Economically Efficient Strategies

for

Preserving Groundwater Quality

by

Michael Kavanaugh

Robert M. Wolcott

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Public Interest Economics Center
1525 New Hampshire Avenue, N.W.
Washington, D.C. 20036-1291

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Preface

Groundwater resources in the U.S. are immense in quantity, exceeding the total capacity of all the nation's lakes and streams and are crucial to the performance of key economic sectors. Over one-half of the U.S. population (110,000,000 persons) are dependent on groundwater for various uses. Approximately 11 billion gallons per day or 38% of the freshwater supply is from groundwater. In terms of total supply more than 95% of freshwater in the U.S. is groundwater.

Groundwater has provided to date a unique, high quality resource. Shielded from surface exposure and encased within stable rock formations, groundwater provides high quality, continuously accessible water for multiple uses. Communities and economies have formed as a result of these waters and the safety and livelihood of millions rely upon the maintenance of their quality.

Despite the importance, quality and quantity of groundwater resources, and the absence, in many cases, of any affordable substitute supply, society has at times failed to foresee the threats which have emerged to groundwater. Excessive pumping in selected areas and infiltration of toxics from both point and non-point sources have generated increased signs of contamination and overdraft. The runoff of pesticides and herbicides from farm and urban pest control operations has long been recognized as a threat to aquifer quality. Industrial waste discharge has also been suspected of contributing to degradation through its adverse effects on the quality of groundwater recharge supplies. (Examples include the runoff of DDT and BCBs from military arsenals and the release of dioxin and other highly toxic compounds from operating chemical/industrial facilities.)

past, but which exhibits the potential for extreme and essentially permanent contamination is the large number of toxic and hazardous waste disposal facilities throughout the country, hundreds of which have been in place for decades.

Under the 1976 Resource Conservation and Recovery Act, the U.S. Environmental Protection Agency is authorized to protect human health and the environment from the dangers associated with the treatment, storage and disposal of hazardous wastes.

In order to issue regulations under RCRA, it is required that EPA portray the relationship between the benefits to be expected and the costs to be incurred as a result of the regulation. The following report presents the conceptual and empirical considerations which underlay an analysis of the most economically efficient control response to a case of toxic degradation of groundwater. In addition to these background considerations, a series of hypothetical case studies are presented to portray the most efficient responses to specified physical conditions including land use, geology, use values, and size and rates of degradation.

This study is not intended as a prototype benefit analysis. It is, instead, aimed at identifying issues which bear upon the development of a specific methodology for a fully integrated regulatory impact assessment. The case studies are intended to demonstrate the role and significance of selected physical and economic dimensions and to show, within wide bounds of uncertainty, what one must believe about the scale of benefits to adopt alternative response options.

This report is submitted by the Public Interest Economics Center (PIE-C) in partial fulfillment of EPA Work Assignment No. 96.

In the performance of this study, the authors have enjoyed the cooperation and advice of Robert Raucher of the Economic Analysis Division in EPA. Also contributing to the study was Edward C. Burrows and the firm of Geraghty and Miller, Inc..

PIE-C is a not-for-profit, public interest organization. Its purpose is to involve economists systematically in various aspects of public policy decisions to advance the public interest. Its main activities fall into four categories: providing a communications link between professional economists and both policymakers and public interest groups; performing, interpreting and disseminating economic research; providing economic educational services; participation in judicial, legislative and administrative processes on matters of economic policy or the economic aspects of other policy.

Like other studies PIE-C has performed on environmental economics, the issue of groundwater contamination is a matter of public interest and is an appropriate undertaking as part of PIE-C's research program.

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I. INTRODUCTION

A. Purpose and Conclusion

The purpose of this report is to identify and explore issues which relate to the level and types of costs which are incurred as a result of toxic contamination of groundwater as well as of control responses to this degradation. The methodology for evaluating control options, which is set forth below, is intended to draw into focus the benefits which may be realized by the pursuit of measures that prevent contamination. However, this report is not put forth as a formal benefit analysis.

The findings of our work in general are the following:

- The most efficient response to an incidence of groundwater contamination is highly sensitive to the length of the time horizon selected, i.e., the number of years during which the effects are assumed to be experienced for purposes of the analysis.

  Abstracting from human health risks and holding other factors constant, the shorter the time horizon, the more likely it is that the most efficient response will be to take no action to arrest the spread of the toxic plume.[1]

- The future value of groundwater is a key determinant of the most efficient contamination response.

  Three factors influence these estimates of future values. In the first instance, the real future value of aquifers is affected by the fact that they are not self-cleansing and not all receive recharge (fresh supplies from precipitation runoff).

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[1]The emerging theories of catastrophe, uncertainty and irreversibility indicate important modifications must be made to benefit analysis.

Hence, groundwater ought be considered as a nonrenewable stock resource.[2]

The second factor is the rate of discount chosen to reflect society's rate of time preference for groundwater quality. There are also nonmarket, option values, i.e., premiums paid over and above market values for increasing the probability that the resource will be available at a given price in some future period.[3] In addition, there are "quasi-option values," which denote the premium paid to preserve a course of action if additional information regarding alternative uses of the resources becomes available.[4] Finally, there is a value of reducing anxiety associated with easing the threat of catastrophe. The particular option chosen from among a menu of feasible choices depends upon local circumstances such as porosity, rates of plume growth, the perimeter of a plume, the land use of the abutting property, the distance to an alternative water supply and the volume of water that must be treated to acceptable standards.

With outcomes dependent upon time horizons, assessments of future values and conditons, and the possibility of a threat to human life and health, groundwater contamination incidents and

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[2]The classic article in the pricing of an exhaustible resource is Hotelling (1931).

[3]The concept was introduced by Weisbrod (1964) and has been the subject of a continuing controversy. See, for example, Bohm (1975) or Feenberg and Mills (1980).

[4]Where option value is regarded as a risk premium and may be positive or negative, quasi-option value is positive regardless of risk preferences and depends upon the present value of future information. See Krutilla and Fisher (1975) and Arrow and Fisher (1974).

their precursors (sitings of hazardous waste dumps, for example) become public problems. The important role played by local conditions make public participation necessary at the local level in siting decisions and in deciding what to do about contamination incidents. The influence of time horizons and the fact that contamination may affect nonmarket values may require changes in liability laws, statutes of limitations, zoning and new or expanded forums for public participation. The assessment of future values requires an ethical posture toward future generations.

Determining the least-cost response to groundwater contamination is a complex problem. There are multiple reasons for this complexity. First, local conditions almost always play a significant role in determining the cost of response options. This requires that highly specific information be collected and analyzed. Second, the costs of the response options are uncertain, as are the effects of groundwater contamination. Accordingly, it is inappropriate in such instances to rely on single-point benefit estimates for planning decisions.[5]

Third, groundwater contamination appears to be irreversible except over long periods of time. Irreversibility is a modification of the classical microeconomic assumption concerning resource mobility.[6] Reduced

[5]Mercer and Morgan (1976) propose the Weibull distribution to generate probability distributions for the relevant input variables, although they acknowledge there is no theoretical basis for describing the input variables as Weibull distributions. The distribution is selected as a matter of convenience.

[6]The first rigorous treatment of irreversibility was provided by Arrow (1968), although Krutilla (1967) mentions the concept in the course of explicating a model of production and natural environments. Fisher, Krutilla and Cicchetti (1972) drew upon the analytical apparatus developed by Arrow (1968) and developed a model for the allocation of natural environments between preservation and development.

resource mobility brings to the fore the importance of forecasting the future value of groundwater. This is because a decision to pollute is a decision that cannot be reversed. Suppose that with today's fair market prices, the value of an aquifer as a waste receptacle is greater than the value of an aquifer as an irrigation source. Also suppose that relative prices change in five years so that the value of an aquifer as an irrigation source surpasses the value as a dump. Although a change in end-use would be signaled, the characteristics of groundwater pollution prevent this switch from occurring.

Irreversibility also connotes that future generations will be affected by today's actions. This raises questions of intergenerational equity, that is, the "fairness" of discounting the values of existing resources to future generations. Irreversibilities, then, dictate caution and conservatism in natural resource decisions insofar as the well-being of future generations is of importance.

Fourth, there are thousands of hazardous waste dumps. Viewed in isolation, one incident may seem of little consequence. Yet, a large number of small incidents may result in a serious national problem as a large number of key aquifers could be sufficiently degraded to preclude high value use of those acquifers. Hence, imposing costly cleanup requirements and/or reductions in water supply might result.

Fifth, there may be a long delay between the time the aquifer is first polluted and the first manifestations of the consequences of pollution. Furthermore, there is likely to be a low probability that any one aquifer is contaminated, but the consequences of contaminated aquifers are high. This combination of low probability, long delay and high consequence reduces the analytical value of the traditional economic tools.

Traditional microeconomic theory deals with small, gradual changes in market values. Groundwater contamination has the potential to cause large, sudden changes in the value of a resource. This is the province of catastrophe theory.[7] The potential contribution of catastrophe theory to benefits analysis and the caution it signals for determining the least-cost responses to groundwater contamination are twofold: (1) Expected losses (derived by multiplying the probability of an event by the value of the event) are likely to be underestimates of the actual damage (Zeckhauser, Shearer and Memishian, 1975). When dealing with situations of catastrophe, individuals are likely to be highly risk-adverse and are unlikely to be able to fathom the damage. (2) The possibility of a catastrophe may lead to anxiety; the avoidance of anxiety may be a form of option value.

Sixth, some values that are reduced by groundwater contamination do not pass through markets. Human health, for example, is not bought and sold in traditional markets, though it may be impaired by groundwater contamination. There need to be processes for developing value judgements that can substitute for market values.

In sum, because of the uncertainty regarding cause and effect, because of the potential for catastrophe, because of the long-term irreversibility of contamination, and because of the value judgements that must be derived from nonmarket sources, the efficient response must blend engineering with economics with political processes.

