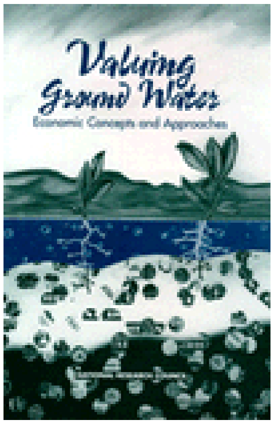
# Free Executive Summary




## Valuing Ground Water: Economic Concepts and Approaches

Committee on Valuing Ground Water, National Research Council

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# Executive Summary

Ground water in the United States is usually considered as either an invaluable good or as a "free" good. At one extreme, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund) implies a very high value for ground water by requiring restoration of contaminated water sources to drinking water quality. Billions of dollars have been spent to clean up contaminated ground water with little comparison of costs or technological difficulty to future benefits. At sites where cleanup is technically infeasible, the Superfund law essentially assigns an infinite value to the resource.

At the other extreme, historically, ground water has been priced well below its value and, as a consequence, misallocated. In many states and localities, no charge is imposed for water withdrawn, and the consumer, whether a public water supply entity, an individual, or a firm regards the cost as being confined to the energy used for pumping and the amortization of well construction and the costs of the treatment and distribution system. As a result, depletion and pollution continue largely because it is not recognized that ground water has a high or long-term value. Further, the Environmental Protection Agency's Science Advisory Board (SAB) report *Reducing Risk* (1990) has been perceived as not properly valuing ground water. The report neglects the uniqueness of the ground water resource and the often irreversible nature of ground water depletion and pollution, implying that declines in ground water quality and quantity need not be major concerns.

Such undervaluation of ground water fosters misallocation of resources in two ways: (1) the ground water resource is not efficiently allocated relative to alternative current and future uses; and (2) authorities responsible for resource management and protection devote inadequate attention and funding to maintaining ground water quality.

In 1994, recognizing the need for better methods and informed decision-making in this area, the U.S. Environmental Protection Agency, the National Water Research Institute, the U.S. Department of Energy, and the U.S. Department of Defense requested that the National Research Council undertake this study. This study examines approaches to assessing the future economic value of ground water as well as the economic impact of contaminating or depleting this resource. Key points addressed include the minimal historical attention given to ground water valuation in general, and specific methods that can be used to perform such valuation studies.

Until the last few decades, attention, even in natural resource and environmental economics, has been given primarily to the effects of exploiting natural resource assets such as extractive minerals, land and timber, ocean fisheries, and surface water resources. The economic value of unique natural and environmental resources, such as wetlands and other ecosystems, has more recently been considered. Most ground water studies to date have focused only on the valuation of limited production-related services provided by ground water, and not on a more comprehensive view of production and ecological services.

A fundamental step in valuing a ground water resource is recognizing and quantifying the resource's total economic value (TEV). Knowing the resource's TEV is crucial for determining the net benefits of policies and management actions. For purposes of this study, ground water services have been divided into two basic categories: extractive services and *in situ* services. Each of these has an economic value, and these values can be summed to yield TEV as follows:

$$\text{TEV} = \text{extractive value} + \textit{in situ} \text{ value}$$

The most familiar of these two components are the extractive values, which are derived from the municipal, industrial, commercial, and agricultural demands met by ground water. The *in situ* services (i.e., services or values that occur or exist as a consequence of water remaining in place within the aquifer) include, for example, the capacity of ground water to (1) buffer against periodic shortages in surface water supplies; (2) prevent or minimize subsidence of the land surface from ground water withdrawals; (3) protect against sea water intrusion; (4) protect water quality by maintaining the capacity to dilute and assimilate ground water contaminants; (5) facilitate habitat and ecological diversity; and (6) provide discharge to support recreational activities. The committee's calculation of TEV as the sum of extractive and *in situ* values can also be expressed by using concepts which often appear in the environmental economics literature. The relationship between those concepts and the ones in this report has been defined in Chapter 1. The committee developed the taxonomy in Chapter 1 so that its use will lead to greater potential for interdisciplinary work on the neglected service areas.

