Determining the Economic Value of WATER

Concepts and Methods

SECOND EDITION

ROBERT A. YOUNG and
JOHN B. LOOMIS

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RESOURCES FOR THE FUTURE

ROUTLEDGE

Determining the Economic Value of Water

Water provides benefits as a commodity for agriculture, industry, and households, and as a public good such as fisheries habitat, water quality and recreational use. To aid in cost-benefit analysis under conditions where market determined price signals are usually unavailable, economists have developed a range of alternative valuation methods for measuring economic benefits.

This volume provides the most comprehensive exposition to-date of the application of economic valuation methods to proposed water resources investments and policies. It provides a conceptual framework for valuation of both commodity and public good uses of water, addressing non market valuation techniques appropriate to measuring public benefits – including water quality improvement, recreation, and fish habitat enhancement. The book describes the various measurement methods, illustrates how they are applied in practice, and discusses their strengths, limitations, and appropriate roles.

In this second edition, all chapters have been thoroughly updated, and in particular the coverage of water markets and valuation of ecosystem services from water has been expanded. Robert A. Young, author of the 2005 edition, has been joined for this new edition by John B. Loomis, who brings additional expertise on ecosystem services and the environmental economics of water for recreational and other public good uses.

Robert A. Young was Emeritus Professor in the Department of Agricultural and Resource Economics at Colorado State University, USA.

John B. Loomis is Professor in the Department of Agricultural and Resource Economics at Colorado State University, USA.

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John B. Loomis

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Author Biographies

Robert A. Young was a faculty member at University of Arizona before joining the faculty at Colorado State University in 1970. He was a faculty member in the Department of Agricultural and Resource Economics for twenty-one years, and then was Professor Emeritus until his death in 2013. He had worked as a water policy consultant for the World Bank and the United Nations. Young's research interests were in water supply and quality, particularly in the case of offstream water uses, in agriculture, municipalities, and industry. Young's research has received awards from the American Agricultural Economics Association, the Western Agricultural Economics Association, the American Water Resources Association, and the Warren A. Hall Medal for Distinguished Contributions to Water Resources.

John B. Loomis joined the faculty at Colorado State University in 1993, after being an Associate Professor at University of California-Davis. Previously he worked as an economist for two agencies in the U.S. Department of Interior. Loomis' primary research interests are in non market valuation of water resources such as recreation, instream flow, endangered species, and public lands. Loomis' research has received several awards including from the Agricultural and Applied Economics Association. He was elected Vice-President of the Association of Environmental and Resource Economists, and was selected as a Fellow of that Association in 2013. He was also selected as a Distinguished Scholar of the Western Agricultural Economics Association in 2006. He was selected as a Fellow of the Agricultural and Applied Economics Association in 2014.

Preface to the Second Edition

The second edition to this book began when Bob Young asked me to join him in updating and revising his encyclopedic first edition of this book. It was with some trepidation that I agreed, as Bob Young was one of the most experienced (forty plus years) and knowledgeable water economists in the world. Our first step involved a revised outline for the book that is reflected in this second edition. As the book progressed, Bob's comments on my revisions of several chapters reinforced my view that he was an insightful water resource economist. Bob Young was also a true scholar in the broad sense of the word: well-read and reflective and he set this scholarly standard in everything he did including this book. It is with much sadness that I must report that several months before the book was completed he suddenly passed away. Bob's wife (Lynn) and I were determined that this second edition would be finished, and finished in a way that would make him proud to have his name on it. We hope we have achieved that very high standard.

Part I of the book on the Concepts and Theory was updated and refined to reflect advances in the way economists think about water resources in the twenty-first century. The biggest change the reader will see is in Chapter 4 on what was valuation of water as environmental public goods. Since this is my specialty, and part of the reason Bob asked me to join him in this revision, this chapter was reorganized around the now widely accepted and used ecosystem goods and services framework. In addition this is an area where great advances have been made in the last decade. In particular, techniques for nonmarket valuation of public goods have been significantly refined and broadened to value several aspects of water-related ecosystem goods and services that were not previously valued.

Part III of the book, on Application of Valuation Methods, has been updated with recent evidence of and more extensive discussion of water markets for agriculture (Chapter 5) and municipal uses (Chapter 7). Chapter 5 now has more and updated references and discussion on the use of optimization models and computable general equilibrium models for valuation of water in agriculture. Chapter 6, on industrial uses of water, has been expanded to include discussions of water in energy production with an emphasis on biofuels and hydraulic fracking for oil and gas production. The chapter on empirical methods for valuing ecosystem services has been updated and expanded to discuss the advances that have been made in choice experiments and other nonmarket valuation techniques. An extensive literature review on the benefits of reducing nonpoint source pollution is now provided.

Overall, I feel that this second edition reflects Bob Young's and my joint vision for what an updated second edition of this book would look like. We hope graduate students and our colleagues continue to find it a useful book and a handy reference on accepted techniques for valuing all the many uses of water resources.

John B. Loomis

Preface to the First Edition

Water economists are called upon to answer some difficult questions:

- What types of goods and services are produced by water? Why are prices for water seldom observed on normal commodity markets?
- What do economists mean by "value" or "benefits" in relation to water resources? Is the economic benefit of an increment of water the same at all times and places and for all purposes? Why are estimates of water-related policy benefits important?
- What nonmarket valuation methods can be used to estimate economic benefits of water-related policies? Which methods are most appropriate for producer goods and which for consumer goods uses of water?
- How are the various methods applied in practice? What are their advantages, limitations, and appropriate roles?