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[7]The original text in the field is by Thom (1975); more recent explications include an introductory work by Woodcock and Davis (1978), an intermediate level text by Poston and Stewart (1978), and a collection of relatively advanced essays edited by Zeeman (1977). Recent applications in economics include: Balasko 1978a; Balasko 1978b; Harris 1979; Varian 1979; Vandijk and Nijkamp 1980; Adelman and Hihn 1981; Brown 1981; and McCain 1981.

B. Approach

Our approach to determining the least-cost response to groundwater contamination is as follows: First, the general context in which groundwater contamination is viewed is described. Second, a general "menu" of responses is developed. The menu may be broken down into two parts: (1) those responses that do nothing to arrest the spread of a plume and (2) those that are capable of arresting the spread. Of those that do not affect the spread, some responses are capable of restoring water quality while others are simply the consequences of inaction. Third, the menu is applied to a hypothetical contamination incident. Fourth, the costs of the various response options are compared.

A hypothetical, rather than a "real" incident was chosen because it is too early in our understanding of the problem to concentrate on a single set of circumstances. Observing what has been done provides an excellent basis for understanding why one particular response was chosen. On the other hand, it may provide no basis for understanding as to why other candidate options were not chosen. It is our intent to provide an understanding of the choices faced by parties affected by groundwater contamination and the decision process they must go through. Isolating a particular historical incident may result in the study of a response option that was not the least-cost option, but merely one that was convenient from a political or engineering standpoint.

Since the data are only approximate, one should not expect to be able to implement a response option at costs which are quoted in the text. The imprecision of the data, however, in no way alters the conclusions that are drawn. This is because the conclusions are not based on absolute prices but on relative prices. Furthermore, the conclusions are based on engineering and economic facts. Namely, high one-time costs must be paid to respond with option A, but option A has low annual maintenance costs. Option B, on the other hand, has low one-time costs but relatively high annual costs. It is this interplay between capital and operating costs, together with an order of magnitude accuracy in the prices of the response options, that gives rise to the conclusions: that the length of the time horizon is the key in determining the least cost-response, that local conditions strongly influence the feasibility of certain options, and that the possible effect of contamination on nonmarket values and the "time bomb" nature of groundwater contamination may require modifications in regulation and law.

C. Plan

In the next section the assumptions and circumstances concerning the hypothetical contamination incident are set out. Section III begins the development of the menu of response options. Section IV continues this development. Section V applies the menu to the incident. Section VI presents our conclusions.

II. THE STORY

The purpose of this section is to set out the assumptions and circumstances concerning a hypothetical contamination incident (the story). The story is told to illustrate and rank the response options. The story is made as general as possible so that the lessons learned in illustrating and ranking the response options might have a greater degree of generality. The section has three parts. Part A describes the setting--a predominantly agricultural region in the arid southwest. Part B places the story's time line in contemporary times. Part C provides details on the plume of contamination (its size and its movements) and the response options.

A. The Settng

The story takes place in a predominately agricultural region in the arid southwest. Fresh water is in short supply from groundwater and surface sources, now and in the future. Such an area might be Water Resource Council Region #1503 which encompasses most of southeast Arizona.[8]

At the outset water may not be redistributed among competing uses or areas. This may be attributed to legal, institutional and/or technological constraints such as the season of the year and/or the additional lack of water rights, and would be referred to as the short-run response. A long-run response might be characterized as one that takes place over a period during which water may be transferred among areas and/or one crop may be substituted for another.

Whether or not it is economically preferable to switch crops or transfer water depends, of course, on the net proceeds from each action.

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[8]A sort, by Geraghty & Miller, Inc., of Water Resource Regions, according to current and future estimates of water availability, revealed this fact.

Assume arguendo that as a result of waste contamination water is unuseable for irrigation of sugar beets. In the long run, water may be transferred from other areas or from other uses, if the net proceeds from transferring or switching are greater than the net proceeds available from the continuation of present usage. The costs of growing another crop or accessing another supply of water are important elements in determining the net proceeds of an action. Clearly, the type of substitute crop that may be grown or the distance to another source of water is, in part, determined by location. Consequently, the feasibility of switching and transferring is, in part, determined by where the story is set. The setting of this story is such that transferring is difficult and only a few high-yielding, high-valued crops are grown. These characteristics tend to produce damage estimates that are high relative to other agricultural regions where transfers are relatively easy and/or low-yielding, low-value crops are common.

Finally, since the story is set away from populated areas, hazards to human health are at a minimum. Nevertheless, potential, long-term threats to human health may warrant responses which are not based solely on assessments of readily monetized costs. A cost or risk-reduction analysis based on observed risk data, by substance, may be of some value to policymakers.

B. When?

The relationship of the timing of the degradation to key economic activities has a bearing on the relative cost of the response options. This is because the relative cost of the response options depends upon the relative prices of the resources used to arrest the spread of plumes of contamination and/or replace the poisoned water and/or value the goods sacrificed by not arresting the plume.

In theory, relative price changes are primarily attributable to changes in preferences and/or technology. As is customary in economic analysis, preferences and technologies are allowed to vary only in selective predetermined ways. Few, if any models of economic behavior, have preferences and technological change determined endogenously. Hence, absent a forecast of how taste and technology change, the relative prices that are quoted in the initial year are the relative prices that are quoted for all subsequent years.

Consideration of irreversibility and exhaustibility point up the importance of this assumption of constant relative prices. Irreversibility requires that an assessment of the future value of water be made explicit. This is because a decision to pollute groundwater is a decision that cannot be reversed. To the exent that the future relative price of water increases, the response option that involves suffering the consequences (using and losing) becomes progressively more costly.

Exhaustibility indicates that the relative price of water may increase over time. Hotelling (1931) has shown that for an exhaustible resource which cannot be replenished, the long-run rate of price appreciation will approach the social rate of discount. In some parts of the country groundwater is an exhaustible resource. After it is used, it "runs off" to another part of the country and is "lost." In such circumstances the relative price of water may be expected to increase over time. In other parts of the country, water is available from a number of sources and aquifers are recharged. In these circumstances groundwater does not have the characteristics of an exhaustible resource. No statement can be made about its future relative price.

In practice, relative prices may change because of inflation and the monetary and fiscal policies employed to counter inflation. Over long periods of time, however, inflation affects only absolute prices, not relative prices. Accordingly, an investigation of relative costs over a long period of time should come to the same conclusions whether 5%, 10% or 0% inflation is assumed. We assume herein that there is no inflation.

The length of time over which the story unfolds may affect the relative cost of the response options. This happens if one option has a high one-time cost and another option has a low one-time cost but annual costs that must be paid into perpetuity. Discount rates allow for intertemporal comparisons. Long time horizons coupled with irreversibilities and exhaustibility necessarily involve intergenerational transfers. These transfers require that an ethical posture towards future generations be taken. Is it fair, for example, to discount the values of unborn generations using a discount rate that is reflective only of the current generation? Is it fair to deny the use of a resource to a future generation without paying compensation?

Schulze, Brookshire and Sandler (1981) directly come to grips with such questions. They examine the long-term storage of nuclear waste (a potential contaminant of groundwater) from a utilitarian and libertarian point of view. The results of the modeling exercise are as follows: When initial incomes and utility functions are identical, the utilitarian ethic (maximize the utility of all) requires discounting if compensation can be paid. If incomes and utility functions are not identical then a zero discount rate is appropriate. The libertarian ethic (harm no one) rejects contamination (requires maximim control of degradation) if compensation cannot be paid, but accepts discounting if compensation between generations is possible.

Schulze and Kneese (1981) examine the philosophical underpinnings of benefit-cost analysis within the context of irreversibility and compensation. They too find that outcomes differ as ethical systems differ. This is particularly the case for uncompensated risk. Even if benefits outweigh costs, libertarians reject, under all circumstances, outcomes involving uncompensated risk. Elitists reject outcomes involving uncompensated risk, unless the risk is borne by a non-elite. Egalitarians and risk-adverse utilitarians reject uncompensated risks, unless the risk falls on an elite. Risk neutral utilitarians accept uncompensated risks as long as benefits outweigh costs.

These studies point up two important considerations. The first is the question of whether the risks are public or private [i.e., are individuals accepting the risk on their own behalf (private), or is the choice being made by some third party (public)?]. The second is the fact that the level of compensation must be assessed. Individuals may value risk differently under conditions of compensated and uncompensated risks.

A few observations regarding payments between generations might be helpful. First, the accumulation of a fund to pay compensation would require higher fees for waste storage. These fees would be reflected in the market price for the goods whose production generates hazardous waste. This increase in price may tend to reduce the demand for hazardous waste disposal capacity. Second, there would have to be some mechanism for determining which members of future generations receive the compensation. How many generations should be provided for? How should damage payments be calculated? These questions redound to the question of setting the appropriate fee for dumping waste in the current time period. The fees in turn send signals to today's consumers about their level of demand for products whose production generates hazardous waste. Failure to provide for compensation to future generations could result in an over-production of current goods that constitute or generate excessive levels of hazardous waste.

In summary, our story is told in a world of unchanging relative prices, with no inflation, with inter-temporal comparisions being affected by the use of discount rates. Changes in relative prices may be accomodated to the extent that the change is specified. It is unnecessary to be concerned about the effects of inflation, since it can be argued on logical grounds that inflation should have no effect. Inter-temporal comparisons are an integral part of the story and require an ethical posture toward future generations as well as institutions to administer transfers.

C. Who/How?

The central character in our story is a plume of toxic contamination. Its size and rate of growth as well as its composition are important for ranking the response options. Plumes are the result of a failure of landfill liner or surface impoundment resulting in the seepage of waste into the water table. It is generally acknowledged that there is no such thing as a fail-safe liner; consequently all dumps leak, sooner or later. It is also acknowledged that decontamination is not possible short of excavation of the site. The length of time between liner failure and pollution of the water table depends in part upon how far the water table lies beneath the faulty liner. These facts are not developed here; instead the story begins as the hazardous waste begins to pollute the aquifer. Many interesting questions are excluded with the adoption of this assumption. The benefits of monitoring groundwater are influenced by the speed at which the waste may leak into the water table. Hence, the vulnerability of an aquifer to contamination may be a key locational parameter in siting a surface impoundment or landfill.