It is important to recognize the TEV of ground water even when one cannot develop specific quantitative separations of the various components. In fact, delineations of what can and cannot be quantified can be useful both to decision-makers for either development or remediation projects, and to researchers seeking to advance conceptual and methodological approaches. Descriptive information or surrogate quantitative measures that are not monetized may be the only information that can be assembled on some TEV components.

In many circumstances even a partial or inexact measurement of TEV can greatly aid decision-making by providing insight into how TEV changes with a policy or management decision. In some cases, the measurement of use values alone, or extractive services alone, can reveal substantial information on how the resource's TEV would be affected by a policy decision. In other circumstances, these limited measures may fail if they provide only a small portion of the components of TEV that would be altered.

## GROUND WATER RESOURCES: HYDROLOGY, ECOLOGY, AND ECONOMICS

Valuation of the extractive and *in situ* services of ground water requires an understanding of the hydrology and ecology of the ground water source. Hydrologic information includes numerous factors such as rainfall, runoff, infiltration, and water balance data; depth to ground water; whether the water-bearing zone is confined or unconfined; ground water flow rates and direction; and type of vadose and water-bearing zone materials. The contribution of ground water to stream base flow and the relationships between ground water and wetland and lake ecosystems are also important.

Knowing natural recharge rates and spatial locations, along with ground water usage rates and trends, is also necessary in water balance calculations and the consideration of ground water depletion. Depending upon the location, relationships between sea water or saline water intrusion and ground water use may also need to be established. Land subsidence can occur in some areas if ground water use is excessive, causing major problems with infrastructure components such as building foundations, roads, sewers, and water and utility lines. The effect of subsidence on flooding (especially) in coastal areas may also be significant. All these should be considered in valuing a ground water resource.

Some ground water supplies can be viewed as nonrenewable because of the long time-frame required to replenish them. Depletion of ground water (including overdrafting and mining) in deep aquifers, for instance, is essentially irreversible. Therefore, because ground water is a unique and potentially exhaustible resource vital to future generations, the costs of valuation studies may be recovered by assisting in the protection of ground water. Without planning and protection of ground water, the resource may not be available to support future generations.

In other circumstances ground water overdraft can be economically efficient and socially beneficial in the short term. For all aquifers, a "steady state" should eventually be reached in which withdrawals are limited to recharge. The level at which this steady state is to be maintained is a matter of choice. During times of drought when surface supplies are scarce, temporary overdraft may be justified, with a subsequent reduction in use of the aquifer to let it recharge. The level would then fluctuate around some average steady state condition.

The tendency for ground water to be treated as an "open access" resource when it is exploited underscores the importance of well-defined, clearly enforceable rights to extract or obligations to protect ground water. In instances where these rights are not defined and enforceable, the availability of ground water is subject to the "law of capture," in which whoever gets to the water first gets first rights to it. If ground water is subject to the law of capture, then the benefits of protection, remediation, and enhancement investments will also be subject to the law of capture. This results in less than optimal investment in the preservation and enhancement of ground water quality, since those investing in such measures cannot reap all of the benefits. (Associated legal and institutional questions are discussed beginning on page 10.)

Treating environmental systems as economic assets that provide goods and services has become an established approach in environmental economics. Ground water systems create ecological services by providing discharge for the maintenance of stream flows and to wetlands and lakes. These discharges support general ecological functions that provide their own services of economic value. For example, discharge to aquatic ecosystems may aid preservation of threatened or endangered species and support downstream uses of water for drinking or irrigation. (Many flowing streams in the southwest U.S., for example, have gone dry after nearby aquifers were drawn on too heavily.) Ground water provides a "derived" value through its contributions to the larger environment.

While the valuation of a given ground water resource may be complex, several simple principles may be applied to almost any valuation problem:

- **Because ground water resources are finite, decision-makers should take a long-term view in all decisions regarding valuation and use of these resources, proceeding very cautiously with any actions that would lead to an irreversible situation regarding ground water use and management. Ground water depletion, for instance, is often irreversible. Some aquifers do not recharge quickly. Moreover, overdrafting can sometimes lead to a collapse of the geologic formation, permanently reducing the aquifer's storage capacity.**
- **Decision-makers should also be cautious regarding contamination of ground water. Restoration of contaminated aquifers, even when feasible, is resource-intensive and time-consuming. Restoration methods are uncertain and unlikely to improve significantly in the near future. As a result, it is**

