Cost–Benefit Analysis and Water Resources Management

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2. Economic criteria for water allocation and valuation

R.A. Young

1. INTRODUCTION

The water resource presents an unusually wide variety of public management issues of interest to economists. In its varied forms, water supplies important benefits to humankind, both commodity benefits (to households, industries and farms) and public environmental values, including recreation, fish and wildlife habitat and a medium for carrying material residuals (pollution) from human production and consumption activities. Moreover, as a resource whose supply is determined by natural forces, too much or too little water creates other public management problems (Young, 1996a). With growth in population and income, serious conflicts over allocations of water are found throughout the world, and in many areas are rapidly becoming worse (Gleick, 1998). Economic evaluation can play a role in public assessments of proposals for addressing water management problems.

Resources have economic value or yield benefits whenever users would willingly pay a price for them rather than do without, that is, whenever resources are scarce.[1] Under certain conditions, market operation results in a set of values (prices) that serve to allocate resources and commodities in a manner consistent with the objectives of producers and consumers. In many parts of the world, the services provided by water have been plentiful enough that the resource could be regarded as a practically free good and, until recently, institutional arrangements for managing water scarcity in such locations have not been of serious concern.

When markets are absent or do not operate effectively (as are typical conditions in the case of water), prices as a basis for allocating resources are biased or non-existent. In such cases, economic evaluations of resource allocation decisions must be based on some non-market methods of estimating resource value. Resource value is measured in the context of a specific objective or set of objectives. The value of the resource reflects its contribution to the objective(s). In the field of water resources, governments have identified several objectives that may be relevant: enhancing economic efficiency (called national economic development in the federal planning literature in the US); enhancing regional economic development; enhancing environmental quality; and enhancing social well-being (US Water Resources Council, 1983; OECD, 1985). This chapter focuses on measuring resource values in the context of the economic efficiency objective.

Estimates of the economic benefits relating to water management are useful for several specific types of allocation issues. Perhaps the most familiar is the contribution to appraising investments on structural approaches to water management. Nations continue to make investments in water resources one of the most important components of public infrastructure budgets. Water-related investments – in irrigation, hydropower, urban and rural water supply, flood control and sanitation – have been designed to contribute to economic development and public welfare. Although most such investments may have been subjected to some sort of economic evaluation to assure that they would represent an economical use of scarce water and capital, many earlier water resource investments have yielded less return than anticipated and have proven to have been based upon overoptimistic pre-project economic evaluations. Among the projects yielding disappointing results, many, it is clear, were evaluated with less than rigorous procedures. Economic evaluation is important because it aids in determining if people want proposed projects and estimating the degree to which they are willing to pay for benefits. In the prevalent situation of constrained public budgets, conceptually correct and empirically valid estimates of the economic contribution of water-related investments are essential for making economically sound public expenditure decisions.

Another class of decisions in which economic values of water are useful is that evaluating non-structural or policy options. For example, as demands for fresh water grow against the finite world supply, estimates of the economic value of water are useful in the context of optimal allocation of water between and among water-using purposes and sectors. Water users will not be able to obtain all of the water they might possibly use. Sharing of the limited supply is a central issue of water management. In the context of water management, decision-makers in many nations face many other questions that invite economic evaluation, such as: how much water should be allocated to the agricultural sector for irrigated food production versus how much to cities with their household and industrial needs? How are needs to develop added food supplies to be balanced with the wish to preserve watercourses or wetlands for fish and wildlife habitat? How are wants for hydroelectric power generation and other in-stream uses to be balanced against demands for water for cities and farms? Each of the above cases are examples of the issue of optimal intersectoral allocation.

Several other non-structural water policy problems for which water valuations are useful come to mind. These include: how much groundwater should be pumped now and how much should be saved for future needs? How much groundwater versus how much surface water should be withdrawn to meet current water demands? And, how much treatment to apply to wastes discharged into watercourses? Considering another dimension – that related to finance and cost recovery – how much can beneficiaries afford to pay for water supplies? For each of these issues, estimates of the net economic contribution of the water resource are important for water policy decisions.

A common theme runs through the above survey of water allocation issues. Each of these are water management problems which involve choices as to how water should be combined with other resources so as to obtain the most public return from scarce resources. Included among the issues are the classic microeconomic resource allocation issues (Varian, 1993): how much of each input to use in production; how to proportion inputs in a production process; which products and how much of each to produce with scarce inputs; which technology to employ; and how to allocate use of resources and consumption of goods and services between the present and future uses. Therefore, these issues can be usefully cast as resource allocation problems and can be best understood within an economic framework.

A truism of applied policy analysis is that 'decisions imply valuation'. Rational decision-making presupposes the forecasting of consequences, and assignment of weights (values) to these consequences. Because of the limited role played by market forces in the allocation of water, market prices upon which to base water-related resource allocation decisions are seldom available. In the jargon of the economist, *shadow prices* reflecting the value of water must be developed in their place.