The chemistry of the plume is a "soup" of organics and inorganics. The plume contains deadly concentrations of contaminants. Deadly concentrations of some pollutants range from .1 to 1 milligram per liter. Given physical conversions from liters to acre/feet and assuming a porosity of 20% to 30%, between .27 lbs and 2.7 lbs of contaminant must enter the aquifer each year to poison (render economically useless) one acre/foot of water. This is a very small amount of contaminants, representing less than a barrel of waste per year. Since the amount is small, it does not require an unbridled imagination to envision a plume growing for 50 years or more without substantial containment.

A plume's growth is influenced by many factors. Some guidance is provided by hydrological engineers who state that limited evidence reveals a plume may move as little as 5 ft. per year or as much as 4,500 ft. per year, depending on the composition of the plume and the physical characteristics of the aquifer. The plumes in this story are assumed to grow 360 ft. per year in one instance, and 3,600 ft. per year in another.

Physics, hydrology and geology give the plume its shape. It is convenient to think of the plume as flowing in one direction through an underground box canyon. In such a world the plume would appear to be an expanding rectangle. In fact a plume resembles a cone, frustrum or lune more than a rectangle.[9] The shape of a plume may be important for comparing those response options whose cost depends upon the dimensions of its perimeter with those options whose cost depends upon the size of the tip of the leading edge. The story is sympathetic and illustrates the response options for two different sized plumes. The first is 65' x 100' x 500'; the second is 65' x 2000' x 1000'.

Plume growth along with porosity determines the amount of water rendered useless. For a response option which excludes any corrective action (suffering the effect of contaminated water), the degradation of water begins as the plume moves beyond the perimeter of the hazardous waste site. (Hazardous waste sites typically have a buffer between the dump and the end of the property belonging to the owner of the dump.) The value of the water that is destroyed under the property of the dump operator was captured by the previous owner when the property changed hands or was considered when the change in uses was made, provided that the rights to water are bought and sold with the land. If this is not the case--and in some states groundwater is "common property"--then the market price for land is not reflective of the present use values of the water. States that treat groundwater as common property may require modifications to traditional approaches to estimate the benefits of siting decisions. One option, not developed herein, is the purchase of water rights under adjacent lands. This action is not uncommon in the

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[9]Since circles and figures that resemble circles enclose more space for a given perimeter than figures that resemble rectangles, a bias is created against the perimeter and leading edge options.

west. Energy companies, for example, are known to have purchased large acreages simply for the water beneath it.[10]

Using the contaminated water and suffering the consequences (referred to as using and losing) is not the only possible response. The contaminated water may be treated to acceptable standards (assumed to be drinking water standards) and then used. Another alternative is to develop another source of water. Using and losing, treatment, and alternative sources share a common characteristic--namely, the spread of the plume is permitted to continue. Each year more water is poisoned and each year the amount of water that must be replaced, treated or used in its degraded status increases. Given the characteristics of irreversibility, uncertainty and the possibility of catastrophe, options that result in more and more water being contaminated cannot be considered the least-cost option unless their resource cost is so low that it more than offsets any premiums society would be willing to pay to keep its options open regarding future uses of groundwater.

An entirely different response is to arrest the spread of the plume. Two responses that may arrest the spread of the plume are slurry walls and counterpumping. Slurry walls, which involve building an underground dam around the plume, are currently in use for construction projects. The applicability of slurry walls to groundwater contamination is limited by the depth of the water table. Current technology prohibits the use of slurry walls beyond a depth of 100 feet. The toxic plume of this story, however occurs in a water table that has a confining layer at a depth of 75 feet.

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[10]Energy firms in the Great Plains area have paid in excess of $400 per acre-foot of water in recent sales.

Another response that may limit the spread of the plume is counter-pumping (pumping/recovery wells). The principle of this option is to exert a force that counters the natural flow of the aquifer and thereby holds the plume in place. This is accomplished by pumping contaminated water to the surface at rates that counter the natural flow of the aquifer. One result is that a new disposal problem is created. Something must be done with water that is pumped to the surface. Accordingly, counter-pumping involves some surface treatment of water to some applicable standard. It may then be reinjected or discharged to a stream.

The plot of the story involves selecting the most efficient option among a given set of responses to prevent a plume or contamination from damaging more water, and/or to correct the damaged water to an acceptable standard, and/or to use water from another source, and/or to use the damaged water and lose utility. Since the consequences of contaminated water may extend for many years, "efficient" means more than just the initial outlay of resources. "Economically efficient" must include some notion of the premiums that must be paid to induce individuals to make irreversible decisions about resources whose future value is uncertain. It also must include some notion of the premiums that must be set aside to compensate future generations for the reduction in water quality.

III. RESTORATION OPTIONS

A. Introduction

One set of responses to a plume of contamination is to do nothing to arrest its spread. In this event someone or some entity (perhaps the public) ultimately may suffer the consequences of polluted water (reduced output, health risks, damage payments or the costs of actions to restore the water to its former state). Restoration actions may involve the provision of another source of water or treatment of the polluted water to acceptable standards. In terms of economic theory, as long as compensation is paid it does not matter who pays for the restoration or who suffers the loss if no action is taken. The result is the same, resources are consumed because the liner on a hazardous waste dump failed and an aquifer was partially contaminated. (There is a question as to the amount of compensation.) In practice who pays may well determine the type of response option selected and, in the long run, determine the value of the resources that are consumed in responding to the plume. The following sections discuss the restoration options.

The first option involves doing nothing and compensating agricultural users (current and future). (We discuss the potential health effect of drinking the contaminated water but we do not carry this option forward because of the problems of incommensurability between health and life on the one hand and restoration on the other.) This is followed by a discussion of treatment costs. The next discussion is about replacing the contaminated water with an alternative source of water. Discussion is limited to groundwater sources since developing new surface water sources generally is of too large a scale for a realistic response to groundwater contamination.

The feasibility of providing alternative sources of water is related to the physical characteristics of the region where the contamination incident occurs and the amount of water which has been degraded. In arid regions it may not be possible to replace the poisoned water with another source. On the other hand in humid regions it may be the case that provision of an alternative source is the least-cost option even after adjusting for the premiums associated with irreversibility, uncertainty and catastrophe.

The overall conclusion is that the costs of paying damages, providing an alternative source or treating water to acceptable standards are all directly related to the volume of water contaminated. Also, the costs of these options relative to one another is unlikely to change through time (given stasis in preference and technology) for any given volume of contaminated water.

B. Agricultural Damages

In this section a method of estimating worst-case damages associated with the use of contaminated water for irrigation in agriculture is developed. Water Resource Council Region 1503 in Southern Arizona is used for illustrative purposes. The cost of using contaminated water varies with the type of crop produced, irrigation practices, the rate of plume growth and porosity.

The logic underlying a calculation of the loss in value associated with using contaminated water is as follows: (1) Contamination degrades water quality, (2) Reduced water quality reduces agricultural output and threatens the value of the output that does survive, and (3) The reduction in agricultural output may be monetized by using market prices. Consequently, the damage caused by groundwater contamination may be approximated by the product of the market price of the destroyed output and the amount of output destroyed, presently and prospectively.

1. Facts and Assumptions

For a worst-case calculation, it is assumed that water quality degrades enough to effectively reduce to zero the agricultural output that could have been produced with uncontaminated water. This may happen in two ways: (1) the contamination effectively "kills" the plant and reduces yields by 100%; (2) the contaminant become embodied in the plant making it unfit for consumption. The results of biological inquiries into the relationship between toxic concentrations and yield reductions indicates yield reductions of 70%, 80% and 90% and report that the contaminants are found in the plants that survive. (Bingham, Page and Bradford, 1964; Lieberg, Vanslow and Chapman, 1942; Ligon and Pierre, 1932; Prince, et al., 1949; Crafts and Rosenfels 1939; Page Bingham and Nelson, 1972.)

Table 1 presents data on value per acre for Water Resource Council area 1503 (Southern Arizona). (Value is the product of yield and price.) Yields per acre for a particular crop vary by time and region. Weather, disease and management practices are important influences on yields. Market prices vary from year to year reflecting changes in supply and demand conditions and, in some instances, changes in agricultural policies. To the extent that market prices are the result of government policy, the market price would overstate the value per acre. In some instances the U.S. Department of Agriculture reports the prices received by farmers net of government payments. This is the case, for example, with the sugar beet price reported in Table 1. The Table shows that the

Table 1

Major Economic Dimensions of Principal Crops of WRC-1503

	Barley	Corn and Sorghum Silage	Cotton	Hay	Sorghum Grain	Sugar Beets	Wheat
Irrigated Acres (000)	76	91	103	205	112	10	125
Quantity Produced[a]	6,860	2,179	241	1,582	11,637	254	7,657
Yield[a]	90	24	2.30	7.70	104	25.40	61
Unit Price ($)[b]	1.02	10.46	92.00	27.00	1.21	20.29	1.33
Value/Acre ($)[b]	92.00	250.00	212.00	208.00	126.00	515.00	81.00

[a]Units are
Barley, sorghum grain, wheat in bushels per year;
corn and Sorghum Silage, hay and sugar beets in tons per year;
cotton in bales

[b]1975 prices/values per year.

Source: Center for Agricultural and Rural Development, Iowa State University also available from Agricultural Statistics, USDA, 1977.

crop producing the highest value per acre is sugar beets; the lowest crops are wheat and barley. Hence, destroying an acre of sugar beets, inflicts about $515 per acre per year in damage.[10]

An estimate of the number of crop acres that could have been produced annually with the water that was destroyed is needed. This depends first on the amount of water applied to an acre per year. In Arizona 4 to 5 acre/feet per acre per year are used for irrigation.[11] The second determinant is the total amount of water destroyed by contamination in a year. This is determined by porosity. In addition, the rate and direction of plume growth are important.[12]

2. The Calculation

The product of the amount of destroyed output and its market price is an approximation of the damage caused by contamination. The amount of destroyed output depends on crop yields, the amount of water destroyed and irrigation practices. The amount of water destroyed depends upon the rate of growth of the plume and soil characteristics.