Water management, historically always important, is an increasingly timely subject. In its varied forms, the water resource supplies important benefits to humankind, ranging from commodity-type benefits in agriculture, industry, and households to environmental values, including biodiversity and recreation. However, significant water management problems can be found throughout the world, and in many areas they are rapidly becoming worse. Growing populations and incomes increase demands for water for agricultural, industrial, and residential uses from limited surface and ground water supplies. These same forces of economic and population growth add to the pollution discharged to the world's waterways, and to the encroachment of human activities upon lowlands vulnerable to flooding or upon important natural ecosystems. Increased prosperity carries with it amplified demand for improved water quality, for more access to recreational and amenity uses, and for the preservation of biodiversity and natural ecosystems.

The price signals which reflect scarcities of goods and services and which are successfully used to guide investments and resource allocation in the private sector are usually absent or distorted for water, complicating public sector decisionmaking related to the resource. A premise of this work is that, although market prices will play an increasing role in water allocation, the market's function will continue to be limited; consequently, applied economic valuation procedures can play an important role in guiding public policies related to water. To address the many public policy issues arising when markets are absent or imperfect, economic researchers and practitioners have adapted the neoclassical economic model to public policy decisions, developing the evaluative procedure termed cost–benefit analysis. A major portion of that effort has been devoted to formulating, perfecting, and applying nonmarket methods for measuring benefits, forgone benefits, and costs of proposed public policies and programs relating to the natural environment. These efforts have often been directed to evaluation of changes in water resource supplies and quality. Tools have been developed and refined which are conceptually consistent with market prices and which permit increasing confidence in bringing economic efficiency considerations to bear on public decisions relating to water (and other environmental resources).

This book is broadly about putting a monetary value on goods and services provided by water. More formally, it is intended to introduce the reader to the application of welfare economics principles to the measurement of economic benefits in the context of assessing water-related policies (intersectoral water allocation and reallocation, investments or policies to augment water supplies or qualities, pricing, or other water planning decisions). A major aim is to provide professional economists (both field practitioners and advanced students) with a consistent conceptual foundation for comparing the economic values of water across alternative uses and with costs of investments. It will show readers the concepts and techniques for applying alternative empirical approaches to measuring the economic benefits of water-related policies or investments, illustrate how to understand the strengths and weaknesses of these alternative approaches, and provide guidance to the more technical literature.

For several reasons, the emphasis here inclines toward offstream and private good issues, valuing water in agricultural crop irrigation, industrial, and municipal uses. First, my professional research has mainly focused on such issues. Second, although there is considerable diverse literature on valuation of water in offstream private good cases, there is no single volume that attempts to integrate this literature with the much more fully developed literature on valuation of environmental goods and services. Moreover, nonmarket methods for valuing water in the production sectors have not received the comprehensive attention devoted in recent decades to environmental issues. Agriculture accounts for the largest consumptive use of water in the United States and worldwide, and industries are also important water users. Accordingly, this volume gives special emphasis to valuing water as a producers' good; it critiques a number of methods frequently employed, and proposes improved approaches. Thus, it attempts to fill the gap in the existing literature regarding application of nonmarket valuation techniques to commodity uses of water in agriculture, industry, and municipalities in a framework consistent with that already well-developed for public environmental goods and services.

The book is organized as follows: Part I sets the stage. Chapter 1 identifies the physical, economic, and social attributes of water and describes a number of standard water policy issues for which economic analysis is frequently needed. Chapter 2 briefly reviews the basic conceptual and analytic issues underlying the neoclassical approach to the economic valuation of water. Chapter 3 introduces applied methods of nonmarket valuation, reviews the procedures appropriate to measuring water values in producer uses of water, and describes their advantages and limitations. Chapter 4 covers issues of applied benefit measurement for consumer uses of water, primarily public good benefits (such as obtained from water-based recreation, preservation values, and water quality enhancement).

Part II describes and evaluates applications of the various methods to specific water use categories. Chapters 5, 6, and 7 discuss the applications of these methods to offstream or withdrawal uses in agriculture, industry (including hydropower), and municipalities, respectively. Methods and applications of measuring the value of water as public environmental goods are addressed in Chapter 9, which reviews methods for addressing such issues as instream flow valuation, and environmental preservation.

The scope is mainly limited to the estimation of direct benefits (and benefits forgone) of water-related policies. A number of broader treatments of the principles of cost–benefit analysis—including the validity of secondary benefits, the rate of discount, the planning horizon, decision criteria, and the general issues of setting up and performing a cost–benefit analysis—are available (e.g. Fuguitt and Wilcox 1999; Boardman et al. 2011, etc.).

The analysis should be, for the most part, accessible to those with training in microeconomic theory, mathematics, and statistics at the upper-division, undergraduate level. The text should also be helpful to water engineers, environmentalists, planners, policymakers, and other noneconomists who make use of water valuations or who interact with economists on water policy and planning activities. It should be a useful adjunct to more general textbooks in academic courses in natural resource and environmental economics and in water planning and management. To the reader and potential user of the materials presented here: *caveat emptor*. First, no single magic number represents the economic benefits of water used for any given sector. Just as the market prices for goods and services are typically specific as to *place, form,* and *time,* nonmarket valuations (often called accounting prices) for water also vary according to these dimensions. They further vary with the situation, the underlying factors, and the policy proposal being evaluated. Given the relative lack of transportability of both the public and private attributes of water, values for water can be expected to vary even more widely than do prices for more conventional goods and services.

