante payments that maintain expected utility. The individual's problem is then to maximize (4.10) over s and z where $s \geq 0$ and $z \geq 0$. Defining $m = y - s - z$, the following first-order Kuhn-Tucker conditions result, given that the unit price of self-protection is independent of option payments:

$$s: \quad \frac{\partial\pi}{\partial s}[U(m,Q_0) - U(m,Q_1)] - \pi \frac{\partial U(m,Q_0)}{\partial m} - (1 - \pi) \frac{\partial U(m,Q_1)}{\partial m} \leq 0,$$

$$s \geq 0, \tag{4.11}$$

$$s\{\frac{\partial\pi}{\partial s}[U(m,Q_0) - U(m,Q_1)] - \pi \frac{\partial U(m,Q_0)}{\partial m} - (1 - \pi) \frac{\partial U(m,Q_1)}{\partial m}\} = 0;$$

and

$$z: \quad \frac{\partial\pi}{\partial z}[U(m,Q_0) - U(m,Q_1)] - \pi \frac{\partial U(m,Q_0)}{\partial m} - (1 - \pi) \frac{\partial U(m,Q_1)}{\partial m} \leq 0,$$

$$z \geq 0, \tag{4.12}$$

$$z\{\frac{\partial\pi}{\partial z}[U(m,Q_0) - U(m,Q_1)] - \pi \frac{\partial U(m,Q_0)}{\partial m} - (1 - \pi) \frac{\partial U(m,Q_1)}{\partial m}\} = 0.$$

The terms $\frac{\partial\pi}{\partial s}$ [•] and $\frac{\partial\pi}{\partial z}$ [•] in (4.11) and (4.12) represent the expected marginal utilities of a change in the subjective probability of Q_0. The $\frac{\partial U}{\partial w}$ terms are the marginal costs, in terms of altered money incomes. If the expected marginal utilities or marginal benefits of the probability change equal the marginal costs of s or z, then an interior solution to the individual's utility maximization problem is implied. In this case the individual makes a payment for the collectively supplied good and purchases some self-protection as well. His relative amounts of option payments and self-protection expenditures will depend upon their relative marginal productivities in securing increases in π.

If the marginal costs of a decreased money income exceed the marginal benefits of a probability increase in Q_0 such that:

$$\pi \frac{\partial U(m,Q_0)}{\partial m} + (1 - \pi) \frac{\partial U(m,Q_1)}{\partial m} > \frac{\partial \pi}{\partial s \text{ or } \partial z} [U(m,Q_0) - U(m,Q_1)], \qquad (4.13)$$

then a corner solution is obtained, implying either that the option price payment or self-protection or both will be zero. If the individual can always produce a given probability increase at less cost by using self-protection than by paying the option price, he will do so. A similar point applies to his contributions to any prospective collectively supplied probability improvements. Basically, self-protection allows the individual to substitute between own and the collective provision of a desirable state of nature. Because it expands the individual's choice set and thereby improves his ability to allocate risk among states, an opportunity to self-protect reduces his demand for collective provision of the desirable state. Since discrepancies in utilities are reduced among states, option prices, as is evident from (4.12), must fall. The value of altering the uncertainty associated with a lottery on a desirable state is reflected in the individual's option payments <u>and</u> in his willingness-to-pay for self-protection. Consequently, any concept of option price which refers only to collective provision of a good may result in underestimates of the actual ex ante value that individuals attach to the prospective provision of desirable states of nature. Similarly, a legitimate part of the benefits of any collective risk reduction effort is the savings in self-protection expenditures that it engenders.

If the availability of self-protection can reduce option price, z, then it can also impact option value, $z - \pi w$. As in Cook and Graham (1977), expected consumer surplus, πw, is the individual's ex ante benefit from having an entitlement to the desirable state, and z, option price, is the aforementioned gain from an increase in the ability to reallocate income among states. Graham (1981, p. 721) demonstrates that the use of expected consumer surplus, πw, to measure ex ante value is appropriate if and only if the individual faces actuarially fair prices, i.e., if and only if complete contingent claims markets exist. Marshall (1976) shows that such markets imply that risk must be exogenous. It follows that πw does not vary with self-protection efforts.

If self-protection is an efficient choice for the individual, then, in accordance with the argument surrounding (4.13), option price, as customarily defined, can be small or zero. Given the definition of $z - \pi w$, it is immediately evident that a small or zero option price causes a smaller or even a zero or a negative option value. It follows that large or even positive option values can exist only when the individual is an inefficient self-protector, or if he is uninformed about opportunities for self-protection. For example, in the perfectly plausible case where the individual would prefer not to have any collective provision whatsoever, then:

$$z - \pi w = -\pi w < 0. \tag{4.14}$$

More generally, the individual's ability to endogenize risk through self-protection implies that collectively supplied risk reductions may be redundant, thereby providing no additional welfare benefits. A complete measure of ex ante value, therefore must include both self-protection and option price expenditures.