**almost always less expensive to prevent ground water contamination than to clean it up.**

- **Ground water often makes significant contributions to valuable ecological services. For example, in the Southwest, many flowing streams have been eliminated by overpumping. Because the ground water processes that affect ecosystems and base stream flow are not well understood, combined hydrologic/ecologic research should be pursued to clarify these connections and better define the extent to which changes in ground water quality or quantity contribute to the change in ecologic values.**
- **Ground water management entities should consider appropriate policies such as pump taxes or quotas to ensure that the cost of using the water now rather than later is accurately accounted for by competing pumpers.**

## VALUATION FRAMEWORK

One of the major challenges in valuing ground water is how to integrate the hydrologic and physical components of ground water resources into a valuation scheme. An appropriate conceptual basis for valuation identifies service flows as the central link between economic valuation and ground water quality and quantity.

Every generation should be concerned about the supply and quality of fresh water, and about who has access to it, at what cost. Defining the best long-term management of the resource requires balancing the needs of the present with those of the future. In theory, the balancing is done everyday by markets as reflected in the discount rate. However, many citizens, policy-makers, and scientists believe that the discount rate does not adequately consider the value of goods or services for future generations.

Discounting is a procedure that adjusts for future values of a particular good by accounting for time preferences. Higher discount rates, which give less weight to future net benefits, encourage present use and deter present investments. The market rate of interest will also influence individual and corporate decisions regarding resource extraction. Public entities can choose the discount rate they prefer, and much has been written about these choices. The discount rate a water utility employs when valuing ground water reflects perceptions of risk, returns, and possibly intergenerational equity. A high discount rate implicitly places a low value on the water's value to future generations. A low rate implies the opposite.

A valuation framework must take into account how time, institutions, water quality and quantity, hydrologic factors, and services interact to affect the resource's value. This necessity has several important implications:

- **As noted earlier, some knowledge of a resource's TEV is vital to the work of water managers, and in the development of policies dealing with**

**allocation of ground water and surface water resources. For many purposes, the full TEV need not be measured, but in all cases where a substantial portion of the TEV will be altered by a decision or policy, that portion should be measured.**

- **Policy-makers must recognize the impact that a utility's choice of a discount rate can have on ground water management decisions. Ideally, the discount rate should give adequate weight to long-term considerations.**
- **An interdisciplinary approach, such as the conceptual model presented in Chapter 3, is useful in conducting a ground water value assessment. The approach should incorporate knowledge from the economic, hydrologic, health, and other social, biological, and physical sciences. Assessments should be site specific and integrate information on water demands with information on recharge and other hydrologic concerns, and to the extent possible should reflect the uncertainties in both the economic estimates of the demand for ground water and in the hydrologic and biophysical relationships.**

## VALUATION METHODS

Ground water services are difficult to value because much of the information needed for valuation is not readily available. Market trades can provide data useful in valuation, for instance, but most of the services provided by ground water are not traded on markets. However, techniques do exist for valuing nonmarket goods.

Economic value is not a fixed, inherent attribute of a good or service but rather depends on time, circumstances, and individual preferences. The economic value of a good or service can be inferred either from someone's willingness to pay (WTP) or willingness to accept compensation (WTA) for giving it up.

Several taxonomies have been developed to categorize the types of economic values associated with natural resources, such as a ground water system. One taxonomy distinguishes between use values, which are determined by the contribution of a resource to current or future production and consumption, and nonuse values, which typically refers to aesthetic or contemplative values arising from goods and services. The critical distinction for decision-making is between goods and services whose economic values are fully captured in market prices and those whose value is not thus captured.

### *Applicability of Valuation Methods*

One prominent technique that attempts to measure total value, including use and nonuse values, is the contingent valuation method (CVM). CVM values are elicited directly from individuals (via interviews or questionnaires (see Appendix B)) in the form of statements of maximum WTP or minimum WTA compensation for hypothetical changes in environmental goods, such as ground water quantity or quality. The CVM can be applied to both ground water use and nonuse values. There are numerous methodological controversies associated with application of CVM, including how the hypothetical ground water change that people are being asked to value is to be specified, the elicitation format for asking valuation questions, the appropriate measure to be elicited (i.e., WTP or WTA), and various types of response biases.