For purposes of illustration the initial size of the plume is 500' x 1000' x 50' or 25 million cubic feet of material. An expansion of the

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[10]For this worst-case calculation, we assume the opportunity cost of all other inputs is zero. Relaxing this assumption will decrease damage estimates.

[11]An acre/foot of water would cover an acre of land to a depth of one foot and is approximately 325 thousand gallons.

[12]Porosity is a measure of the space available for water in the material. Since the plume size is dimensioned in cubic feet, the porosity figure produces a measure of cubic feet of waste contained in the plume. Use of physical equivalents allows for easy conversion to acre/feet of water. There are about 7.5 gallons of water in a cubic foot and 325,000 gallons in an acre/foot. In practice, determining the size of plumes and their rate and direction of growth is done by monitoring. Monitoring is a cost common to all options and is not an influence on the ranking of options.

plume to 500' x 1100' x 50' will encompass 27.5 million cubic feet of material or 2.5 million cubic feet of additional material per year. With a porosity of 30%, an additional 750 thousand cubic feet (17.3 acre/feet) of water are destroyed each year the growth of the plume is not arrested. Given that current irrigation practice is to apply 4 to 5 acre/feet per acre per year, about 4 acres of additional output are destroyed each year the plume is not arrested.[13] These losses will accumulate through time.

The value of this loss depends upon the crop sacrificed. The lowest valued crop was wheat at $82 an acre, while the highest was sugar beets at $515 an acre. A loss of 4 acres ranges from $328 to $2,000 the first year; $628 to $4,000 the second year; $984 to $6,000 the third year and so on. It may be seen that the critical variables in determining agricultural loss are: the per acre value of the crop, the amount of water that is poisoned, the amount of water that is applied to each acre and the amount of water that is poisoned depends upon plume growth and porosity. It must be emphasized that agricultural losses accumulate through time. This will be seen to be a distinguishing feature of this response. As noted, this calculation results in an estimate of the worst-case of agricultural loss, give existing practice. This is because the highest valued crop was assumed to be damaged, the other inputs into farming were assumed to have zero opportunity cost, and the farmer was assumed to take no other action such as crop switching to reduce the amount of agricultural loss. Changing any of these assumptions will tend to reduce the amount of agricultural damage. It must be pointed out, however, that irrigation

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[13] 1974 Census of Agriculture, Arizona, Table 3.

practices were assumed to be constant. If changes in irrigation technologies occur that permit less than 4 acre/feet of water to grow an average yield of sugar beets, then the value of water may increase and agricultural damages would tend to rise.

C. Health Effects

The same series of analytic steps which yields estimates of agricultural losses can be used to infer health related damages resulting from degraded municipal water supplies, at least in theory. In practice, however, the problems of applying the methodology are formidable. The logic and problems may be stated as follows. Contamination degrades water quality and reduced water quality impairs health and threatens life. Health effects are not readily expressed in dollar values, thus, requiring the inference of such values from the literature on nonmarket effects.[14] It is worthy of note that many are uncomfortable with this idea of valuing risk to human life or health and reject any monetized results generated by any analytical procedure.

There are several reasons for being wary of the results of procedures to value life in monetary terms. First, life is a fundamental value of society that is apart from the commercial values of society.

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[14] Safety, or avoidance of the risk of death, is valued (sometimes) in labor markets. Informed individuals demand a priori compensation for risks undertaken. This should not be confused with valuation of the certain death of particular individuals. The latter, of course, is not valued in labor markets. Studies have shown that different groups of individuals require between $340 (Thaler and Rose, 1976) and $1000 (Smith, 1974) more in annual income to accept job-related risks of death of about one in 1,000. This may be interpreted as the collective valuation by a group of 1,000 people of the death of one of their number over a year's time at $340,000 to $1,000,000. For a full discussion of the principle of valuing lives, see Ferguson and LeVeen (1981). Zeckhauser (1974) and Graham and Vaupel (1981) suggest that in those studies where a value to life has been assigned, seldom does the assigned value lead to a change in the policy implications of the study.

One way in which analysts have directed scientific inquiry to respect the fundamental value of life has been to distinguish between life and a small increase in the risk of death. The inquiry proceeds by attempting to determine how much a priori compensation must be paid for accepting a small risk. Even the valuation of small risks to life is not without controversy, and there is acknowledged confusion in the professional literature as to the correct method to apply (Graham and Vaupel, 1981). Early attempts to value life on the basis of lost productivity have been shown to be incorrect and irrelevant (Schulze and Kneese, 1981).

Second, if one accepts the premise that small risks to life are commercial values, monetization is difficult, if not impossible. This is because human life, considered as a commercial good or service, possesses a large number of special characteristics that frustrate valuation in other than natural units. Human life when lost is irreversible. As noted, this characteristic forces the analyst to place a premium on forecasting the future value of avoiding small risks. Life is not standardized. A standardized risk to a non-standardized object results in a unique outcome. Accordingly, there has to be an analytic process that accounts for these unique aspects.

The loss of life is a loss of high consequence. As noted above, special methods may be needed to assess the consequences of catastrophe because the size of the loss may be especially difficult to estimate and because there may be great anxiety over even a small probability of catastrophe. Finally, no markets exist in which life may be traded and the "markets" in which small risk may be traded may be highly imperfect. Analysts have attempted to use wage differentials to measure trade-offs between risk to life and monetary compensation (Rosen, 1976). The quality of estimates of this type depends upon workers voluntarily accepting this bargain, their understanding the risk, and having ready alternative sources of employment. Choices that are uninformed, by virtue of a lack of alternatives, are not fair market values.

Third, even if one accepts the notion that small risks to human health can be represented by a commercial value and that the special problems that surround the valuation problems may be surmounted, important distinctions between compensated and uncompensated risks must be made. Schulze and Kneese (1981) have argued that assessing uncompensated risks requires that an ethical posture be assumed. As argued, the libertarian ethic rejects policies that result in uncompensated risks.

A fourth consideration involves the distinction between private and public risks. Private risks are those where threats to life are accepted voluntarily by those who would be affected by an adverse outcome. It is up to the individual to weigh future values, to value unique, high-valued objects (one's own life) and to voluntarily accept compensation [or forego compensation, if one is an elite in an egalitarian society run by utilitarians for accepting a small increase in the risks to one's life (Schulze and Kneese, 1981)].

Public risks are those where threats to life are accepted by those who may not be the ones affected by an adverse outcome. Someone else does the choosing, so to speak. It is public risk that is the most vexing question to face. This is because public decisionmakers must first communicate to the public that small risks to life have commercial values. Public decisionmakers must also communicate to the public that they are capable of inferring the values associated with accepting small increases in the risks to life. This may be done by establishing new processes for determining the values of a community or expanding upon already established political processes. Third, the public decisionmaker must stand ready to accept the judgments of a community that they, the community, will not accept uncompensated risks.

The significance of these reasons for being uncomfortable with "standard" or "average" or "intellectually respectable" measures of the value for life or the value of accepting small risks to life is that the analysis of health risks must end, in most cases, with the expression of risk in natural units.

Truncating the analysis and expressing the results in natural units has the effect of expressing the results in units which are incommensurable with other monetized effects. In consequence, the damages caused by groundwater contamination to human health and life either cannot be expressed in commensurable units or are rejected out of hand. Further, the minor premise--a reduction in water quality impairs health and threatens life--is difficult to document with high degrees of certainty from scientific evidence. Experimentation on humans is unacceptable. The life scientist must extrapolate experimental data from lower life forms to humans; the epidemiologist must wait for accidents to happen and statistically analyze the consequence. Many biological differences exist between other species and humans. Accidents are uncontrolled events. As a consequence, the human dose-response relation is never completely verified by biological inquiry. The epidemiologist requires large numbers to make predictions and large scale contamination incidents either have not happened (fortunately) or remain undetected (unfortunately).

It may be argued that groundwater contamination that threatens health and life requires that whatever is "capable of being done" must be performed.[15] This is not an economic argument. An economic argument would require that the costs of a response option be approximately equal at the margin, to the benefits of exercising the option. This principle of weighing costs against benefits is made problematic by the above noted problem of commensurability, i.e., the risks to human health and life are not market goods. What is "capable of being done" in a non-economic context may mean that if there are places where hazardous materials may be stored that will not endanger human health and life, then those may be the places to put the materials.

A third way to proceed is to perform a cost of risk-reduction analysis. If the risks of exposure to contaminated water can be determined and if the costs of avoiding or reducing the risk can be estimated, then it is possible to estimate the cost of reducing risk to human health. Studies of this type have reported that the costs of saving a life have ranged from zero dollars to $169 million (Graham and Vaupel, 1981). Of course, it is beyond economics to argue whether the costs are worth the benefit. Given different preferences toward risk, differences in preferences toward accepting compensated versus uncompensated risk, it is not even possible to say that a society with limited resources should

[15]Supreme Court of the United States, American Textile Manufacturers Institute, Inc., et al., v. Donovan, Secretary of Labor, et al., June 17, 1981.

seek to save as many lives as possible with a limited budget (Schulze and Kneese, 1981).

Performing a cost of risk-reduction analysis for contaminated groundwater is problematic. The presence of organics and inorganics in drinking water may present many and varied risks to human health. Perhaps the most studied risk is the risk from cancer. A recent review of health risks from carcinogens found that mortality risks from organics in drinking water range from a high of 48 in 10,000 to a low of 3 in 10 million (Crump and Guess, 1980). Treating the water to remove the harmful substances may reduce the risks to human health. The costs of so doing are the subject of the next section which focuses on the problem of industrial waste.

D. Treatment

One approach to restoring water quality is to physically or chemically treat the water. The optimal level of treatment depends on the intended use of the water in the future. Water used for industrial cooling may require little or no treatment. Drinking water would require extensive treatment.