4•2 Ex Ante Valuation. The previous section provides an economic rationale for focusing upon the ex ante rather than the ex post damages arising from leaking underground storage tanks. In general, damages are a choice-bound concept and choices are based upon "what could be" rather than upon "what might have been". The individual's valuation decision, implicitly the damages he suffers, and thus his proposed behaviors are dated at the time of his decision based upon the information that he has available. Damages, then, in their relationship to choice, the representation of valuation, must be based on expectations, not the realized outcome of the decision problem in question. The appropriate nexus for assessing values corresponds to the instant of the individual's decision.

In this section, we develop expressions that can be used to estimate the ex ante value that an individual places upon the prospect of having his health or property harmed by groundwater or soil contamination originating in leaking underground storage tanks. Our analysis proceeds through a selected range of cases with and without insurance and self-protection. We span the domain of plausible cases but we do not exhaust them. We start from the simplest case of no self-protection and no insurance and conclude with the case of partial insurance and self-protection that influences both the probability and the severity of a prospective loss.

Our particular concern is with the individual householder. The housing market is distinctive because a very large fraction of the housing services consumed in a given period are produced from the standing stock and this stock is expensive to modify. Thus, at least to a first approximation, housing prices are strictly demand-determined since existing dwellings are "auctioned" for occupancy by the highest bidder. We shall consider the effect of a danger upon the behavior of the householder when he is tied to his current residence.

4·2·1 No Insurance, No Self-Protection. Suppose that the individual annually engages in a two-stage budget process where the full income that he allocates is a combination of his money income and his leisure time. In the first stage he allocates this income between housing services and other commodities such that the necessary and sufficient conditions for weak separability are fulfilled.[9] He then decides how the full income to be devoted to housing services will be allocated across prospective activities or attributes at a number of housing sites.

A vector, $x \equiv (x_1, \ldots, x_n)$ represents these site-specific attributes, where each x_i, $i = 1, \ldots, n$, is the quantity of the attribute at a site. Central to the enjoyment of any site is environmental quality, Q, which varies inversely with leaking storage tank-induced groundwater and soil contamination, A; that is $Q = Q(A)$, and $Q' < 0$.

The individual obtains utility, U, from more x and more Q. He must select a particular bundle from his planned budget set, $B = [x | px \leq y]$, where $p \equiv (p_1, \ldots, p_n)$ is the vector of exogenous prices such as space-heating and commuting costs that he confronts, and y is his full housing income, including the predetermined opportunity cost of the leisure time that he plans to devote to enjoying housing services.

Consider a risk-averse individual who is momentarily and irrevocably committed to a stay of fixed length at a particular housing site; however, he is uncertain about the environmental quality condition that will prevail during his stay. When the formulation of Cornes (1980) and Crocker (1985) is modified to accord with Anderson (1979), Smith (1987), and other ex ante valuation literature, the individual's second stage decision problem can be stated as:

$$\sum_{j=1}^{h} \bar{V}_j(p,\pi_j(A),Q_j,y,\bar{x}) = \max_{x,Q}[\sum_{j=1}^{h} \pi_j(A)\bar{U}_j(\bar{x},Q_j) | \bar{x}\varepsilon B], \tag{4.15}$$

where $\bar{V}$ $(\cdot)$ is continuous, quasi-concave, homogeneous of degree zero, monotonically increasing in Q and y, and nonincreasing in p. The bar over the x-vector indicates that its elements and their magnitudes are invariant. Assume, as in Neary and Roberts (1980), that there exists a finite, nonzero vertical price at which the current site-specific stay would be made when x is a choice variable.

Q_j is a random variable with distribution function $F(Q_j;A)$ during the planned stay. It has subjective probability, π_j, in the jth of h mutually exclusive pollution, A, states. The pollution level thus defines the state. Of course, for any given state, $\sum_j \pi_j = 1$. $\bar{V}_j(\cdot)$ is a state dependent, indirect, restricted, expected utility function [Karni (1985)] showing the individual's maximum attainable expected utility given a parametric planned full income, price vector, attribute vector, and subjective distribution, $F(Q_j,A)$. For the housing site in question, first-order stochastically dominant reductions in the individual's subjective probability of a less desirable environmental quality level will increase his maximum attainable expected utility since:

$$\frac{\partial \bar{V}_j}{\partial A} = \frac{\partial \bar{V}_j}{\partial \pi_j} \cdot \pi_j' < 0. \tag{4.16}$$

A lottery stochastically dominates another if the new lottery can be obtained from the old by shifting probabilities from less preferred to more preferred outcome levels such that $F_A(Q_j;A) < 0$ [Machina (1982)].