Economists have in recent decades developed a number of techniques for measuring the economic values or benefits associated with non-market allocation in the subject matter areas relating to the environment and natural resources. These techniques call for a wedding of economic theory and applied economic practice. The theoretical foundations of non-market economic valuation of environmental resources have come to be well developed (see, for example, Freeman, 2003). Applied methods for estimating economic benefits in actual cases relating to environment have been greatly advanced (see, for example, Garrod and Willis, 1999). Valuation techniques for producers' uses of water such as crop irrigation, hydroelectric power and industries, appear to have received relatively less attention (see Gibbons, 1986; and Young, 1996b).

This chapter summarizes the conceptual framework for economic valuation of non-market goods and services as applied to water resources.

It begins by reviewing some of the distinctive attributes that characterize supply and demand for water-related goods and services. Most effort is given to developing the basic concepts and definitions used in measuring economic value or benefits of public water projects or policies. The chapter concludes with a discussion of some issues in valuation relatively important or unique to appraising public decisions regarding the water resource.

2. THE DISTINCTIVE NATURE OF WATER SUPPLY AND DEMAND

A number of special characteristics distinguish water from most other resources or commodities, and pose significant challenges for the design and selection of water allocation and management institutions. On the physical side, water is usually a liquid. This trait makes it mobile: 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. Water supplies tend, due to natural climatic fluctuations, to be variable, so that the risks of shortage and of excess are among the major problems of water management.

Water, due to its physical nature, and for other reasons, 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. Frequently, then, property rights in water are incomplete or, more likely, absent.

Turning to the demand side, humankind obtains many types of values and benefits from water. Because each of the different benefit types usually call for specialized evaluation and management approaches, it will be useful to group the types of water-related economic values into several classes. These are (a) commodity benefits, (b) public and private aesthetic and recreational values, (c) waste assimilation benefits; and (d) disbenefits or damages. Each of these categories clearly involves economic considerations, because they are characterized by increasing scarcity and the associated problems of allocating resources among competing uses to maximize economic value. Whether certain other values associated with water, such as intrinsic values associated with endangered species preservation, ecosystem preservation and certain sociocultural issues of rights to water, can be measured within the economic framework remains a matter of debate. Resolution of that issue is not attempted here.

To consider water demand more closely, note that the economic characteristics of water demand vary across the continuum from *rival* to *non-rival* goods (Randall, 1987). A good or service is said to be *rival* in consumption, if one person's uses in some sense preclude or prevent uses by other individuals or businesses. Goods that are rival in consumption are the types that are amenable to supply and allocation by market or quasi-market processes, and are often called *private* goods. Goods that are *non-rival* in consumption, meaning that one person's use does not preclude enjoyment by others, occupy the opposite end of the continuum. Goods that are non-rival are often called *public* or *collective goods*. Because non-payers cannot be easily excluded, private firms will not find it profitable to supply public goods. Water for agricultural, residential or industrial uses tends toward the rival end, while the aesthetic value of a beautiful lake or stream is non-rival.

The significance of non-rivalry can be better understood by noting its association with high exclusion costs. *Exclusion cost* refers to the resources required to keep those not entitled from using the good or service. Water is frequently a high-exclusion-cost good because of its physical nature noted above: when the service exists for one user, it is difficult to exclude others. In such cases, it is hard to limit the use of the good to those who have helped pay for its costs of production. (The unwillingness of some beneficiaries to pay their share of the provision of a public good from whose benefits they cannot be excluded is called the *free rider* problem. To circumvent the problem, public goods must normally be financed by general taxes rather than by specific user charges.)

The commodity benefits – the first type of benefit mentioned above – are those derived from personal drinking, cooking and sanitation, and those contributing to productive activities on farms and in businesses and industries. What are here called commodity values are distinguished by the fact of being mostly *rival* in use, meaning that one person's use of a unit of water necessarily precludes use by others of that unit. Commodity uses tend to be private goods or services.

Continuing with the discussion of commodity-type uses, some additional distinctions will be helpful. Those types of human uses of water, which normally take place away from the natural hydrologic system, may also be called *withdrawal* (or *off-stream*) uses. Since withdrawal uses typically involve at least partial depletion or consumption (for example, from evaporation and/or transpiration), they may further be 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 labelled *in-stream* water uses: hydroelectric power generation and waterways transportation being important examples. Since in-stream uses often involve little or no physical loss, they are also sometimes called *non-consumptive* uses. (Although in-stream uses do not 'consume' much water, in the sense of evaporating it into the atmosphere, they do often require a change in the time and/or place of availability – as are the cases with water stored for future use for irrigation or hydropower generation – and therefore exhibit some aspects of the rivalry of a private good.)