Water may be treated at the surface or a well may be "rehabilitated" by pumping out the contaminant or by neutralizing it within the aquifer. Well rehabilitation techniques under experimentation are expensive and of doubtful effectiveness at this time. Rehabilitation is made difficult because contaminants can adhere to rock and soil within an aquifer. Because of these questions regarding the technical and economic feasibility of well rehabilitation, well rehabilitation costs are not included.

Surface treatment of groundwater may take place at a centralized plant from which water is distributed to users or it may take place at the point of use. Although "faucet treatment" is currently in use, these devices require frequent replacement of treatment agents and other maintenance. In addition, they are of doubtful effectiveness and reliability. Several treatment techniques for pesticide removal and for turbidity control may be effective to varying extents at removing some toxic chemicals, but they are not considered sufficiently effective or reliable for removal of the full range of compounds which are common constituents of hazardous waste. Our attention is limited to treatment techniques for removal of inorganic compounds and volatile organic compounds (VOCs).

High concentrations of organics have been reported in groundwater and can be transported great distances because they have little affinity for soils (Love and Eilers, 1981, p. 2). An EPA survey found that VOCs were detected in approximately 45% of public water systems using groundwater serving over 10,000 people and in approximately 12% serving less than 10,000 (Federal Register, 1982).

Costs for two aeration processes--packed tower and diffused air--and GAC are reported in Table 2; such costs in the table are for 99% removal (500 mg/l to 5 mg/l). Although the costs in Table 2 are for removal of trichloroethylene (TCE), costs for removing TCE from drinking water generally represent average costs or removal of VOCs from a water supply for a given removal efficiency (Malcolm Pirnie, 1981). Assuming linear dose-response relationships, 99% removal of harmful substances has the effect of reducing a risk of 48 to 10,000 to 48 in 1,000,000. It may be observed that as system size increases by a factor of 10, costs increase by a factor of 4 indicating some economies of scale. Nevertheless, treatment costs for a medium-sized system can easily amount to over $100,000 annually.

Table 2

Summary of Preliminary Costs
For Controlling TCE* in Drinking Water
(1981 Dollars)
(000)

500-5 ug/1 Removal

	System Size (millions of gallons per year)		
	2.3-11.5	23-115	230-1,150
Aeration-Packed Tower			
1. Capital Cost	28-42	115-153	416-649
2. Annual Cost	3-5	14-18	50-78
3. Operating Cost	6-8	20-26	89-118
Total Annual Cost (2 + 3)	9-13	34-44	139-196
Aeration-Diffused Air			
1. Capital Cost	67	277	1,362
2. Annual Capital Cost	8	33	163
3. Operating Csot	15	69	400
Total Annual Cost (2 + 3)	23	102	563
Absorption-GAC			
1. Capital Cost	82	344	741
2. Annual Capital Cost	10	41	89
3. Operating Cost	15	66	243
Total Annual Cost (2 + 3)	25	107	332

Notes: Opportunity cost of capital is 12%.
Cost data presented for planning purposes only.
Actual cost data may vary depending on local conditions.

*Tricholorethylene

Source: Malcolm Pirnie, Inc. (1981).

Aeration and Granulated Activated Carbon (GAC) are not strict alternatives, but may be used in combination to increase effectiveness (Love and Eilers, 1981, p. 75). The cost of treating contaminated groundwater may, therefore, in some instances, approximate the sum of the GAC cost and the cost of one of the aeration techniques reported in Table 2.

Additional treatment costs resulting from an increase in contaminant concentration depends on whether a facility already exists. Estimation of the "incremental" cost of treating an increase in contamination requires knowledge of several "operational parameters" which affect treatment cost, such as pH, coagulant, coagulant dose, and valence of the contaminant. A change in any one of these operational variables to achieve optimum removal of the contaminant may result in an increase in operating cost of no more than a cent or two per 1,000 gallons of water treated (U.S. EPA, 1978, p. 34).

One fact of economic life is that large systems cost more than small systems. The construction of a large treatment facility requires capital outlays of $500,000 to about $1.5 million. Medium sized systems require outlays of $100,000 to $400,000. Given that a decision limited to the treatment of the contaminated water is a decision to permit the growth of the plume, more and more water each year is poisoned. In arid areas where there is no surplus water, poisoned water must be treated and used. A small system may soon become inadequate.

Sizing a treatment plant in arid areas depends upon the rate of plume growth and porosity. The sample plume reported in the section on agricultural damage would require a medium sized treatment plant after about 3 years. A larger plume would require a larger sized system. It may be concluded that medium to large sized treatment facilities are the proper size to use when making comparisons among response options.

Finally, the costs that have been reported are for treatment systems capable of cleaning water to drinking water standards. This level of quality may not be needed in all instances. Using water for agriculture, for example, may not require that the water be potable. Accordingly, the cost estimates for treatment may be high for comparisons involving agricultural damage. The level of treatment, however, is not the only variable that influences cost. As has been noted the volume of water that must be treated exerts a significant influence on cost levels.

E. Alternate Sources

This section provides a cost estimate for replacing a contaminated well with water derived from another source. The sources considered are: a new well with pipeline conveyance, tank truck delivery, and bottled water. Esoteric options, which include various means of increasing the availability of water in a region, such as desalinization and weather modification, as well as options that supply water in quantities that are out of proportion to the amount of water lost are not considered.

There are several preliminary considerations. In the first instance the feasibility of tapping into an alternative source depends upon water availability. The setting of the story is in Southern Arizona. This area of the United States is arid. The Water Resource Council reports that there is a shortage of groundwater and surface water sources and that this deficit is likely to continue.

In terms of comparing response options, an alternative source may not be feasible throughout all regions, especially this region. A further complication involves water law. In some states, water is a common property resource, while in others water is private property. This means that a potential user of an alternative source may in some states have to bargain with a public agency for its use, while in other states the transaction may occur between (among) private parties. Some states, however, do not permit water to be sold (Arizona has this type of law). Owners of land have the rights to water under their land and may pump as much as they can afford. They may not, however, sell groundwater to anyone else. Laws of this type reduce the feasibility of tapping an alternative groundwater source. In this circumstance--where sale of water is proscribed--tapping an alternative source would require that the land above the water table be purchased. This would increase the private cost of using an alternative source.

A final consideration concerns the distance between the new source and the point to which the water must be delivered. Tapping into an aquifer at a point some distance from the plume requires that the new water be conveyed at some cost to the point at which it is needed. Tapping the contaminated aquifer too close to the plume may cause the plume to change the direction and rate of its growth. The result might be that pollution would be drawn to the new source.

1. New Well

The costs of obtaining water from an alternative well, to replace that from a contaminated one, depend on four major factors: (1) the costs of drilling and casing, (2) the operating and maintenance costs (not treated here), (3) the difference in the cost of transporting water from the new as opposed to the original well, and (4) the cost of obtaining legal access to the substitute water. The costs of drilling and casing for a new well are reported in Table 3. For each of the six well diameter categories, mean costs per foot are reported. The means are calculated over a nationwide (non-scientific) sample of geologic conditions. There is considerable variance around the mean. For example, the mean cost, over 19 firms responding, of drilling a 10" well is $12.55 per foot. The lowest drilling cost reported was $2.60 per foot and the highest cost was $29.00 per foot. The cost of casing a 10" well ranges from a low cost per foot of $6.00, through a mean of $9.65, to a high cost of $15.00.

Data on pumping cost and other operating and maintenance cost are not available. However, since pumping cost is generally correlated only with "lift," or the distance water must be pumped from the water table to the surface, it is not likely to greatly affect the cost of using alternative new wells.

2. Pipeline Conveyance

Depending on hydrological conditions (which determine both the physical availability of water and the safe distance, in the same aquifer, from a contaminated well) a replacement well may require transporting clean water a substantial distance. Further, replacing a private well with municipal water may require extending the public conveyance system. If the affected aquifer affects a municipal supply, piping from outside sources may prove to be impractical.

Table 3 contains a breakdown of the costs associated with pipeline conveyance of water. A water user might have a pipeline constructed from a public or private well. In the case in which the source is public,

Table 3

Costs of Alternative Water Supplies: New Well

(1981 dollars)

Diameter	Investment Cost Per Foot[1] Drilling	Casing	Total	Investment Cost for 75' Well	Annualized Cost[2]	Pumping Volume[3] (000) gal/day
2"-4"	$ 5.53	$ 3.18	$ 8.71	$ 653	$ 78	.345
6"	8.24	5.55	13.79	1,034	124	5-144
8"	11.6	8.07	19.71	1,478	177	108-245
10"	12.55	9.65	22.20	1,665	200	216-576
12"	24.36	14.43	38.79	2,909	349	504-936

Source/Explanation

[1]Drilling and casing cost per foot are from the Water Well Journal, January 1981, pp. 79-97. Costs for each diameter well are sample means; over 49 firms reported drilling costs and 279 firms reported casing costs. Although the survey included firms which use either cable tool or rotary drilling rigs exclusively, the costs reported here are for firms which use both cable tool and rotary rigs. The Water Well Journal survey was not scientifically designed. Questionnaires were sent to members of the National Water Well Association and subscribers to the Water Well Journal.

[2]Opportunity cost of Capital = 12%.

[3]Pumping volumes were provided by Geraghty and Miller, groundwater hydrologists. 2" and 4" wells are assumed to be for residential use. Average residential use is taken from Economic Systems Corporation, Urban Water Resources Research, 1968.

Table 4

Pipeline Conveyance[a]

	Capacity (thousands of gallons per day)			
	20	200	1,000	2,000
Investment Cost				
Line Cost ($/mile)	$29,384	$49,727	$103,410	$158,222
Pump Station Cost ($/mile)	316	6,555	17,065	14,647
Total Investment ($/mile)	29,700	56,282	120,475	172,869
Total Annual Investment[b] ($/mile)	3,564	6,754	14,457	20,744
Operating Cost				
$ per mile	3,200	4,000	10,000	8,000
Total Annual Cost				
$ per mile	6,764	10,754	24,457	28,744

Source: Koenig, Louis, Disposal of Saline Water Conversion Brines--An Orientation Study, Office of Saline Waters, U.S. Dept. of the Inteiror, Washington,D.C., 1957.