Upon differentiating (4.15) with respect to π_j and M, setting the change in expected utility at zero, and using Roy's Identity, one obtains the restricted Marshallian demand, ν_{jA}, of a pollution - induced change in the probability of the jth environmental quality state during the given planned stay:

$$\bar{\nu}_{jA}(p,\pi_j(A),Q_j,y,\bar{x}) = \frac{\frac{-\partial\bar{V}_j}{\partial\pi_j} \cdot \pi_j'}{\partial\bar{V}_j/\partial y}. \tag{4.17}$$

Inversion of expression (4.15) or estimation of the parameters of expression (4.17) produces a restricted cost of utility or planned expenditure function for the jth state:

$$\bar{C}(p,V_{0j},\pi_{0j}(A),Q_j,\bar{x}). \tag{4.18}$$

This expression specifies the minimum expenditures the individual must make to attain the utility level, $\bar{V}_{0j}$, given p, π_{0j}, and $\bar{x}$. Application of Shephard's Lemma to (4.18) brings forth the following Hicksian compensating surplus measure for a change in π_j from π_{0j} to π_{1j}:

$$\bar{z}_j = \bar{C}(p,\bar{V}_{0j},\pi_{0j},Q_j,\bar{x}) - \bar{C}(p,\bar{V}_{0j},\pi_{1j},Q_j,\bar{x}). \tag{4.19}$$

By definition of the planned expenditure function,

$$\bar{C}(p,V_{0j},\pi_{0j},Q_j,\bar{x}) = y; \tag{4.20}$$

thus

$$\bar{z}_j = y - \bar{C}(p,\bar{V}_{0j},\pi_{1j},Q_j,\bar{x}). \tag{4.21}$$

$\bar{z}_j$, or "willingness-to-pay" is therefore the change in planned expenditures that would have to be allowed the individual if he is to be indifferent between π_{0j} and π_{1j}. When there are h states, $\bar{w}_j$ is then the average of the changes in planned expenditures that must be allowed him if he is to recover his initial expected utility level.

The average across states of the $\bar{z}_j$ in expression (4.21) is a generalization of the Diamond and Stiglitz (1974) mean utility preserving spread. While working within a state-independent framework, the defined the spread as a change in the distribution of utility that maintains utility but shifts the probability mass toward the tails of the distribution. A state dependent utility function allows utility to increase in some states and decrease in others if average utility taken across states is unchanged.

If the individual's expected utility function is concave in the π_j, Jensen's inequality implies that $\bar{z}_j$ will be greater than the income change required to recover the individual's expected utility level after the realization of what was the average of the visibility states. This difference, $z - \pi w$ in Section 4•1, represents a risk premium which incorporates risk attitudes and risk beliefs or perceptions. As Helms, (1985) demonstrates the risk premium changes as the probability density function, $F_A(Q_j;A)$, changes.

The standard view is that the marginal valuation of a desirable probability change is positive and decreasing.[10] The analytical basis of the conventional view is obscure. Consider, for example, the change in the individual's restricted Marshallian demand, $\bar{\nu}_{jA}$ in (4.17), when pollution changes such that the probability of realizing a particular environmental quality level is altered:

$$\frac{\partial \bar{\nu}_{jA}}{\partial A} = - \frac{1}{\partial \bar{V}_j / \partial y} \left[\frac{\partial^2 \bar{V}_j}{\partial \pi_j^2} (\pi_j') + \frac{\partial \bar{V}_j}{\partial \pi_j} \cdot \pi_j'' + \bar{\nu}_{jA} \frac{\partial^2 \bar{V}_j}{\partial_A \partial \pi_j} \cdot \pi_j' \right]. \tag{4.22}$$

This expression obviously lacks simplicity, implying that its sign is likely to be ambiguous.

4.2.2 Self-Protection, with Limited and Predetermined Insurance. Marshall (1976) shows that exogenous risk requires a complete set of Arrow-Debreu continent claims contracts. Because the writing of contracts is costly, complete contracts rarely if ever exist: the individual must therefore choose between contractually defining states of nature or making an effort to alter states of nature.[11] Though, as Ehrlich and Becker (1972) point out, one can always redefine a problem such that the state of nature is independent of human actions, the redefinition will frequently be economically irrelevant. They ask the reader to consider the probability that a bolt of lighting will burn down a house. The probability of this event will be altered if the owner places a lightning rod upon his roof. One might redefine the state of the world to be independent of the owner's actions by thinking in terms of the probability of lightning striking the house. The owner has no control over the probability of a strike. However, this probability is not economically relevant. The owner is interested in the probability of his house burning and he is able to exercise some control over the event.