Second, noneconomists and those economists who are new to the field should be aware that accurate economic valuation of the impacts of water-related polices is seldom quick, easy, or simple. Developing appropriate and reliable estimates of the value of water requires substantial skills, time, and research resources. To adequately perform the assignment calls for command of many if not most of the technical skills of the applied economist. Rigorous estimation of economic benefits of water policies and projects must begin with a close understanding of microeconomic theory. Successful shadow pricing of water in any particular use will further demand proficiency in one or more forms of quantitative economic modeling. Competence with advanced statistical and econometric techniques is a necessity for developing sound contingent valuation, travel cost, and hedonic price estimates. Probably the quantitatively least demanding of the commonly used methods of valuing water and other nonmarket environmental goods are simple benefit transfer techniques, but advanced approaches here too call for considerable statistical skills. For valuing water as a producers' good, an essential foundation is familiarity with production theory, business accounting, and spreadsheets. Moreover, mathematical optimization and computable general equilibrium modeling are increasingly used for addressing this type of problem. Finally, careful collection of accurate and representative primary data or selection of adequate secondary data is an often underemphasized requirement. Only a handful of economists have the training, native abilities, resources, and time to become proficient in more than a few of the many types of issues that arise in shadow-pricing. Specialization, as elsewhere in the economy, is here a necessity.

This volume arose from numerous assignments and collaborations during my work on water economics over the past four decades. I became interested in water valuation as applied to arid-area water policies in the mid-1960s working with William Martin and the late Maurice Kelso at the University of Arizona. Subsequently, as a visiting scholar at Resources for the Future, I was fortunate to collaborate with Charles Howe in several research efforts, an association that has continued intermittently since we moved to different state universities in Colorado. Applied economic valuation of water became a major research focus of mine at Colorado State University where, with Lee Gray and others, a two-year effort for the National Water Commission developed a conceptually consistent framework for estimating the economic value of water in alternative uses and applied it to various regions across the United States (Young and Gray 1972). Research and consulting assignments with the U.S. Agency for International Development, the World Bank, and the Asian Development Bank provided an international dimension to the research agenda. Particular thanks are extended to Lee Gray for his valuable contributions to the conceptualizations and implementations of specific valuation techniques and, more recently, for his administrative support. For over two decades I taught a graduate course in water resource economics at Colorado State University which emphasized water valuation techniques, and supervised graduate students' research in water economics. Numerous students, both in the classroom and in applied research, posed valuable questions and challenges to the concepts and methods discussed here. Several years ago, in a consulting capacity, I prepared a technical report on water valuation for the World Bank (Young 1996). More recently, the Government of Switzerland provided a grant to the World Bank that enabled me to update and expand that work toward completion of this monograph.

Robert A. Young

Acknowledgements

Second Edition

I wish to thank Brian Quay who carefully read each chapter to provide edits and suggestions for clarifications as well as helping to update the references. Thanks to Frank Ward for an examination of Chapter 5 on irrigation values of water. Susanne Scheierling's many contributions to the first edition of the book continue to be reflected in this second edition. Thanks are due to David Harpman and James Booker for assurance in the clarifying and updating of the hydropower section of Chapter 6. Susanne Scheierling's many contributions to the first edition of the book continue to be reflected in this second edition.

First Edition

Particular acknowledgments are due to Ariel Dinar of the World Bank for encouragement and support of this effort and for discussions and advice on the subject and content of the work. Several anonymous reviewers provided useful and insightful suggestions for improvements on earlier drafts. Susanne Scheierling deserves special mention; while on leave from the Asian Development Bank, she read and commented on the entire draft manuscript and was very helpful in improving both the content and the presentation. I am grateful to all of those mentioned above for help in refining and clarifying the ideas presented here.

Part I

Concepts and theory

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Chapter 1

Water, Economics, and the Nature of Water Policy Issues

> Economists are interested in the subjective values associated with the sources of individual satisfaction because of their concern with the economy's ability to allocate resources and coordinate production and distribution so as to create the greatest benefit to society. For many needs and desires, competitive markets are a relatively good means for determining and responding to individual preferences. There are limits to this solution, however, because not all sources of satisfaction go through markets, and markets may fail in other ways as well. National product and income estimates as measured by market transactions are therefore incomplete, and inadequate measures of overall welfare. Correcting for this by estimating values uncounted by the market can help, although this is often difficult, and at times virtually impossible.
>
> (Tibor Scitovsky 1993)

Public policies relating to water supply and quality can have significant economic consequences for households, communities, farms, and business firms. In many parts of the world water is allocated to less valued uses, water quality continues to decline, groundwater basins are overexploited, water-related ecosystem services receive inadequate attention, and floods and droughts take an unnecessarily severe toll on life and property. If climate change projections are reasonably accurate increased temperatures are expected to result in greater water demand and increase the variability in water supply. Future population increases, coupled with climate change, are likely to exacerbate current water resource management challenges. Thus it will be even more important for water managers and government agencies to understand the economic values of water in alternative uses in order to make the most of limited water supplies, i.e. efficiently allocate the available water to maximize its value to society.