[a]All costs except pump energy are inflated in 1981 dollars on the basis of the Engineering News-Record construction cost index.

[b]Investment cost is annualized by using a 12% opportunity cost of capital.

it is uncertain the price charged to the user will reflect the marginal cost to the municipal authority of providing the water. It probably will not, however, because customers (or classes of customers) are typically charged a uniform rate, regardless of marginal costs of service. Since the interest is on the incremental resource costs to society of avoiding groundwater contamination, the pipeline conveyance costs are based on actual construction cost, rather than on an assessment of charges by municipal water supplies for extension of service.

3. Tank Truck Delivery and Bottled Water

Estimates of the cost of water delivery by tank truck and the cost of bottled water are as follows. The charge for water delivered by truck is 12 cents per gallon plus 83 cents per mile for transport of 5,500 gallons (or 15 cents per 1,000 gallons). The incremental transportation cost may be lower if there is an established delivery system in the affected area. The cost of bottled water is 95 cents per gallon plus whatever costs the consumer may incur in transporting the water. Since the cost of bottled water is eight times the cost of tank truck delivery, no further discussion of this alternative is warranted here.

E. Conclusions and Comparisons

The costs of responding to a groundwater contamination incident by suffering the consequences or restoring water quality depend primarily on the amount of water damaged. In order to compare the different methods it is necessary to make assumptions about well depths (75 feet), pipeline conveyance distances (10 miles) and trip lengths for tank truck delivery (10 miles). Table 5 compares the cost of the various response options.

First, it must be remembered that the consequences of using and losing and tank truck delivery grow through time. For using and losing,

Table 5

Comparison of Annual Cost of Restoration Options
(1981 Dollars)

(Assume 325,000 gallons damaged)

Option	$/yr.
1. Use and Lose--Agriculture[a]	125
2. New Well[b] plus 10 miles of pipeline[c]	67,665
3. Tank Truck Delivery[d]	39,000
4. Treatment[e]	34,000-107,000
5. Use and Lose--potable water	No cost estimation

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[a]Damage payment based on 4 acre/feet of water applied to each acre of sugar beets. Since one acre/foot (325,000) gallons was poisoned,this is equivalent to destroying 1/4 of an acre of sugar beets worth $500 an acre.

[b]The New Well is 75 ft. deep, with 12" diameter. It requires an investment of $2,909 or an annual cost of $350. A 75 ft. well with a 6" diameter would cost $125 per year, but would be too small after 5 years.

[c]Table 4: The small pipeline would be adequate for 60 years.

[d] .12 x 325,000 + .15(10)(325) = 39,488.

[e]Table 3: The medium sized treatment plant would be adequate; the range derives from the effluent treatment methods, if the cost of these options increases through time.

the first year's expense is shown as $125, the second year's expense would be $250 and the third year's expense would be $375. The costs of tank truck delivery also grow through time. Since these costs are over a hundred times greater than using and losing, consideration of tank truck delivery as an efficient response option is curtailed. Even with annual increases in the cost of using and losing, it will take a very long time (250 to 500 years) for the annual using and losing costs to equal the cost of treatment or a new well with 10 miles of pipeline. This comparison points up two important observations: (1) the length of the time horizon is important in determining the cost response, and (2) since the cost of an alternative source is dominated by pipeline costs, the distance over which water must be piped is central to determining the least-cost option. If local conditions are such that only one mile of pipeline is required, the alternative source becomes the least-cost option in 50 to 60 years instead of about 500 years.

It should be pointed out that as the value of the crop damages decreases, the annual use and lose costs decrease. The comparison is based on a loss of sugar beets which are relatively high-valued crops.

On the other hand, the costs of using and losing depend upon the amount of water poisoned each year. The loss of one acre/foot that underlies this comparison is small. Larger amounts of water poisoned would increase the use and lose loss proportionately. Since pipelining and treatment exhibit economies of scale, a doubling of water loss would not double the cost of alternative sources or treatment. Accordingly, as rates of plume growth increase, one would expect that the provision of alternative sources or treatment would become the efficient option over a shortened time horizon.

Second, local conditions, such as terrain, distance to a safe water source and type of crop grown, appear to be the most significant variables affecting the ranking of the options in the agricultural case. The economic time horizon also is important. If the planning horizon is less than 250 years, using and losing would appear as the least-cost option. Accordingly, policies (such as financial responsibility laws or the posting of bonds) that lengthen the time horizon would lead to different ranking of response options than policies that shortened the economic planning horizon.

Finally, the options discussed in this section do not prevent the plume from spreading; they only offset its effects. In the next section we consider response options that arrest the spread of the plume.

IV. CONTAINMENT OPTIONS

A. Pumping/Recovery Wells

Pumping/recovery well systems, sometimes referred to as counter-pumping, may be used to arrest the spread of a plume of contamination. This is accomplished by drilling wells into the plume so that when the wells are pumped, the force of the pumping counters the natural movement of the plume. There are two configurations of recovery wells. The first is to drill the wells along the leading edge of the plume. This geometry is effective if the plume is expanding in one direction. The second consists of drilling wells at the boundry of the plume and along major axis in the plume's interior. This configuration is effective if the plume is expanding in more than one direction. In theory, and in practice, a balance is struck between the forces of the aquifer and the forces exerted by the pumping wells.

One consequence of the counterpumping option is that contaminated water is pumped to the surface and a new disposal problem is created. Consequently, the costs of treating the water to an acceptable standard (a level that would permit either the use of the pumped water or its disposal into surface water) is included in the costs of this system. The major variables affecting the cost of counterpumping are groundwater flow properties, plume size and plume depth.

Six hundred and eight (608) cost estimates for a counterpumping system were prepared by Geraghty and Miller (1982). There were 19 different categories of groundwater characteristics and pumping configurations. Within each of these categories, eight different plume sizes and four types of treatment were considered. For our purposes we isolated on 16 estimates. A small plume (100 x 200 x 65) and a large plume (2000 x1000 x 65), a fast growing plume and a slow growing plume, two types of treatment of the counter-pumped water, and two well configuations. The costs associated with these categories are presented in Tables 6 and 7.

It may be seen that given a plume size, a treatment option and a strategy, slow growing plumes cost less to control than fast growing plumes. This is because more water must be pumped to control a fast growing plume necessitating more wells and a larger volume of water to be treated.

It may also be seen that given a specific plume size, treatment option and rate of growth, a strategy 2 configuration (i.e., interior pumping) costs more than strategy 1 (leading edge pumping.) This is because more wells are required to implement a strategy 2 configuration. Finally, filtration costs more than carbon treatment for a given sized plume, rate of growth and strategy.

B. Slurry Walls

Slurry walls are a means of arresting the spread of a plume. Constructing a slurry wall involves boring around the perimeter of a plume and injecting impermeable substances into the bore holes.

The wall extends down to the confining stratum and an underground tub is created. (For this example, the confining stratum is assumed to be 75 feet below the surface.) In order to keep this tub from overflowing, there must be some type of surface treatment. In areas where rainfall is infrequent, grading, contouring and vegetation of the surface above the underground tub may suffice. In other areas where rainfall is plentiful a surface seal must be installed. These alternatives are referred to as countouring and sealing.

Table 6

Containment Costs for Counterpumping
($000's)

Fast-Growing Plume
(3,600 ft/yr.)

	Small (depth x width x length)						Large (depth x width x length)					
Size	65' x 100' x 500'						65' x 2,000' x 10,000'					
Treatment	Carbon			Filtration			Carbon			Filtration		
Cost Element	K	O&M	A	K	O&M	A	K	O&M	A	K	O&M	A
Strategy #1 (leading edge)	132	41[a]	57	228	69[b]	96	807	127[c]	224	1,227	127[d]	274
Strategy #2 (interior axis pumping)	356	98[e]	141	626	109[f]	184	2,044	1,423[g]	1,668	4,004	503[h]	983

Source: Geraghty and Miller, Inc. (1982).

[a]Table F-9, Column 2, Row 2
[b]Table F-9, Column 2, Row 4
[c]Table F-9, Column 8, Row 2
[d]Table F-9, Column 8, Row 4
[e]Table F-19, Column 2, Row 2
[f]Table F-19, Column 2, Row 4
[g]Table F-19, Column 8, Row 2
[h]Table F-19, Column 8, Row 4

A = Total annual costs

Notes: Capital costs annualized at an opportunity cost of capital of 12 percent.

Table 7

Containment Costs for Counterpumping
($000's)

Slow-Growing Plume

	Small (depth x width x length)						Large (depth x width x length)					
Size	65' x 100' x 500'						65' x 2,000' x 10,000'					
Treatment	Carbon			Filtration			Carbon			Filtration		
Cost Element	K	O&M	A	K	O&M	A	K	O&M	A	K	O&M	A
Strategy #1	106	20[a]	33	170	55[b]	75	519	60[c]	122	619	77[d]	151
Strategy #2	158	48[e]	67	248	74[f]	104	1,146	172[g]	310	1,666	149[h]	349

Source: Geraghty and Miller, Inc. (1982).

[a]Table F-6, Column 2, Row 2
[b]Table F-6, Column 2, Row 4
[c]Table F-6, Column 8, Row 2
[d]Table F-6, Column 8, Row 4
[e]Table F-18, Column 2, Row 2
[f]Table F-18, Column 2, Row 4
[g]Table F-18, Column 8, Row 2
[h]Table F-18 Column 8, Row 4

A = Total annual cost

Notes: Capital cost annualized by an opportunity cost of capital of 12 percent.

The cost of a slurry wall depends upon the size of the plume, in particular its perimeter. Wall costs are insensitive to other aquifer characteristics such as hydraulic gradient, porosity and transmissivity.[16] Accordingly only two categories of costs are reported: those for large and for small plumes both with contouring and seals. These costs estimates are reported in Table 8.