Consider an individual who must decide how much self-protection to undertake as he faces the prospect of being involuntarily exposed at his residence to contaminated groundwater and soil. Assume that he is immobile for the period in question, implying that the following expressions are "restricted" in the sense of expressions (4.15) - (4.22). For a particular liability regime, his dilemma arises because his prior self-protection expenditures that reduce the likelihood and the severity and hence the costs of any ex post damages that he suffers will also cause his ex ante personal consumption to fall. Because of adverse selection, moral hazard, and nonindependence of risks, the individual chooses not to or cannot acquire enough market insurance to avoid the dilemma completely. Given his insurance purchases and given that his utility is intertemporally separable the individual's choice problem is then:

$$\underset{x,s}{\text{Max}}\ EU = \int_a^b U(x,Q)f(Q;s,A)dQ \,\Big|\, x + s + C(Q;s,A) \leq y, \tag{4.23}$$

where E is the expectations operator and U is a von Neumann-Morgenstern utility index with the same properties as the index in (4.15).

Expression (4.23) says that the individual's decision problem is to choose, given a full income, y, that combination of expenditures on personal consumption, x, and on self-protection, s, which maximize his expected utility. His probability-weighted utility is a function of his personal consumption and environmental quality, Q, where $U_x > 0$, $U_Q > 0$, $U_{xx} < 0$, and $U_{QQ} < 0$. Subscripts refer to partial derivatives.

The probability weights in (4.23) are represented by a symmetrical subjective probability density function, f, defined over the minimum, a, and the maximum, b, environmental quality that the natural and the developmental history of the site allows. Alternatively, f might be defined over the feasible health states that the individual's genetic and developmental history allows. We presume that the interval [a,b] is independent of self-protection expenditures. The probability density function of health states is dependent upon self-supplied protection, s, from prospective site-specific contaminated groundwater and soil, A. Let $f_s > 0$ and $f_A < 0$ exhibit first-order stochastic dominance. in Machina's (1982) sense. Though the individual acting alone is unable to influence the extent of site-specific contamination, he uses self-protection to reduce his exposure, thus influencing the cumulative probability distribution, F(•), of site-specific environmental quality states. No restrictions are placed on the signs of f_{ss}, f_{AA}, and f_{sA} in the immediate neighborhood of the expected utility maximizing level of self-protection, s*.

For each environmental quality outcome that the individual realizes, he selects a minimum cost combination of medical care and foregone work and consumption. His ex ante efforts to protect himself from the contamination influence these costs, C, such that $C_s < 0$, $C_A > 0$, and $C_{ss} > 0$. A person may suffer, for example, from lead-induced hypertension but the severity of this hypertension will vary with his ex ante dietary habits. The signs of C_{AA} and C_{sA} have no restrictions. Our reluctance to sign f_{sA} and C_{sA} reflects the possibility that these responses depend upon the environmental concentration (quality) of contamination as well as the extent to which the individual chooses to reduce his exposures.

4•2•3 Endogenous Risk. A few recent refinements to the willingness-to-pay approach to valuing environmental hazards have acknowledged their frequently endogenous form. For example, Rosen (1981), Berger, et al. (1987), and Viscusi, et al (1987) note that self-protection affects survival or injury probabilities, while Gerking and Stanley (1986) allow self-protection to influence the severity of ex post damages. In a nonstochastic world or in an uncertain world with only two feasible states, these studies demonstrate that marginal willingness-to-pay can be expressed solely in terms of the marginal rate of technical substitution between damages and self-protection. This result cannot be generalized to a continuous state, endogenous setting.

Proposition 1: Given the model assumptions, when self-protection influences the probability or the severity of health outcomes or both, the individual's marginal willingness-to-pay for reduced risk cannot be expressed solely in terms of the marginal rate of technical substitution between the hazard and self-protection. In particular, except for a risk-neutral individual with an identity map of ex post costs, unobservable utility terms cannot be eliminated from willingness-to-pay expressions.

Proof: Solve for personal consumption in the budget constraint, $x = y - s - C(Q;\, s,\, A)$, and substitute the result into the objective function in (4.23). Maximization over self-protection then yields the following first-order condition for an interior solution:

$$EU_x = \{\int_a^b U[y - s - C(Q;s,A),A]f_s(\cdot)dQ\} - E(U_xC_s). \tag{4.24}$$

The left-hand side of (4.24) represents the marginal cost of increased self-protection in terms of the utility of foregone personal consumption. Its right-hand-side shows the two types of marginal self-protection benefits: the bracketed terms are the indirect utility effect of a first-order stochastically dominating shift in the probability distribution of damage outcomes; and the term outside the brackets is the direct utility effect of the enhanced personal consumption resulting from reduced ex post costs.