Descriptive statistics illuminate broad water use and consumption patterns and place water allocation issues in context. In the United States, crop irrigation continues to be the major user of water, accounting for 31 percent of withdrawals (Kenny et al. 2009) but 80–90 percent of consumption (Schaible and Aillery 2012). (*Withdrawal* refers to an amount of water diverted from a surface source or removed from a groundwater source for human use, while *consumption* is understood as that part of water withdrawal that is transpired through plants, evaporated, incorporated into products, consumed by livestock or humans, or otherwise removed from the immediate water environment.) The domestic-commercial category represented 12 percent of withdrawals (Kenny et al. 2009) and 7 percent of consumption, while industry withdrew 4 percent of total withdrawals. Thermoelectric power (e.g. cooling) accounted for 49 percent withdrawals but only 2 percent of consumption (Schaible and Aillery 2012). Elsewhere, water withdrawal and consumption patterns reflect climate, degree of economic development, and other factors. However, as in the United States, crop irrigation represents the major consumptive use of water in the world. (See Rogers 1993 or Solley et al. 1998 for national and regional data on water withdrawals and consumption by sector for the United States, and see United Nations World Water Assessment Program 2012 for an global overview.)

This chapter begins with a review of some of the physical, economic, social, and political characteristics of water that are important for designing water policies. Then it describes the significant issues that confront analysts and policymakers. Finally, it addresses the broad approach to economic appraisal of public policies.

1.1 Why is Economic Valuation Needed?

Water is distinguished from most other resources and commodities by a number of special characteristics that pose significant challenges for the design and selection of water allocation and management institutions such as markets (see Young 1986). Water's unique characteristics are described below under four headings: hydrological and physical attributes, water demand, social attitudes, and legal–political considerations. These considerations explain why water is for the most part a good not traded on regular markets, why nonpriced side effects frequently accompany water use, and when and why some configuration of a governing institution setting the rules in use are needed. These governing institutions range from informal or formal "user associations" such as irrigation or water districts to different levels of government, e.g. local, state and/or national (Ostrom 2010). One factor often raised in government resource allocation decisions is the economics of those decisions. For uses of water involving government decisionmaking, it is often necessary to estimate simulated market prices or what economists call shadow prices to guide efficient water allocation and investment decisions.

1.1.1 Hydrologic and Physical Attributes of Water

Water is Mobile

Typically found in liquid form, water tends to flow, evaporate, and seep as it moves through the hydrologic cycle. Mobility presents problems in identifying and measuring specific units of the resource. Primarily because of this attribute, water is what economists call a "high-exclusion cost" resource, implying that the exclusive property rights which are the basis of a market or exchange economy are relatively difficult and expensive to establish and enforce.

Supplies Tend to be Highly Variable

As a generally renewable natural resource, basic raw water supplies are mostly outside human control; they are typically variable and unpredictable in time, space, and quality. Local water availability usually changes systematically throughout the seasons of the year (with climatic variations) and over longer cyclical swings. Significant global climate changes are forecast, with a majority of the models suggesting reduced snowpack in snow dominated watersheds (Barnett et al. 2005) resulting in less water availability in summer when crop water demand is the highest and stream flows are naturally low (further impacting instream ecosystem services). Some models of climate change suggest the extremes of the probability distributions of supply—floods and droughts—will increase with resulting problems for humankind. Flooding imposes significant human toll and interruption of economic activity, and most governments have undertaken programs for mitigating the risks of floods. At the opposite extreme, droughts can devastate local economies, particularly those heavily relying on agriculture.

Water is a Nearly Universal Solvent

Water—when in plentiful supply—provides (from the private perspective) an inexpensive capacity for absorbing wastes and pollutants, and further for diluting them and transporting them to other locations. Managing the assimilative capacity of the hydrologic system should, then, be understood as the management of a scarce collective asset. In many situations, water quality considerations are as economically important as are direct use and other public benefits.

Interdependency among Users is Pervasive

Water is rarely completely lost to evaporation in the course of consumption or production activities. So-called "water uses" generally result in return flows to surface streams or aquifers. In crop irrigation, for example, it is not unusual to find that 50 percent or more of the water withdrawn from watercourses is returned, in the form of surface runoff or subsurface drainage, to the hydrologic system. An even larger proportion is typically returned from municipal and industrial withdrawals. Downstream users or those depending on the same lake or reservoir are affected (usually, but not always, for ill) by the quantity, quality, and timing of releases or return flows by upstream users. These interdependencies lead to effects called *externalities* (or "spillover" or "third-party" effects), which are uncompensated side effects of individual economic activities. The presence of externalities implies that the full costs of economic activity are not recognized in the upstream individual producer or consumer decisions. In this case the outcomes for the society will be less than optimal unless some sort of governing institution (e.g. user association or government) can set rules of use that lead to economically efficient outcomes.

Supply Facilities Exhibit Economies of Large Size

The capture, storage, and delivery of water (especially surface water) typically exhibit economies of scale (i.e. falling unit costs). When costs decline over the range of existing demands, a single supplying entity can be the most economically efficient organizational arrangement. For example, the least-cost approach to capture, storage, treatment, and delivery of residential water supplies in an urbanized area is usually by a single public utility: a classical "natural monopoly." Accordingly, public ownership or public rate regulation of water supply industries is often invoked to avoid monopolistic pricing.

Groundwater Supplies Have Distinctive Attributes

Groundwater deposits, or aquifers, supply much of the world's water. Unlike surface water, groundwater flows slowly, and it is difficult to assess the potential yield and quality of an aquifer. Most size economies are achieved at relatively small outputs. Moreover, these may be partially or completely counterbalanced by increased pumping costs and rising third-party spillover costs due to water table drawdown.