Data on wall longevity or design life of a wall are not available. Clearly, if all liners on surface impoundments leak sooner or later, then all slurry walls must also leak eventually. If they did not, hazardous waste liners could be made of the same material as slurry walls. The implication is that slurry walls do not arrest the spread of the plume forever. Given rough equivalence between the costs of counterpumping and slurry walls, the more effective option would appear to be counterpumping.

C. Comparison

Several observations may be made at this point. For a large plume, the capital expenditures associated with slurry walls are 3 to 40 times greater than the capital costs of counterpumping, while the operating costs of counterpumping are 2 to 14 times greater than the operating costs of slurry walls. In these circumstances, the least-cost option may depend upon the opportunity costs of capital.

Consider, as an example, a slurry wall confining a large plume with a seal over the surface and counterpumping a large, fast-growing plume, with a strategy #2 well configuration and carbon treatment. The costs for a slurry wall (in $1000) are $21,565 for capital, $10 for operating and maintenance. The costs for counterpumping are $2,044 for capital

[16]For a more complete discussion of slurry walls, see Geraghty and Miller (1982), pp. 84-104.

Table 8

Containment Costs for Slurry Walls 75 Feet Deep
($000's)

	Small depth x width x length)						Large (depth x width x length)					
Plume Size	65' x 100' x 500'						65' x 2,000' x 10,000'					
Surface Treatment	Seal			Contour			Seal			Contour		
Cost Element	K	O&M	A	K	O&M	A	K	O&M	A	K	O&M	A
Strategy #1	528	10[a]	73	502	10[b]	70	21,565	10[c]	2,598	11,395	31[d]	1,398

Source: Geraghty and Miller (1982), Appendix A.

[a]Table H-6, Column 2, Row 3
[b]Table H-5, Column 2, Row 3
[c]Table H-6, Column 8, Row 3
[d]Table H-5 Column 8, Row 3

A = Total annual cost.

and $1,423 for maintenance. At a 4% cost of capital, the annual cost of a wall is $872, and for counterpumping it is $1,505. At a 15% cost of capital, the annual cost of a wall is $3,234 and for counterpumping, $1,730. Plainly, at the low opportunity cost of capital, the slurry wall is the least-cost option; at high opportunity costs of capital, counterpumping is the least-cost option.

The least-cost option, when a choice is made between walls and counterpumping, may depend upon the ability to use a strategy #1 (leading edge pumping) well configuration versus a strategy #2 (interior pumping) well configuration. Consider, as an illustration, a slurry wall confining a large plume with a seal over the surface and counterpumping a large, fast growing plume with first a strategy #1 configuration and then with a strategy #2 configuration. Assume opportunity cost of capital to be 4%. The annual cost of a slurry wall is $872: the cost of counterpumping with a strategy #2 is $1,505: but the cost of counterpumping with a strategy #1 is $143. It may be seen that local conditions are important determinants in ranking these options. Is the plume growth unidirectional so that it can be controlled with a strategy #1 configuration instead of strategy #2; is rainfall sufficient to warrant a seal instead of contouring and vegetation? Finally there is an economic dimension, is the cost of capital high or low?

As stated at the outset these options prevent the plume from damaging additional water. In effect, these options keep the plume from spreading to another landowners' property. How these containment options compare with the restoration options is the subject of the next section.

V. SELECTING AMONG RESPONSE OPTIONS

A. Introduction

The purpose of this chapter is to draw together the preceding chapters and to use the illustrative estimates developed there to show the relative cost of options under alternative scenarios. Our approach is to present four illustrative calculations of hypothetical pollution incidents. For each calculation the key facts the decisionmaker would have to ascertain in order to determine the preferred response are identified and specific assumptions about the values are made to permit making the illustrative computations.

The previous sections contained discussions of five (5) response options to a plume of groundwater contamination. The options are:

- counterpumping
- slurry walls
- suffer agricultural and health losses
- alternative groundwater sources
- treatment of contaminated water (to acceptable standards.

Bottled water and tank truck delivery, are not discussed at length. As noted earlier, both are considered to be more costly than the response options that are discussed.

As noted above, estimating the cost of human health effects is particularly troublesome. This is because the literature on health effects expressed in natural units produces wide ranges (from 10^{-4} to 10^{-8}) for the risks imposed by exposure to contaminants at a given concentration. Second, it is extremely, difficult to infer a dollar value of human life. It is possible, however, to estimate the cost of reducing the risks to human health based on observed risk data. Such an analysis should not be construed as a conclusion regarding the net social benefit of reducing uncompensated risk.

Below, four hypothetical incidents are developed in terms of agricultural damage. To place the incidents in a context wherein the threat is not to plants but to human life, one may simply disregard the response option of use and lose and implement the low-cost option of the remaining four responses. The cost of the least-cost option, after using and losing has been eliminated, is the price of reducing the risk to human health (whatever that may be) caused by exposure to contaminated groundwater.

The incidents have common elements and distinguishing features. The distinguishing features are:

- o slow growing small plume,
- o fast growing small plume,
- o slow growing large plume,
- o fast growing large plume.

The common elements are:

- o the location is Southern Arizona,
- o the growth of the plume is unidirectional,
- o the contaminants are a "soup" of organics and inorganics.

Locating the incident in Southern Arizona influences the costs of the responses. Arizona is arid, receiving less than half of the national average of 30 inches of precipitation per year. (The average precipitation in Arizona is 14 inches.) One consequence of the low levels of precipitation is that for the case of slurry walls, contouring and vegetation may be considered an effective surface treatment to prevent the "tub" from overflowing. A second consequence involves the crops that may be profitably grown. Earlier the principal crops for the area were listed, along with their own irrigation requirements. Locating the incident in another area will change the crops affected, the market value of the crops affected and the extent of reliance on irrigation as a water source. The less reliant an area is upon irrigation, the less the value of groundwater, other things constant.

The consequences of assuming that the growth of the plume is unidirectional are two. First, it faciltates projections of plume growth and the amount of water that is contaminated each year. Second, the assumption enables the strategy #1 or leading edge configuration to be used.

Treatment costs and health effects are affected by the assumption that the contaminants mix and form a highly toxic soup. For the case of treatment, high cost methods are used.

B. The Decision

The liner on a landfill or surface impoundment has failed and hazardous waste is seeping into the water table. The failure has gone undetected for a sufficiently long period of time that a plume of highly toxic soup has formed and is spreading. Even if the liner failure has been discovered and corrected, it is assumed that there are sufficient concentrations of toxics in the aquifer so that natural dispersion will not reduce the toxicity for scores of years. Assuming that all land abutting the operator's property has been assigned, further growth of the plume will poison another proprietor's water.

Instead of arresting the spread of the plume, an alternative source of water could be tapped and used to replace the contaminated water. This requires that there be "surplus" water available. A third possibility is to do nothing and compensate the owners of the abutting property; a fourth possibility is to treat the water to acceptable standards. These possibilities are compared below.

C. Case I: Slow-Growing, Small Plume

This plume is expanding at a rate of 360 feet per year. It is 65 feet thick, 100 feet wide and presently measures 500 feet from end to end. The porosity of the soil is 20%. This implies that a plume that is expanding at a rate of 360 feet year per year will contaminate about 3.5 million gallons per year.

A recovery well system or a slurry wall may be viewed as a response option which is protecting 3.5 million gallons per year. The estimated annual cost of a recovery well system that could arrest this plume is found to cost $75,000 (Table 7, column 2, row 1). Strategy #1 is employed because the plume is growing in one direction; high treatment costs are required because there is a multiplicity of the contaminants. The cost of a slurry wall that could contain this plume is $70,000 (Table 7, column 2). Contouring is an effective surface treatment because the location of the incident is in an arid region.

Three and one half million gallons (the amount of water which is expected to be contaminated) is equivalent to about 11 acre/feet of water, or enough to irrigate about 3 acres in Southern Arizona. If the crop is sugar beets the value of the output lost is $1,500 per year. The cost of supplying water from another groundwater source located 10 miles away is about $68,000. The cost of these and other alternatives are reported in Table 9.

The results of this comparison indicate that arresting the spread of the plume by constructing a slurry wall or counterpumping are about 50 times greater than the damages to the sugar beet farmer. If the cost of all available response options increased at the same rate through time, it would never be efficient to arrest the spread of the plume or to employ other than the use and lose option. All response option costs do not increase at the same rate, however. The annual cost of counterpumping remain constant over time. Costs incurred by the abutting sugar beet farmer would increase at a rate of $1,500 per year each year as more crops are lost. In other words, annual damage payments would grow and would eventually equal the cost of counterpumping. In the example, this point occurs in about 48 years.

In what future period total agricultural damages would equal the total costs of counterpumping would depend upon the discount rate. If the rate of discount were zero, it would take 96 years of plume growth to inflict enough agricultural damage to make counterpumping (or a slurry wall) the least-cost option. The higher the discount rate, the longer the time horizon.

Tapping an alternative source of water by drilling another well 10 miles away and transporting the water to the site is estimated to cost about $68,000 per year. In 90 years the costs associated with doing nothing would approximately equal the cost of providing an alternative source, if discount rates were zero. Assuming a medium-sized treatment facility, treatment costs range from about half the cost of the slurry

Table 9

Estimates of the Cost of Response Options for a Slow-Growing, Small Plume

Response Option	Annual Cost ($000)
o Recovery Well/Treatment[a]	75
o Slurry Wall[b]	70
o Use/Lose Agriculture[c]	1.5 (first year)[d]
o Alternative Source[e]	67.8
o Treatment[f]	34-107

[a]Opportunity cost of capital is 12%, Table 13.

[b]Table 8.

[c]Sugar beets provide revenues of $500/A.

[d]Annual cost grow overtime for this option.

[e]Table 3, Table 4, 10 miles of pipeline.

[f]Table 2.

wall or counterpumping options to more than one and one half the cost of these options.

It may be concluded that, given the above cost estimates, location, and plume characteristics, the least-cost option is to arrest the spread of the plume provided the planning horizon is 90 or more years and the discount rate is zero. This is a problem. Ninety years is a long time and $70,000 (the approximate cost to arrest the plume) annually is a sizeable sum of money. The actual discount rate is above zero. Whether a sufficient legal and regulatory infrastructure is in place and whether it is strong enough to enforce a long time horizon remains an open question.