The advantage of the contingent valuation method, however, is that it allows analysts to focus precisely on the total resource attribute (e.g., quantity or quality changes) to be valued. CVM provides reliable estimates of value when an individual has a close connection to the resource being valued. When there is a large nonuse component to the TEV being elicited, application of CVM is difficult, making it one of the most controversial areas in the valuation literature. CVM practitioners believe that it is the only method capable of capturing a substantial part of value when nonuse value is a large part of the TEV. However, the continuing controversy over both the theoretical validity and the practicality of CVM-based studies of nonuse values raises questions regarding its use in natural resource damage assessments and litigation situations. Table 1.6 in Chapter 1 and Table 4.5 in Chapter 4 compare the advantages and disadvantages of CVM along with other valuation methods.

In contrast to direct elicitation via CVM or some other stated preference technique, economists also have developed indirect methods (e.g., hedonic price models), which infer values from other behaviors associated with the good. A strength of indirect methods is that they rely on observed behaviors of producers and consumers. Examples of observed behaviors, such as how much water is applied in irrigation or as drinking water at a given cost, expenditures on water purification systems, or how much people will spend to travel to a recreational resource, help to establish a water resource's value. However, because indirect approaches generally measure only one component of the TEV (use value) and in some cases require large amounts of data, care must be taken when employing them.

In any case, for valid and reliable results to be obtained, the valuation method must be well-matched to the context and the ground water function/service of interest. (Chapter 4, Table 4.5 provides a summary of potential matches.) Methods for valuing the quality of drinking water include cost of illness, averting behavior, contingent valuation, and conjoint analysis (e.g., contingent ranking or behavior).

### *Uncertainty*

The decision-maker attempting to value ground water faces significant uncertainties regarding hydrologic, institutional, economic, and human health aspects of ground water management. One source of uncertainty lies with the problem of predicting the consequences of environmental policies and actions. A related set of challenges stems from the difficulty of assessing ground water benefits in the future and the irreversible nature of some present ground water management decisions and impacts. Economic uncertainties regarding nonmarket goods and services are even more substantial because there is no accurate documentation of monetary values when markets are absent.

The notion of risk contrasts with uncertainty. Risk characterizes situations about which there are a known set of probabilities. By contrast, uncertainty characterizes situations in which the probabilities are incompletely known or unknown. Techniques of risk analysis can be customarily applied to characterize risky situations analytically. One method of accounting for risk involves addition of "risk premiums" to the discount rate. The size of the "risk premium" varies directly with the degree of risk. The concept of risk is extremely important in analyzing the potential costs associated with degraded water quality.

A careful consideration of these valuation factors leads to several conclusions:

- **For valid and reliable results to be obtained, the valuation method must be well-matched to the context and the ground water function or service of interest.**
- **It is hard to make generalizations about the validity and reliability of specific valuation approaches in the abstract. The validity of the approach depends on the valuation context and the type of ground water services that are of interest. Different approaches are needed to value different services; care must be taken not to double-count values associated with different services.**
- **Previous ground water valuation studies have focused primarily on a small part of the known ground water functions and services (identified in Chapter 3). Thus, the current empirical knowledge of the values of ground water is quite limited and concentrated in a few areas, such as extractive values related to drinking water use.**
- **The contingent valuation method (CVM), when used correctly, has the potential for producing reliable estimates of ground water use values in certain contexts. CVM has the advantage of allowing analysts to focus precisely on the total value of a resource attribute, compared to the results from other indirect approaches that generally fail to capture total economic value. However, few, if any, studies to date meet the stringent conditions, as established by a NOAA panel of Nobel-Laureate economists, that are required to produce defensible estimates of nonuse values. More research is needed to compare use values from CVM with those of other methods to determine whether CVM will consistently yield reliable estimates.**
- **Given the problems in using CVM to measure ground water values, EPA and other appropriate government agencies should encourage ways of enhancing the utility of CVM. For example, contingent ranking or behavior**

**methods may be useful in improving the robustness of CVM estimates and may expand the potential for transferring existing CVM estimates to other empirical settings.**