Water as a Bulky Commodity

Although there are exceptions (bottled drinking water, for example), the economic value per unit weight or volume of water tends to be relatively low, placing water among commodities which economists call "bulky." Capital and energy costs for transportation, lifting, and storage tend to be high relative to economic value at the point of use. For example, in irrigated agriculture, much of the raw water used on crops may yield direct economic values—roughly speaking, the return net of nonwater production costs available to cover the costs of supply—of less than \$0.04 per ton. Even water intended for urban residential uses—after being captured, filtered, treated, stored, and delivered by municipal water supply systems—typically costs the user less than US \$0.50 per ton. Extensive waterconserving technologies (closed conduits, recycling, metering) as well as incentives for conservation (marketable property rights, increasing block pricing) are presently found only where water is recognized as scarce and valuable. Although water is generally a low-valued commodity, it nevertheless may still be underpriced relative to the cost of supply or opportunity costs.

1.1.2 Water Demand: Characteristics from Users' Perspectives

Because the different benefits obtained from water usually call for specialized management approaches, it will be useful to group the types of values into different categories.

One typology of water demands separates water demands by end uses: (a) municipal; (b) industrial; (c) irrigation (usually agriculture); and (d) environmental (instream flows for recreational fishing and boating as well as to maintain a natural environment—what are increasingly referred to as water-related ecosystem services). The demand for municipal water, especially indoor water uses, is fairly stable and predictable over time. This contrasts with out of home use of water, mainly for lawns, which varies seasonally. The needs of agriculture oscillate in response to temperature and rainfall patterns over the seasons of a year and over longer cycles. Industrial water demands also vary depending on weekday versus weekend, and seasonal considerations. Both storage and conveyance systems and management institutions must be prepared to satisfy peak loads in high-demand periods.

Some distinctions will be helpful regarding the commodity-type uses of water. The commodity benefits are those derived from personal drinking, cooking, and sanitation, and those contributing to productive activities on farms and in commercial businesses and industries. These types of human uses of water that normally take place away from the natural hydrologic system may also be called *offstream* uses and usually involve withdrawal of water from a river or lake/reservoir. Since these uses typically involve at least partial consumption (evaporation or transpiration), they may be further distinguished as *consumptive* uses.

Other types of economic commodity values associated with water may not require it to leave the natural hydrologic system. This group may be labeled *instream* water uses, hydroelectric power generation and waterways transportation being important examples. Since instream uses often involve little or no physical loss, they are also frequently called *nonconsumptive* uses. Although instream uses do not "consume" much water, in the sense of evaporating it to the atmosphere, they do on occasion require a change in the time or place of availability. This is, for example, the case with reservoir releases for hydropower or navigational purposes. So these uses exhibit some aspects of the rivalry of a private good.

No categorization can capture all the many dimensions of water, however. In Chapter 4 we map specific water uses according to the ecosystem goods and services they provide. Here we map water into demand and supply categories and type of good following a classification scheme presented in Table 1.1, adapted from Brown et al. (2007). These are (a) private commodity benefits for municipal, industrial, and agricultural uses, and (b) instream flow uses for waste assimilation benefits, public (but sometimes private) aesthetic, recreational, and fish and wildlife habitat values.

In Table 1.1, the term rival means that one person uses up some or all of the resource or reduces the amount available to others. Ostrom (2010) calls this subtractability, while Baumol and Oates (1988) call it depletability. A nonrenewable groundwater deposit usually involves one landowner's withdrawal resulting in less water available for others. Nonrival means one person's use does not reduce the amount available to others. Instream flow uses such as rafting or run-of-the river hydropower is characterized by being nonrival use of water as one use does not diminish the amount of water available to another user downstream. For example in the case of rafting the marginal cost of allowing another boater on a given river is zero in terms of water use.

If the marginal cost of allowing another person to use the water is zero, then the price should be zero. This efficiency condition arises from the well known principle in

Table 1.1 Economic Categorization of Water Supply and Demand Use Values

Hydrology/Supply	*Characteristics*	*Type of Good*
Withdrawal		
1. Surface Water	Rival	
	(Riparian: Nonexcludable)	Common Pool
	Appropriative: Excludable	Club Good
2. Ground Water	Nonrival, Nonexcludable	Common Pool
Instream	Nonrival, Nonexcludable	Public Good
Demand		
Municipal (piped)	Rival, Excludable	Private Good
Industrial (piped)	Rival, Excludable	Private Good
Agriculture	Rival, Excludable	Private
Environmental	Nonrival, Nonexcludable	Public good
	Nonrival, Excludable	Club good

welfare economics that in the absence of externalities, an economically efficient price occurs where the price equals the marginal cost. This simply means that the marginal value of using another unit (e.g. its price) is equal to the opportunity cost to society of producing another unit. This condition occurs with perfect competition but not monopoly or when there are positive or negative externalities.

Excludability relates to whether one person can technically or cost-effectively exclude other users of the resource. In the case of excludability, some water resources are technically excludable, but the cost of doing so may exceed the value of the resource lost to non-payers. Thus exclusion cost refers to the resources required to keep those not legally entitled from using the good or service. Water is frequently a high-exclusion-cost good because of its physical nature: it is often difficult and expensive to limit the use of the good to those who have helped pay for its costs of production.