Solve for the compensating variation statement of the willingness-to-pay for reduced risk by first totally differentiating the expected utility function and budget constraint in (1). Then apply the first-order condition in (2). When self-protection influences both the probability and the severity of health outcomes such that $f_s > 0$ and $C_s < 0$, the willingness-to-pay expression is:

$$\frac{dy}{dA} = - \left[\frac{\int Uf_A dQ - \int U_x C_A f(\cdot)dQ}{\int Uf_s dQ - \int U_x C_s f(\cdot)dQ}\right] > 0, \tag{4.25}$$

where all integrals are evaluated over [a, b].

Even the assumption of a simple two state world will fail to remove the total and the marginal expected utility terms from (4.25). For example, let

$\pi(Q_0;s,A)$ and $[1 - \pi(Q_0;s,A)]$ respectively represent the subjective probabilities of status quo and damaged states, and $U_0(y - s;\ Q_0)$ and $U_1[y - s - C(Q_1;s,A),\ Q_1]$ be the utilities, $U_1 < U_0$, respectively associated with the status quo and the damaged states. The individual must choose s to maximize:

$$EU = \pi(Q_0;s,A)U_0(y - s,\ Q_0) + [1 - \pi(Q_0;s,A)]U_1(y - s - C(Q_1;s,A),Q_1). \quad (4.26)$$

The willingness-to-pay expression is then:

$$\frac{dy}{dA} = - \frac{\pi_A(U_0 - U_1) - (1 - \pi)U_1'C_A}{\pi_s(U_0 - U_1) - (1 - \pi)U_1'C_s}, \quad (4.27)$$

where $\pi_A > 0$, $\pi_s > 0$, and $U_1' = \partial U_1/\partial x$.

Now allow, as do Gerking and Stanley (1986), self-protection to influence the severity, $C_s < 0$, but not the probability of damaging outcomes, $f_s = 0$. Further assume that $f_R = 0$ which, with $f_s = 0$, implies that neither collective nor individual action will influence the probability of a particular damaging outcome, i.e., groundwater and soil contamination resembles sunspots or the phases of the moon. With these assumptions, expression (4.25) reduces to:

$$\frac{dy}{dA} = - \frac{EU_xC_A)}{EU_xC_s)} = - \left[\frac{EU_xEC_A - \mathrm{cov}(U_x,\ C_A)}{EU_xEC_s - \mathrm{cov}(U_x,\ C_s)}\right] > 0. \quad (4.28)$$

For the unobservable utility terms to be absent from (4.28), the two covariance terms must be zero; however, our model assumptions do not allow them to be zero since each is a function of Q. Therefore the two utility terms cannot be removed. Although an assumption of a risk neutral individual with an identity map of ex post costs would remove the unobservable utility terms, such an assumption is extremely restrictive.

Finally, assume, as does Rosen (1981), that self-protection affects probability, $f_s > 0$, but not severity, $C_s = 0$. In Rosen's (1981) terms, one cannot be more severely dead. For similar reasons, $C_A = 0$. Under these conditions, expression (4.25) reduces to:

$$\frac{dy}{dA} = - \frac{\int U f_R dQ}{\int U f_s dQ}, \tag{4.29}$$

and again the willingness-to-pay expression cannot be rid of the utility terms.

Some authors on the economics of uncertainty, e.g., Mirrlees (1974) and Holmstrom (1979), have used pointwise optimization techniques to eliminate utility terms. However, pointwise optimization evaluates self-protecting choices at each and every environmental quality state rather than in terms of lotteries over health states. It thus adopts an ex post rather than an ex ante perspective.

We could examine additional cases. For example, self-protection might influence only the probability of a health outcome, but hazard concentrations could affect probability and severity, or vice versa. The results would not change: unobservable utility terms would loom up in the willingness-to-pay expressions, implying that policy efforts to aggregate and to account simultaneously for the reality of probability and severity unavoidably involve interpersonal utility comparisons.

4.2.4 Nonconvex Cause-Effect Relations. Proposition 1 poses hurdles to procedures which would establish a social risk-benefit test by summing unweighted compensating or equivalent variations across individuals. Ambiguities for any individual in the signs of these variations with respect to changes in prospective damages pose yet another problem for consistent aggregation.

In a contingent valuation study of the risk valuations attached to hazardous waste exposures, Smith and Desvousges (1986, 1987) report increasing marginal valuations with decreasing risk. This finding is but the latest in a 15-year long series of analytical [Starrett (1972), Winrich (1981)] and empirical [Crocker (1985), Repetto (1987)] papers which use prior information on physical cause-effect relations, individual abilities to process information about these relations, or individual perceptions of the relations to produce a declining marginal valuation result for more of a desirable commodity. However, when risk is endogenous, no one has yet asked whether knowledge of the form of physical cause-effect relations is sufficient to sign the change in the marginal value of risk when cognition is not an issue. This leads to a second proposition.