- **If data are available and critical assumptions are met, indirect valuation methods (e.g., travel cost method (TCM), hedonic price method (HPM), averting behavior) can produce reliable estimates of the use value of ground water.**
- **The EPA, and other federal agencies as appropriate, should develop and test other valuation methods for addressing the use and nonuse values of ground water, especially the ecological services provided by ground water.**
- **Technical, economic, and institutional uncertainties should be considered and their potential influence delineated in ground water valuation studies. Research is needed to articulate such uncertainties and their potential influence on valuation study results.**
- **Ground water values obtained from both indirect and direct methods are dependent on the specific ground water management context. Attempts to generalize about or transfer values from one context to another should be pursued with caution.**
- **If data are available and critical assumptions are accurate, traditional valuation methods such as cost of illness, demand analysis, and production cost can be used for many ground water management decisions that involve use values. Such methods offer defensible estimates of what are likely to be the major benefits of ground water services.**
- **The pervasiveness and magnitude of nonuse values for ground water is uncertain. Few and limited studies have been conducted, and little reliable evidence exists from which to draw conclusions about the importance of nonuse values for ground water. Additional research is needed to document the occurrence and size of nonuse values for ground water systems.**
- **What is most relevant for decision-making regarding ground water policies or management is knowledge of how the TEV of ground water will be affected by a decision. Pending documentation of large and pervasive nonuse values for ground water, it is likely that in many, but not all, circumstances, measurement of use values or extractive values alone will provide a substantial portion of the change in TEV relevant for decision-making.**
- **In some circumstances the TEV is likely to be largely composed of nonuse values. At the current time, pending documentation of large and pervasive nonuse values for ground water systems, this appears to be most likely when ground water has a strong connection to surface water and a decision will substantially alter these service flows. In these situations, focusing on use values alone could seriously mismeasure changes in TEV and will ill serve decision-making. Decision-makers should approach valuation with a careful regard for measurement of TEV using direct techniques that can incorporate nonuse values.**

## LEGAL CONSIDERATIONS, VALUATION, AND GROUND WATER POLICY

The last two decades have brought changes in emphases in both technical and institutional issues related to ground water management. Due to society's misplaced perceptions of ground water's "pure" natural quality, there has been overemphasis over several decades on ground water quantity issues rather than quality issues. This has included the magnitude of water supplies being developed and associated costs. Quality considerations were mainly related to chlorides, nitrates, and the need for disinfection prior to human consumption. Since the mid-1970s increasing attention has been given to deteriorations in ground water quality. With ground water issues becoming more complex, the incorporation of economic valuation of ground water and other natural resources in decision-making takes on more urgency. This is especially true where a resource supports an ecosystem of national significance that not all citizens may be in contact with but still want protected (e.g., the Everglades or the Grand Canyon).

Sixteen federal laws relate directly or indirectly to ground water management. Key laws include the Clean Water Act (CWA), Safe Drinking Water Act (SDWA), Resource Conservation and Recovery Act (RCRA), Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, or Superfund), and Superfund Amendments and Reauthorization Act (SARA). The SDWA addresses the quality of public drinking water supplies and ground water protection. The CWA addresses pollution control, while RCRA relates to waste disposal sites and underground storage tanks. Soil and ground water remediation are the subjects of the Superfund laws (CERCLA and SARA). Numerous state and local laws also address ground water usage (quantity allocations) and quality via numerical standards or descriptive criteria. These multiple laws and regulatory agency overlaps can create conflicts regarding ground water usage, quality protection, and/or remediation responsibility.

Command-and-control approaches have historically dominated pollution control in environmental quality laws. More recently, market-based considerations, incentives for pollution prevention, and risk management have been advanced as additional components in environmental management, including the management of ground water. Many of these recent environmental management approaches include consideration of some economic issues, including program or project costs and benefits.

Water marketing (the buying and selling of water rights) has emerged as a valuable policy alternative for allowing water allocation laws to efficiently respond to all water use demands. Theory suggests that where price reflects the TEV, reliance on water marketing is a more efficient way to allocate scarce resources.