In the case where use is nonrival but it is cost-effective to exclude non-payers, too little of the good is consumed. That is because when the marginal cost is zero, but the price charged by the owner is greater than zero, then price is greater than marginal cost. For example, if the price to gain access to a stream for fishing or rafting is $50, but the person only values it at $20, there is a net loss in benefit of $30 to the individual and hence society. Why do we say a net loss to society? This is because if the marginal cost (opportunity cost) of allowing another person to use the river is zero, i.e. no resources are given up to allow another person to use it and yet $30 of net benefits are forgone. In fact, the inefficiency is even worse than the $30 lost to the angler because the owner incurred expenses excluding the person from consuming a good. Thus this is a double waste of resources, as the scarce resource cost employed by the owner for exclusion could have been used to produce other goods and services that society values.

However, in some cases there are either direct costs to produce or maintain public goods or opportunity costs of keeping a public good in its current use versus converting it to some private use (e.g. draining a lake for municipal water supply as Los Angeles did in the case of Owens Lake in California). However, it can be difficult to get all the beneficiaries of a public good to pay since they cannot be excluded if they do not pay. Thus many users of the public good would opt not to pay if given the choice. The refusal of some beneficiaries to pay their share of the cost provision of a public good is called the "free rider" problem. To circumvent the problem, public goods must normally be financed by general taxes rather than by voluntary payments. However, setting the tax and determining the optimal amount of the public good (e.g. amount of stream flow) to provide requires an estimate of how much users benefit. Techniques for doing this are detailed in Chapter 4.

Table 1.1 presents the concepts of rivalness and excludability as polar extremes, but of course, there may not always be sharp distinctions between what is rival or not and what is excludable or not. In the real world, it is best to think of these as continuums with a degree of excludability and a degree of rivalness. For example, instream flow for waste assimilation is nonrival up to a point, and beyond that the water source begins to lose its ability to break down waste products or dilute pollution to unharmful levels. At that point additional users' discharge of waste becomes rival, and continued use dischargers cause economically relevant damages to other water users. Discharges going beyond the optimal level result in a net loss in benefits to society as a whole.

Table 1.1 also serves as a useful overview of the different uses and users of water that will be touched upon. Below we elaborate on these.

The book will go into detail on the interaction of supply and demand for the types of goods listed in Table 1.1. In particular, Chapters 3 and 5 will discuss valuation of water in agricultural uses. Chapters 4 and 9 will focus on the public good dimension of water and the ecosystem services provided by water as instream flow, water quality, and fisheries habitat. Chapters 4 and 9 will also touch on the *nonuse* (often called *passive use*) values of water as well. Chapter 6 will focus on industrial uses of water including hydropower. Chapter 7 is on domestic and other municipal uses of water.

1.1.3 Social Attitudes toward Water

More than for most commodities, social and cultural values relating to water are often in conflict with economic values. Because water is essential to life, and because clean water and sanitation are essential to health, many argue that market allocation mechanisms should be rejected in favor of regulatory approaches. The Dublin Conference on Water and Environment in 1992 asserted as one of its guiding principles for action that "…it is vital to recognize first the basic right of all human beings to have access to clean water and sanitation at an affordable price" (United Nations 1992). The significance of water for life is even greater in arid regions, where crop irrigation is essential to production of that other staff of life, food.

For many, water has special cultural, religious, and social values, and these people prefer not to have water treated as an economic commodity. Goals other than economic efficiency play an unusually large role in selecting water management institutions. Boulding (1980) has observed that "the sacredness of water as a symbol of ritual purity exempts it somewhat from the dirty rationality of the market." Many people intuitively reject pricing of a resource that is necessary for life, and some cultures or religions proscribe water allocation by market forces.

However, an exclusive focus on the necessity of water for life as the basis for designing allocative institutions tends to obscure the fact that in most societies only a tiny fraction of water consumption is actually used directly for drinking and for preserving human life. Most direct water use is for convenience, comfort, and aesthetic pleasure. In the arid western United States, for example, average residential water withdrawal frequently reaches 500 liters per capita per day. Only a fraction of a percent of this use is for drinking; nearly half may be applied to irrigate lawns and gardens, and most of the remainder is for bathing, flushing toilets, and washing cars (Gleick 1998).

1.1.4 Institutional, Legal and Political Considerations

A number of considerations for water policy design fall on the border between economics and political science, or what is sometimes called political economy.

Transactions Costs versus the Relative Scarcity of Water

The term *transactions costs* refers to the resources required to establish, operate, and enforce a resource allocation, management, or regulatory system. Transaction costs may be also termed "ICE" costs, because they comprise the costs of obtaining *i*nformation (such as knowledge about the needs and attitudes of other participants), *c*ontracting costs (resources required to reach agreements), and *e*nforcement costs (the expense of enforcing contracts and public laws and regulations). Given the supply and demand characteristics of water noted earlier, especially interdependency of users, transactions costs for water management and allocation tend to be high relative to its value. Where water is plentiful relative to demand, water laws tend to be simple and only casually enforced. Where water is scarce, more elaborate management systems have evolved. In many regions, water supplies are only now becoming scarce enough to require formal management systems. Increased resource scarcity and technological advances which reduce the transactions cost of monitoring and enforcing regulations both act to encourage innovations in allocative institutions, so as to economize on the scarce resource.