In these calculations, we abstract from transaction costs. These may be considerable if there is litigation. One way to reduce transaction costs is to require large buffer zones around the landfill or surface impoundment. This would have the effect of postponing the growth of the plume into the abutting property. When the plume does threaten the abutting property it may be larger and pose more of a threat. The increased threat may bring forth a stronger sense of the value of arresting the plume's growth or replacing the poisoned water.

D. Case II: Slow-Growing, Large Plume

This plume is 65 feet thick, 2,000 feet wide and extends for 10,000 feet. It is highly toxic necessitating high cost treatment. It is in an arid region. The porosity is 20%. Each year its growth is not arrested, the plume grows 360 feet. This plume is poisoning 70 millions gallons or 216 acre/feet of water each year. This water could be used to irrigate 47 acres of sugar beets each year. A crop of sugar beets of this size is worth about $24,000. Table 10 reports the cost of the options that could be used to respond to this incident.

The cost comparisons for this case indicate that, relative to agricultural damage, tapping an alternative source is about three times as expensive. Agricultural damage will continue to increase, and eventually exceed, the cost of an alternative source. If the assumed discount rate is zero, the total cost from paying damages will equal the total costs of an alternative source in about six years. An alternative groundwater source may not be available in Arizona. If this is the case, recovery wells or treatment emerge as the least-cost options in about 12 years if discount rates are zero.

It may be seen that relative to the slow-growing, small (narrow) plume in Case I, the plume in this incident--because it is wider--threatens to do more damage to agricultural enterprises. This increased threat may be seen in the shortened time horizon (12 years compared to 90 years with a zero discount rate) over which the cost of doing something is less costly than doing nothing.

It may be concluded that slow-growing plumes may require strong legal and regulatory systems, if substantial agricultural costs are to be avoided.

E. Case III: Fast-Growing, Small Plume

This plume is expanding at the rate of 3,600 feet per year. It is 65 feet thick, 100 feet wide and 500 feet long. With 20% porosity about 35.1 million gallons of water (108 acre feet) are

Table 10

Estimates of the Cost of Response Options for a Slow-Growing, Large Plume

Response Option	Annual Cost ($000)
Recovery Wall[a]	151
Slurry Wall[b]	1,400
Agricultural Damage[c]	23.5 (first year)[d]
Alternative Source[e]	68
Treatment[f]	140-560

[a]Table 7, Row 1, Column 4.
[b]Table 9, Column 4.
[c]47 crop acre at $500.
[d]Annual cost grow over time for this response.
[e]Tables 3 and 4.
[f]Table 2, Column 4.

contaminated each year. Table 11 presents the cost of responding to this plume.

In order to illustrate a point, a modification in the basic story is made--namely, that between 1 mile and 10 miles of pipeline are necessary to move clean water from an alternative source. Previously, it had been assumed that 10 miles were necessary. This change assumed distance generates pipeline costs which range from $6,800 (a sum less than the first year of agricultural damage) to $68,000 (over five times the first year's agricultural damage).

A second modification is made. It is assumed that alternative sources are unavailable. This change makes agricultural damage the least-cost alternative with slurry walls next in rank, but about five times more expensive.

For the case where alternative sources are available from a nearby source, the cost comparisons are straightforward. From the outset the least-cost option is the provision of an alternative source of water. As the distance between the alternative source and the site to which the clean water is to be delivered increases, the cost comparisons become more complex.

A decision to incur the full amount of agricultural damage emerges as the least-cost response option if time horizons are short. If time horizons are long (greater than 15 years), a distant alternative source or slurry walls becomes the least-cost option.

Assuming that an alternative source is not available, and this is not unlikely in arid regions of the southwest where the incident is assumed to occur, the strength of the legal and regulatory institutions

Table 11

Estimates of the Cost of Response Options for a Fast-Growing, Small Plume

Response Option	Initial Cost ($000)
Recovery Wall[a]	96
Slurry Wall[b]	70
Agricultural Damage[c]	12 (first year)[d]
Alternative Source[e]	6.8-68
Treatment[f]	140-563

[a]Table 6, Row 1, Column 2.
[b]Table 8, Column 2.
[c]24 crop acre at $500.
[d]Cost grow over time for this option.
[e]Tables 3 and 4.
[f]Table 2, Column 4.

comes to the fore. Once again, the economic horizon over which the cost effectiveness of prevention must be compared is 15 years and the annual cost of prevention is sizeable ($70,000) when compared to the initial cost of agricultural damage ($12,000). In other words, failure to account for the irreversible damage that may be caused in the future by continued spread of the plume may easily lead to the choice of an inefficient option.

F. Case IV: Fast-Growing, Large Plume

This plume is 65 feet thick, 2,000 feet wide, 10,000 feet long and is growing at the rate of 3,600 feet a year. Given 20% porosity, 702 million gallons (2,160 acre/feet) of water are contaminated annually. Table 12 reports the cost of responding to this plume.

Construction of a recovery well system emerges as the efficient option. This is because the volume of water potentially contaminated was very large, generating $250,000 in damages in the first year with each ensuing year recording an additional $250,000. The large size of the plume makes construction of a slurry wall prohibitive. Similiarly, the large size of the plume casts doubt on the effectiveness of replacement options. The region chosen for the study is arid and the availability of an alternative source capable of supplying first 700 million gallons per year, then 1,400 million gallons per year with an annual growth of 700 million gallons is remote.

The least-cost prevention option is a recovery system that holds the plume in place. The difference in treatment costs between those for a recovery system and those for treatment and subsequent use of the water arise from two sources. First, the volume of water that must be

Table 12

Cost Estimates for Responding to a Fast-Growing, Large Plume

Response Option	Annual Cost ($000)
Recovery Wall[a]	274
Slurry Wall[b]	1,398
Agricultural Damage[c]	270 (first year)[d]
Alternative Source[e]	N/A
Treatment[f]	140-563

[a] Table 6, Row 1, Column 4
[b] Table 8
[c] 540 crop acre at $500/A
[d] Cost grow over time for this option
[e] Tables 3 and 4
[f] Table 2

treated under the recovery well system is less than under the treatment and subsequent use option. This is particularly the case after the first year. Second, the water must be cleaned more thoroughly under the subsequent use response option than under the recovery well option.

In this incident, the time horizon over which prevention of the plume is contained is relatively short since the costs of agricultural damages and recovery wells are on a par in the first year. Given the initial comments about all liners failing sooner or later, hazardous waste operators would--if they are informed and liable for damages--avoid siting hazardous waste facilities near aquifers where plumes could grow large and fast. Put differently, an operator who located a dump over an aquifer where plumes would grow large and fast would, eventually, face the prospect of paying over $250,000 annually to control the plume's spread or cause millions of dollars of agricultural damages. Further, the financial resources of an operator might not be sufficient to cover losses of this magnitude and the problem could become "public."

VI. Conclusions

This look at a hypothetical contamination incident leads to two sets of conclusions.

The first set concerns the factors that affect the costs of responding to a groundwater contamination incident. (See Table 13.) The first are general economic conditions. The opportunity costs of capital and relative prices (such as agricultural products and construction materials) are the key factors. The opportunity costs of capital are important because of the high one-time costs that must be paid to implement some response options. Low opportunity costs of capital imply low annual costs for slurry walls and counterpumping. The price of agricultural products relative to construction materials is important because agricultural products are sacrificed by not arresting the plume, or construction costs are paid to arrest the plume. Second and third, local hydrological and local economic conditions appear to dominate the feasibility of implementing any particular response as well as determining the relative costs of the feasible options. Porosity is important for calculations involving the amount of water poisoned, and plume growth enters the calculations for counterpumping, agricultural losses and the amount of water that must be treated or provided from alternative sources. The use of the abutting land and the availability of alternative sources (the relative scarcity of water) influence the costs of the responses. Clearly, if the abutting land use is for a municipal water system or a residential area, the possibility of adverse health effects arises.

Finally, the quantity and quality of the contaminant is important. For obvious reasons, small quantities of a given soup of contaminants are

Table 13

Influences on the Costs of Responding to Groundwater Contamination

General Economic

- Costs of capital
- Relative prices (e.g., agricultural products to construction materials)

Local Hydrological

- Porosity
- Plume growth

Local Economic

- Abutting land use
- Availability of alternative sources
- Irrigation practice
- Value of water

Contamination

- What chemical
- In what quantities

likely to cause less damage than large quantities. Similarly, a given quantity of highly toxic contaminants is likely to cause more damage than the same amount of a less toxic soup of contaminants.

The second set of conclusions concerns the institutional environment. Plumes grow slowly; the damage accumulates over time. It may take a long time for options with high capital costs to become the least-cost option. Further, the amount of damage caused by not arresting the plume is, in part, determined by the value of water. The future value of water is unknown but is determined by changes in supply and demand. Thus, an unknown amount of damage will be caused at some time in the future (perhaps to generations as yet unborn). This raises a number of questions involving intergenerational equity and the role of discounting future values in making public decisions. It challenges the legal and regulatory frameworks which institutions use to administer justice over long periods of time and among generations. The choices that may come before these bodies may well involve decisions regarding events which have low probabilities of occurring, but if they occur, will entail high consequences. For example, should a regulatory body require a hazardous waste operator to post a performance bond or acquire operating authority that cannot be returned for 50 years? Failure to require such a bond would leave the operator free to walk away form any contamination incident by declaring corporate bankruptcy. The ownership and laws regulating the use of groundwater vary from state to state. These legal differences influence the availability of alternative sources of water, as well as whether an operator of a dump may be considered liable for damages.

The combination of local influences over the costs of response and the need for long-term values to dominate the decisionmaking practice

The combination of local influences over the costs of response and the need for long term values to dominate the decision-making practice requires a mixture of local and non-local participation in deciding questions of groundwater contamination. Whether existing laws and policies are adequate to cope with these problems is an open question.

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