On a national level, regulatory impact assessment has been used to address some economic issues. For example, President Reagan initiated a formal balancing of the benefits of environmental protection and regulatory compliance costs through Executive Order 12291, which required EPA and other agencies to prepare benefit-cost analyses for any proposed regulations imposing public and private costs of at least $100 million annually. Presidents Bush and Clinton issued similar Executive Orders. Current congressional interests include expanded use of risk assessments coupled with economic evaluations for both programs and projects.

At times, specific legislative mandates or principles may take precedence over the consideration of economic valuation information or benefit-cost analyses. Most federal environmental, health, and safety programs contain program requirements that are unfunded mandates. Accurate information regarding ground water values would make unfunded mandate regulatory reviews better relative to evaluation of the economic and environmental trade-offs involved in ground water protection policies. Historical ground water allocation schemes and water rights laws are examples, as is the concern over human health effects and their immediate reduction in the near-term requirements of the Superfund laws.

These institutional considerations suggest several areas of governmental action:

- **Federal, state, and local agencies should give consideration to the TEV of ground water in their deliberations on new or amended legislation or regulations related to ground water management.**
- **States should consider the authorization and promotion of water marketing, including transfer of ground water rights when appropriate. Although a transition to a market that adequately captures the full value of the resource may be difficult, water markets provide flexibility in water use and more efficient allocation of water among uses. Water markets also provide real world prices of water for current use values, and their prices aid decision-makers in valuing ground water.**
- **States should be encouraged to develop clear and enforceable rights to ground water where such rights are either lacking or absent. A system of clear and enforceable extractive rights to ground water is a prerequisite to economically efficient use of that water. Without such rights, users lack the incentive to value ground water appropriately (consideration of the full TEV) either now or in the future.**
- **EPA and other pertinent agencies should plan and implement an integrated and comprehensive research effort on ground water valuation. Federal agencies should conduct research and develop case studies in ground water valuation that includes a range of environmental conditions and economic circumstances. In addition, governmental agencies should sponsor further research jointly with private institutions to develop valuation methods that quantify ecological services and values. The results of such research will assist states in managing and protecting their ground water resources and could help to demonstrate improvements that valuation can bring to decision-making.**

## CASE STUDY OBSERVATIONS

Chapter 6 contains brief synopses of seven case studies in which ground water valuation has been or could be used to enhance problem analysis and the decision-making process. The case studies illustrate different themes associated with the integration of hydrogeological, ground water usage and economic valuation information in real-world decision contexts. The Treasure Valley, Oregon, case illustrates the role of ground water in ecological services and how valuation can be incorporated in the allocation of scarce water supplies. The Laurel Ridge, Pennsylvania, study focuses on institutional fragmentation and the need for a watershed approach in ground water valuation and management. A study of Albuquerque, New Mexico examines the importance of hydrological information and the interaction of ground and surface waters in developing a long-term sustainable ground water policy. The Arvin-Edson, California, study illustrates the buffer value of ground water relative to extractive services in an area subject to surface water drought conditions. The Orange County, California, case study emphasizes the value of artificial recharge as a means of averting the loss of a ground water supply due to sea water intrusion. A Woburn, Massachusetts, example describes the use of benefit-cost analysis to integrate valuation information in a Superfund remediation dilemma. Finally a water supply study for Tucson, Arizona illustrates planning considerations associated with the valuation framework in Chapter 3, the methods illustrated in Chapter 4, and the importance of substitute water supplies.

These case studies offer several lessons, with most of them supportive of earlier conclusions. Among other things, they show that TEV provides a useful context for the qualitative recognition and/or quantitative valuation of ground water services. At the same time, each study is unique, thus limiting opportunities for subsequent benefits transfer analysis; and highlighting the technical, economic, institutional, and political uncertainties characterize the current state-of-the-art of ground water valuation.

# Valuing Ground Water

## Economic Concepts and Approaches

Committee on Valuing Ground Water

Water Science and Technology Board

Commission on Geosciences, Environment, and Resources

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The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. William A. Wulf is president of the National Academy of Engineering.

The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Kenneth I. Shine is president of the Institute of Medicine.

The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Bruce M. Alberts and Dr. William A. Wulf are chairman and vice chairman, respectively, of the National Research Council.