Proposition 2: Even in the absence of cognitive illusions or failure to consider all scarcity dimensions of the risk-taking problem, a maintained hypothesis of strong convexity of risk is insufficient to guarantee that increased exposure to a danger requires progressively increasing compensation to maintain a constant level of expected utility. Similarly, strong nonconvexity is insufficient to guarantee progressively decreasing compensation.

Define strong convexity of risk as: convexity of ex post costs, $C_{AA} > 0$; concavity of risk, $f_{AA} < 0$; and declining marginal productivities of self-protection, $C_{sA} > 0$ and $f_{sA} < 0$. The opposite signs define strong nonconvexity.

Proof: Differentiate the compensating variation in expression (4.24) with respect to environmental quality:

$$\frac{d^2y}{dA^2} = \frac{1}{\Omega}[-2\int U_xC_Af_AdQ + \int Uf_{AA}dQ + E(U_{xx}C_A^2) - E(U_xC_{AA})]$$

$$- \frac{1}{\Omega^2}[\int Uf_{sA}dQ - \int U_xC_Af_sdQ + E(U_{xx}C_AC_s) \tag{4.30}$$

$$- E(U_xC_{sA} - \int U_xC_sf_AdQ]\Delta,$$

where

$$\Omega = [\int Uf_sdQ - E(U_xC_s)] > 0,$$

and

$$\Delta = [\int Uf_AdQ - E(U_xC_A)] < 0.$$

Whether one imposes strong convexity or strong nonconvexity the sign of (4.30) is ambiguous. Although sufficient conditions for increasing or decreasing marginal willingness-to-pay can be determined, there is, in the absence of prior information or simple ad hoc assumptions, no reason to expect that one or two terms will dominate expression (4.30). This result supports Dehez and Drèze (1984, p. 98) who note that the sign of the marginal willingness-to-pay for safety given an increase in the probability of death is generally ambiguous. Drèze (1987, p. 172) concludes that any assertions about this sign "...must be carefully justified in terms of underlying assumptions".

Proposition 2 contradicts the argument of Weinstein, et al (1980) and others that individuals at greater risk with greater wealth (Proposition 1) must have a greater demand for safety. Consequently, contrary to Rosen (1981), individuals at greater risk with greater wealth cannot necessarily be weighted more heavily when risk reductions are valued. Similarly, the Kahneman and Tversky (1979) and the Smith and Desvousges (1987) assertions that declining marginal willingness-to-pay constitutes a lapse from rational economic behavior are not supported.

4•2•5 Self-Protection Expenditures as a Lower Bound. Consideration of self-protection has not been limited to problems of ex ante valuation under uncertainty. A substantial literature has emerged, e.g., Courant and Porter (1981), and Harrington and Portney (1987), which demonstrates that under perfect certainty the marginal benefit of a reduction in a danger is equal to the savings in self-protection expenditures necessary to maintain the status quo. This result cannot be extended to the uncertainty case when self-protection influences both ex ante probability and ex post severity.

Proposition 3: Neither strong convexity nor strong nonconvexity of risk is sufficient to sign the effect of a risk change upon self-protection expenditures. Therefore these expenditures cannot be used to determine the welfare effect of a risk change.

Proof: Take the first-order condition in Expression (4.24) and apply the implicit function theorem. The effect of increased exposure upon self-protection is then:

$$\frac{ds}{dA} = -\,[E(U_{xx}C_sC_A) - E(U_xC_{sA}) + \int U_x(1+C_s)f_A dh + \int Uf_{sA}dQ + E(U_{xx}C_A) - \int U_xC_Af_s dQ - \int U_x(1 + C_s)f_A dQ]/D, \tag{4.31}$$

where

$$D = E[U_{xx}(1 + C_s)^2] - E(U_xC_{ss}) - 2\int(U_x + U_xC_s)f_s dQ + \int Uf_{ss}dQ < 0$$

is the second-order sufficiency condition of the maximization problem in (4.23). It is assumed to hold whenever (4.24) is satisfied.

Given $D < 0$, the sign of (4.31) depends on the sign of its right-hand-side numerator. With strong convexity of risk, Expression (4.31) will be positive (zero/negative) if the first term in the numerator exceeds (equals/is less than) the next four terms. With strong nonconvexity, Expression (4.31) will be positive (zero/negative) if the first three terms in the numerator exceed (equal/are less than) the last two terms. Whether strong convexity or strong nonconvexity be imposed, there is no a reason to believe that any one set of terms in (4.31) dominates the others.