As the reader may recognize some of these intersections of water supply and water demand in Table 1.1 are more amenable to being dealt with by markets (e.g. industrial uses) some by governments (e.g. instream flow), and some that could be dealt with by other institutions such as users associations (e.g. water districts). For example, to avoid the "potential tragedy of the commons" (Hardin 1968) associated with rival but nonexcludable use of water resources, some form of limitation to individual user self-interest is needed. Depending on whether the aquifer is contained within a single political jurisdiction or cross multiple political jurisdictions, an appropriate level of government could be chosen that would internalize the externality. The appropriate government agency would regulate groundwater pumping by setting rules on the number extractors and the rate of pumping to achieve an intertemporal social optimum over time. However, this requires government to obtain users' values of groundwater, often an unpriced resource. This book presents the methods that government agency economists or others might use to determine the value of unpriced groundwater. If the transactions costs are low enough due to only a small number of users, these users may be able to join together to "self-regulate" using either informal or formal mutually agreed upon constraints on their self-interested behavior (Ostrom 2010). (See Provencher and Burt 1994 for discussion of optimal groundwater management and a review of alternative institutional arrangements for groundwater allocation.)

The need for some governing institution is also required to deal with the nonrival, nonexcludable public goods case in Table 1.1. Here again the appropriate level of government would depend on the spatial scope of the benefits provided by the public good, or what is called the "economic jurisdiction" (Olson 1969; Loomis 2000). Protecting instream flows for a nationally designated wild and scenic river used by boaters from all over the country would suggest a national government would be the appropriate "political jurisdiction" (Olson 1969; Loomis 2000).

However, in many cases the level of government for regulating water use was set decades ago if not in previous centuries before public goods or significant groundwater pumping externalities were recognized. But institutions can and in some cases do evolve as increased scarcity make water resources more valuable. Two visible examples of this include: (a) U.S. Endangered Species Act. Here to protect endangered fish and wildlife the federal government has "forced" multiple state water agencies that regulate water use to come together on the Platte River in Colorado, Nebraska, and Wyoming to provide sufficient instream flows to endangered species habitat downstream of Colorado and Wyoming (U.S. Department of the Interior 2006). (b) Public trust doctrine in some states requires local water districts or municipalities not to divert so much water as to unreasonably damage the water related resources (e.g. fish and waterbird habitat). The Mono Lake case in California is often held up as an example of the State of California using the public trust doctrine in this way to limit Los Angeles' water diversions (Casey 1984; Loomis 1995).

Cumulative Impact of Many Small Decisions

Water policymakers must often confront the problem aptly termed the "tyranny of small decisions" (Kahn 1966). This issue arises when markets or other mechanisms to ration resources are absent. Even though each individual act of water use, taken alone, might have a negligible impact, the sum total of many individual decisions can be of major importance. Numerous small decisions become important for policy in groundwater extraction by numerous individual small wells, nonpoint pollution from chemicals carried by runoff from farmers' fields, and sediments arising from forest harvest. Effective public regulation of many small, scattered decisionmakers is exceedingly difficult and expensive, but increasingly necessary.

In sum, we see that the unique characteristics of water make it a truly unusual resource; for numerous physical, economic, social, and political reasons, it presents special challenges to measuring benefits and costs and establishing appropriate institutional arrangements.

1.2 The Role of Economic Valuation in Water Management

> **Water has an economic value in all its competing uses and should be recognized as an economic good**. …Past failure to recognize the economic value of water has led to wasteful and environmentally damaging uses of the resource. Managing water as an economic good is an important way of achieving efficient and equitable use, and of encouraging conservation and protection of water resources.
>
> (United Nations 1992, Principle No. 4)

The Dublin Statement does not, as some have believed, urge that markets be generally adopted for allocation of water. Indeed, as described earlier in this chapter, market failures relating to the services of water (including externalities, public goods such as ecosystem services, and decreasing costs of production) are common enough that markets will be applicable only in a limited number of situations. However, the Dublin Statement can be interpreted as recommending that water allocation policies be analyzed with economic evaluation techniques (benefit–cost analysis; BCA), thus justifying the framework and procedures presented in this book.

Estimates of the value of water provide signals of relative scarcity that are otherwise not available due to the absence of markets. Economically efficient river basin management calls for measures of economic benefits or the monetary value of changes in water availability. A standard example is evaluating investment decisions for capturing, storing, delivering, and treating new water supplies. Marginal values of water are also useful for setting prices that will recover some or all of the costs of the investment in water supply systems. In the face of global warming, having estimates of the economic values of increasingly scarce water resources may be an important step to facilitate economically efficient adaptation (Hurd et al. 2004). Given the increased pressure that climate change puts on water resources keeping estimates of the value of water resources up to date would facilitate the capability to dynamically reallocate water among competing water-using sectors over time.

1.2.1 Investment in Water Supply, Storage, and Conveyance Facilities

Consider a proposed investment in a multi-purpose water project which is being assessed for its economic feasibility. The economic feasibility criterion can be written:

$$PVNB = \Sigma_t[\Sigma_i(B_{it})/(1 + r)^t] - \Sigma_t[(C_{it})/(1 + r)^t] - \Sigma_t[(D_{jt})/(1 + r)^t] \quad (1.1)$$

where:

$PVNB$ = Present value of net benefits;
B_{it} = Incremental Benefit (willingness to pay) for incremental water use or availability in sector i in year t;
C_{it} = Capital and operating costs in sector i in year t;
D_{it} = Incremental project-induced disbenefit (forgone benefits and external costs) to sector i in year t; and
r = The discount (interest) rate.

The economic feasibility hypothesis to be tested is:

Is $PVNB > 0$?

Of course, the test can be also expressed in the alternative, but largely equivalent forms of the benefit–cost ratio or the internal rates of return. See any standard text on BCA, e.g. Boardman et al. 2011 or Campbell and Brown 2003, for further discussion.

In implementing this test, economic valuation (shadow pricing) will normally be required for the terms B_{it} and D_{jt}. and possibly for elements of C_{it}.