# Preface

Ground water, while providing much of the nation's supplies of water for domestic, industrial, and agricultural purposes, is surprisingly underappreciated and usually undervalued. Water managers at various levels of government are faced with an array of decisions involving development, protection, and/or remediation of ground water resources. Examples of questions basic to such decisions at the local level include:

(1) Should ground water be used singly or in conjunction with surface water supplies to meet increasing water usage requirements?

(2) Should a comprehensive water conservation program be implemented in order to extend the availability of ground water and minimize or preclude ground water depletion?

Examples of questions basic to decisions at the state or federal level include:

(1) Are the benefits of ground water protection programs greater than their costs, and how should such wellhead protection efforts be funded?

(2) How should ground water remediation projects be prioritized given that the costs of remedial actions typically far exceed available funding? Should the value of ground water resources be considered in deciding if remediation efforts should be undertaken at a site?

Valuation of ground water resources is critical in determining an efficient outcome in each of these examples as well as many other ground water development, protection, and/or remediation projects, programs, or policy decisions. However, the ground water resource, a non-market good, is difficult to value;

and, as a result, economic valuation and future considerations have historically played almost no part in decision making.

The fundamental need to value natural resources was recognized in a 1990 report of the Science Advisory Board (SAB) of the U.S. Environmental Protection Agency (EPA, 1990). Based on the review of comparative risk assessments of environmental problems, a committee of 39 distinguished scientists, engineers, and other experts drawn from academia, state government, industry, and public interest groups developed ten recommendations; of relevance to this report is Recommendation 10—EPA should develop improved methods to value natural resources and to account for long-term environmental effects in its economic analyses (EPA, 1990).

In 1994 the U.S. Environmental Protection Agency requested that the National Research Council (NRC) appoint a committee to study approaches to assessing the future economic value of ground water, and the economic impact of the contamination or depletion of these resources. This committee was appointed in 1994 under the auspices of the NRC's Water Science and Technology Board. The committee was charged to:

(1) review and critique various approaches for estimating the future value of uncontaminated ground water in both practice and in theory;

(2) identify areas in which existing approaches require further development and promising new approaches which might be developed;

(3) delineate the circumstances under which various approaches would be preferred in practice for various applications of decision making regarding long-term resource use and management;

(4) outline legislative and policy considerations in connection with the use and implementation of recommended approaches, and related research needs; and

(5) illustrate, through real or hypothetical case examples, how recommended procedures would be applied in practice for representative applications.

Due to the relevance of the committee charge to other public interest groups and agencies, three other sponsors provided financial support for this NRC study in addition to EPA: the National Water Research Institute, the U.S. Department of Defense, and the U.S. Department of Energy.

The focus of the study on ground water valuation and the composition of the committee established the need for economists to work with ground water experts. Disciplines represented on the committee included agricultural economics, environmental engineering, hydrogeology, microbiology, public policy, resource economics, and water law. The members were drawn from academia, private consultants, and water management positions in local government.

While the assignment was challenging, the committee quickly agreed on three matters that provided its starting points. First, an interdisciplinary approach is necessary for ground water valuation studies. Second, when valuing ground water, the *in situ* and ecological services must be recognized along with the more obvious extractive services. Finally, it was recognized that common terminology was not available as a foundation for this study. Thus concepts and principles from environmental economics and ground water management had to be appropriately integrated to provide a basis for the work of the committee.

The committee has completed its task and, in so doing, has received considerable assistance from the NRC staff. Accordingly, on behalf of the committee, I wish to express our thanks to the following persons: Sheila David, Study Director; Etan Gumerman, Project Coordinator; Mary Beth Morris, Project Assistant; Ellen de Guzman, Project Assistant; Joel Darmstadter, Consultant; and Steve Parker, Director of the Water Science and Technology Board (WSTB). In addition, Henry Vaux, WSTB member and liaison to this committee, provided both helpful guidance and technical input.

Finally, I wish to express my appreciation to all committee members for their willingness to discuss new concepts from an interdisciplinary perspective, to prepare and revise materials for this report, and to strive for consensus-building on key issues. We have all learned from this process!

Larry W. Canter,
*Chairman*

## Reference

U.S. EPA. 1990. Reducing Risk: Setting Priorities and Strategies for Environmental Protection, Science Advisory Board, Relative Risk Reduction Strategies Committee, U.S. EPA, Washington, D.C.

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