Proposition 3 contradicts Berger et al.'s (1987) argument that if increased exposure increases the marginal productivity of self-protection, $f_{sA} > 0$, then self-protection will increase with increased exposure. Consequently, Berger, et al.'s (1987, p. 975) sufficient conditions for "plausible" results cannot hold when self-protection influences both probability and severity.

4•2•6 Self-Protection and Market Insurance. If market insurance is a choice variable rather than predetermined, the above results are not altered. To see this, allow the individual to maximize the two-state dependent von Neumann-Morgenstern utility function

$$\begin{aligned} EU &= (1 - \pi(s))U_0[y - \alpha\beta(s)Q_1 - C(Q;s,A)] \\ &+ \pi(s)U_1[y - \alpha\beta(s)Q_1 - (1 - \alpha)\beta(s)Q_1 - C(Q_1;s,A)], \end{aligned} \tag{4.32}$$

where the undesirable environmental state, Q_1, is stated in pecuniary terms, α is the proportion of loss for which the market insurance compensates when Q_1 occurs, β is the price of market insurance per unit of covered loss, and the other variables are earlier defined and have already discussed properties. Assume that $\beta' < 0$. If both self-protection and market insurance are acquired, the first-order optimality conditions are:

$$\frac{\partial EU}{\partial s} = -(\alpha\beta'Q_1 + C_s)[(1 - \pi)U_{1s} + \pi U_{0s}]\pi'. \tag{4.33}$$

and

$$\frac{\partial EU}{\partial \alpha} = -(1 - \pi)\beta Q_1U_{1s} + \pi(1 - \beta)Q_0U_{0s}. \tag{4.34}$$

The first term on the right-hand-side of (4.33) is the effect of self-protection upon total wealth via changes in the unit price of insurance and in the minimum cost combination of medical care and foregone work and consumption if Q_1 is realized. The second term in (4.33) is the direct effect upon expected utility of a change in the probability of Q_1. Note that expression (4.34) implies that an increase in insurance coverage, α, increases the wealth level when Q_1 does occur and reduces it when Q_1 is unrealized. If the market insurance premia are actuarially fair, then $\beta(\cdot) = \pi(s)$. By substituting π for β in (4.32), expression (4.34) then implies that $U_{0s} = U_{1s}$. Given risk aversion, it follows that $y - \alpha\beta(s)Q - C(\cdot) = y - \alpha\beta(s)Q_1 - (1-\alpha)\beta(s)Q_1 - C(\cdot)$, and thus that $U_{0ss} = U_{1ss}$. Incomes in both states would be equal, thus implying actuarially fair prices and complete contingent claims markets. However, given that the unit price of market insurance is inversely related to the individual's observed self-protection activities, an incentive to self-protect would remain; that is, Expression (4.33) would reduce to

$$C_s = -\alpha\beta' Q_1 = -Q_1\pi' \tag{4.35}$$

which simply says that the individual will equate the marginal cost of severity to the marginal benefit of reducing damages, given that $\alpha\beta(s) = \pi(s)$ for all s and that the second-order conditions are satisfied. This marginal benefit is weighted by the proportion of any loss for which the insurance will compensate and by the response of the price of market insurance to the individual's observable self-protection activities.

As Ehrlich and Becker (1972, p. 642) show, Expression (4.35) implies that self-protection and market insurance are complements. Market insurance can increase the demand for self-protection, and an increase in the productivity of self-protection or a decrease in the price of insurance would increase the demand for both. Note, however that Expression (4.33) also implies that if the insurance price is independent of self-protection, then the availability of insurance discourages self-protection. Therefore, for those kinds of insurance having prices that are largely independent of attempts to self-protect, the demand for insurance should be large and the demand for self-protection small, or vice versa. Given the lack of householder access to market insurance against groundwater and soil contamination, the demand for self-protection against this contamination is thus likely to be large.

4•2•7 Empirical Implementation. Previous subsections have demonstrated that the degree of his knowledge of the dangers it poses him, his self-protection opportunities and their relative prices, collective protection efforts, and the extent, the price of his insurance coverage, and his degree of risk aversion will influence the ex ante value a householder attaches to a reduction in the prospect of groundwater and soil contamination at his home site. These earlier subsections have also provided insight on the properties of these influences. The question of empirically implementing and testing these models remains. This is a task, the details of which, that we leave to the next phase of the project.

We shall note here, however, that the earlier-mentioned (pp. 38-40) contingent valuation and hedonic pricing techniques are the two obvious approaches to empirical implementation and testing. The random utility, discrete choice model originally set forth by MacFadden (1974) Manski and McFadden (1981) provides a unified, statistical means of applying the contingent valuation and the hedonic pricing approaches.