1.2.2 Intersectoral Competition for Water

Increased population growth, climate change, and society's changing demands for water (e.g. more emphasis on environmental purposes) will bring about a need to consider reallocation of water from lower- to higher-valued uses. Irrigation of agricultural crops is the largest user of water worldwide, particularly in arid regions, although its value at the margin is relatively low. One source of increasing demands for water is growing needs for offstream uses: residential, industrial, and commercial uses. Demands for instream uses, such as power generation, and water-based ecosystem services such as waste load dilution, recreation, biodiversity, and fish and wildlife habitat, are also increasing. Proposals for major water storage and conveyance projects to meet these demands often confront the reality that the low-cost sites are already utilized. Moreover, increased costs for energy and capital and a rising public recognition of the potential forgone environmental benefits arising from water developments represent additional scarcity considerations. These factors combine to encourage a search for water supplies from existing uses, the marginal economic value of which is less than the cost of developing new supplies.

When a likely economic efficiency improvement opportunity from reallocating water among use sectors arises, the question facing the analyst is: can a reallocation from sector *i* to sector *j* yield incremental gains to sector *j* in excess of the forgone benefits in sector *i*? In applied cases, the hypothesis of suboptimal allocation is tested for specific proposals for reallocation.

Consider a proposal to reallocate water from agriculture to municipal uses. Indirect impacts are expected on the hydropower sector. The economic feasibility test can be expressed by developing measurements for two conditions (Howe and Easter 1971; Young 1986). The first condition is that the benefits (both direct and related sectors) to the municipal (purchasing) sector exceed the sum of forgone direct benefits to the selling sector plus forgone related sectors benefits to the selling sector plus forgone related benefits to the hydropower sector. This can be written (assuming all benefit and cost expressions are in present value terms, employing a consistent planning period and price level):

$$DB_i + RB_k > FDB_j + FRB_k + TPC + CC \tag{1.2}$$

where:

DB_i = Direct economic benefit (value) to receiving sector;
RB_k = Economic benefit to related sector(s), if any;
FDB_j = Forgone direct benefit (value forgone) in source sector;
FRB_k = Forgone benefit in related sector(s);
TPC = Transactions and planning costs (for information, contracting, and enforcement of transfer agreement plus project design costs);
CC = Physical conveyance and storage costs.

A second condition is that the forgone direct benefits in the source sector should be the *least-cost* source of water for the purchasing sector:

$$FDB_j + FRB_k + TPC + CC < AC \tag{1.3}$$

where AC is the cost of the next best alternative water source. This second condition thus asserts that the proposal's costs (the sum of direct and indirect forgone economic benefits and the transactions and conveyance costs) should be less than AC.

Economic analysis of both issues—as well as the other resource allocation and cost recovery problems mentioned previously—require the estimation of marginal or incremental benefits and benefits forgone of changes in water supply or use. The overall task of an intersectoral economic study is to estimate the components of equation 1.2. This book provides the theory and methods to attempting to do so.

1.2.3 The Benefits of Improved Water Quality

In addition to quantity available, the quality of water also influences its economic value. Water in natural environments is never perfectly pure, and natural processes of erosion and transport of plant and animal materials add to the load carried by water. Humans use water bodies as sinks for disposal of numerous wastes from production and consumption activities. The extent to which microorganisms and dissolved or suspended constituents are present varies greatly; in sufficiently high concentrations it can affect health and reduce aesthetic values and productivity. Therefore, the content of pollutants, or conversely the degree to which the water is treated for various uses, is important in determining its economic value.

Estimating benefits of improved water quality raises some complex and challenging policy issues. For the important cases of degradable effluents—those which are transformed after discharge into receiving waters—the detrimental effects depend on the nature of downstream water uses, the distance downstream, the temperature, rates of flow, and the quality of receiving waters. Willingness to pay for a given project or regulatory policy aimed at water quality improvement is usually assumed to reflect the damages avoided by subsequent users. See Spulber and Sabbaghi (1998, Chapter 2) for a rigorous exposition of this type of model.

A related example is the need to measure economic damages from releases of hazardous materials into public water bodies. This issue has increasingly come into prominence in the United States, exemplified by enactment of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980 (see Kopp et al. 1997).

1.2.4 Policies for Alleviating Flood Hazards

Throughout the world, floods damage property, disrupt economic activity, and cause injuries and deaths every year. By some measures, floods cause more damage and deaths to humankind than any other natural hazard (Rodda 1995). Most governments have programs to change flood flow regimes and influence land use behavior by citizens in order to reduce loss of life and property and optimize the use of valuable floodplain lands. The benefit of public floodplain management programs is alleviation of the risk of flooding. Recent research suggests that increases in greenhouse gas emissions is contributing to more intense rainfall (Min et al. 2011) and to increased flood risk (Pall et al. 2011). Thus updating estimates of the economic benefits of flood risk reduction with the increasing greenhouse gas concentrations expected throughout the twenty-first century will increasingly be important to governments trying to optimally managing flood risk.

Benefits of flood alleviation projects typically are measured as the difference between *expected* flood losses with versus without the intervention. The evaluation is, of course, site-specific, depending on both hydrologic conditions and the nature and density of present and prospective future human activity on the floodplain. The principal technique for estimating urban flood risk reduction benefits has been the property damage avoided (PDA) approach, which reflects the present value of real (inflation-free) expected property damages avoided by the project or policy. (See Chapter 8 for a more detailed exposition of the economic model of flood risk reduction.)