Consider the hedonic pricing approach first. Utility maximization implies that each household chooses a vector of housing attributes, h, to maximize

$$U[h, y - p(h)]. \tag{4.36}$$

The housing attribute vector includes a householder-perceived probability density function for groundwater and soil contamination. For the individual householder the hedonic price function, p(h), is exogenously determined, but it is endogenous to the housing market since it results from the competitive behavior of households solving the maximization problem in (4.36). The hedonic price function is given by the solution to

$$\frac{\partial U(h, y - p(h)/\partial h}{\partial U(h, y - p(h)/\partial y} = \frac{dp}{dy}. \tag{4.37}$$

The left-hand-side of (4.37) is the marginal-rate-of-substitution of housing for income, i.e. the income compensated demand for housing, or the household's marginal bid for an additional unit of a housing attribute. In equilibrium the marginal bid just equals the market-dictated marginal price of the housing attribute, the right-hand-side of (4.37). Given a class of utility functions containing all of the common utility functions [Brockett and Golden (1987)], and given some mapping of housing to income, y = p(h), the market-wide hedonic price relationship can be computed.

Although the housing bundle is composed of a variety of attributes, actual housing choice involves one unit from a large number of discrete alternatives. As MacFadden (1974) showed, if (4.36) contains an additive stochastic component, and if this component is independently and identically Weibull-distributed across households, then the probability, θ, that a household will choose a particular dwelling h*, is

$$\theta(h = h^*) = \exp[U(h^*,y - p(h^*))]/\sum_h \exp[U(h, y - p(h)]. \tag{4.38}$$

If the preference function is linear in the parameters, then they may be estimated uniquely, up to a factor of proportionality, by maximizing a log-likelihood function of the form:

$$\log L \propto \frac{1}{k} \sum_{k} \frac{\log e^{U(h^*,\ y - p(h^*))}}{\log e^{U(h,\ y - p(h))}}, \tag{4.39}$$

for a sample of k observations on choices h* and available alternatives h. Haneman (1984) explains how this formulation may be interpreted in willingness-to-pay (accept) terms. King (1980) demonstrates how the discrete nature of housing choice and the continuous nature of the choice of the quantity of a single attribute may be jointly estimated when the error terms of the discrete and the continuous choice models are correlated.

A similar random utility formulation may be adapted to the data generated by a contingent valuation approach. For example, the current state of householder information by groundwater and soil contamination and the dangers it poses may be ascertained. The householder might then be asked whether he would pay a specific price in order to have this danger removed; alternatively he might be asked how high the danger would have to be in order to cause him to move to a predetermined location within the same city. These value would differ with the factors specified in the theoretical subsections of this chapter. The decision to move or to state a purchase intention implies that the expected utility from taking action exceeds the expected utility when adhering to the status quo. The random utility formulation involves a deterministic utility component and a random component that reflects the researchers' inability to observe all factors that might influence householders' decisions [Cameron and James (1987)]. Estimation requires specification of the arguments of the deterministic portion of the utility function and a form for the random errors. Again, using the restrictions implied by constrained utility maximizing behavior in a random utility formulation, the willingness-to-pay for the posited scenarios can then be estimated.

FOOTNOTES

1. See Shavell (1980), for example.

2. Several states have modified the tort law applying to impurities from environmental toxins. Under these discovery rules the statute of limitations starts ticking at the time a damage initially appears rather than at the time of a spill or an exposure. See U.S. Congress (1982).

3. Scarce collective and private resources necessitate some sort of balancing. The Federal Clean Air and Clean Water Acts expressly forbid such balancing; however, policymakers with scarce enforcement resources must still decide which of the site-specific problems covered by the Acts are to receive their ministrations and which are to be left alone for now.

4. See Adams, Crocker, and Katz (1984) for an example.

5. See Mishan (1976) for a full treatment of this case.

6. By "planned", we mean that the individual expends resources to acquire claims that he will exercise upon the realization of one or another states of nature.

7. Gallagher and Smith (1985) and Smith (1985) refer to changes in probabilities in combination with individual adjustment opportunities, but they do not treat self-induced changes in the probabilities of alternative states as an adjustment opportunity. The adjustments to which they refer appear to involve only the redistribution of income toward undesirable states rather than self-manipulations of the probabilities of these states.

8. See Greenley, et al. (1981), Brookshire, et al. (1983) Walsh, et al. (1984), and Smith and Desvousges (1987), for example.

9. See Deaton and Muellbauer (1980, Chap. 7) for an extensive treatment of these conditions.

10. See Weinstein, et al. (1980), for example.

11. Psychologists agree that individuals perceive that they have substantial control over events [Perlmuter and Monty (1979)]. Stallen and Tomas (1984) conclude that "...the individual is not so much concerned with estimating uncertain parameters of a physical or material system as he is with estimating the uncertainty involved in his exposure to the threatening event and in opportunities to <u>influence</u> or <u>control</u> his exposure" [emphasis added].

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