The economic benefits from water for recreation, aesthetics, and fish and wildlife habitat are a second group or type of value of water. Benefits in this class are also closer to the non-rival end of the spectrum. Although aesthetics and recreation were sometimes viewed as non-essential goods inappropriate for public concern, as incomes and leisure time grow, these types of benefits are increasingly important. In developed countries, the populace increasingly chooses to utilize water bodies for outdoor recreational activities. Even in developing nations, water-based recreational activities are becoming more important for their own citizens, and also often provide a basis for attracting the tourist trade. As with waste assimilation, recreational and aesthetic values are also nearer the public good end of the spectrum. Enjoyment of an attractive water body does not necessarily deny similar enjoyment to others. (However, congestion at uniquely attractive sites, such as waterfalls or mountain lakes, may adversely affect total enjoyment of the resource.) Significant in-stream values also are found as habitat for wildlife and fish forms a basis for sporting activities.

The economic benefit from waste disposal is a third general class of economic benefits of water use. Bodies of water are considered as a sink for carrying away a wide range of residuals from processes of human production and consumption. Water resources are used for disposal of wastes, diluting them and, for some substances, aid in processing wastes into a less undesirable form. They are therefore significant for what is called their 'assimilative capacity'. The assimilative capacity of water is closer to being a public or collective (rather than private) value, because of the difficulty in excluding dischargers from utilizing these services.

Dis-values (also called damages or negative benefits) of water represent an important related classification. Examples are found in connection with evaluations of floodplain and water quality management. Flood waters or excesses of pollutants reduce welfare. Conversely, reduction of disbenefits increases human welfare. In such cases, mitigation policies may be assessed by valuing the projected reductions in damages.

Non-use values are also an important consideration in water allocation, and for the economic valuation of water. It is observed, in addition to valuing the commodity benefits of water use, that people are willing to pay for environmental services they might neither use nor experience. Non-use values are benefits received from knowing that a good exists, even though the individual may not ever directly experience the good. Voluntary contributions toward preserving an endangered fish species represent an example. Most resource economists have concluded that non-use values should be

added to use values so as to more accurately measure total environmental values (Freeman, 2003).

Because of differing conceptual frameworks, an additional useful distinction is between intermediate goods and final consumption goods. *Intermediate* goods (also called *producers'* goods) are employed to make *final* products (to be eventually used by consumers). Intermediate goods represent the largest class of off-stream uses of water by humankind. For example, water for crop irrigation, the largest single consumptive user of water in the world, is an intermediate good; cotton or maize grown under irrigated conditions are destined eventually to be further processed to become clothing or food. Industrial processing and hydroelectric power generation are other intermediate uses of water. *Consumption* goods are those providing direct human satisfactions. Residential water is an example of a final consumption good from the private (rival) good classification, while recreation and amenity services provide non-rival final consumption values. The importance of this distinction between intermediate and consumer goods is that the economic theory of a profit-maximizing producer provides the conceptual framework for the valuation of intermediate goods, while the theory of the individual consumer is the basis for valuing consumer goods.

Yet another useful distinction is between *real* and *pecuniary* economic effects. Real effects are actual changes in quantities of goods and services available, or changes in the amount of resources used. Real effects are positive or negative changes in welfare. Real effects are further subdivided into direct and indirect effects. *Direct* economic effects of water projects or policies are those which accrue to the intended beneficiaries; those that can be captured, priced or sold by the project entity, or – in the case of costs – which must be paid for. *Indirect* or *external* effects are those uncompensated side effects affecting third parties. Economists classify external effects as either technological or pecuniary. Technological externalities are real changes in production or consumption opportunities available to third parties, and generally involve some physical or technical linkage among the parties (such as with degraded water quality). This type of externality represents a change in welfare, and should be reflected in evaluation of the economic efficiency effects of policies or projects. *Pecuniary* impacts (often referred to as secondary economic impacts in the water planning literature) are those reflected in changes in incomes or prices (such as effected by increased purchases of goods and services in a regional economy). Secondary economic impacts typically represent income distribution impacts. From the larger perspective of nation or state, secondary impacts registered on a specific locality are likely to be offset by similar, but more difficult to isolate, effects on income of opposite sign elsewhere.

Economic convention therefore suggests that secondary impacts not be taken into account in economic evaluations, or only in special cases (see, for example, Boardman, et al., 2001, p. 114).

3. ECONOMIC VALUE VERSUS OTHER CONCEPTS OF VALUE

The economic approach is not the only way to assign values to natural and environmental resources. Broadly speaking, values can be termed *extrinsic* or *intrinsic*, both of which are relevant for water and environmental policy. The distinction rests on whether the basis for valuation derives from consequences for human welfare. Extrinsic (sometimes also called *instrumental*) values are those that arise because things or acts are instruments for humankind for attaining other things of intrinsic value. As an example, water resources may be valued (instrumentally) for their contribution to human health, welfare or satisfactions. Intrinsic values, in contrast, are assigned to things, actions or outcomes for their own sake, independent of means of providing or attaining other items or situations of value for humans (Anderson, 1993, pp. 204–6). For example, people often value environmental resources in ways other than from their use or consumption by humans; the public wishes to preserve endangered species or protect delicate ecosystems, without consideration of whether these offer immediate human utility.

It is important to recognize that both approaches to valuation are legitimately applied to environmental and resource policy (Pearce, 1993, pp. 13–15). However, the prevailing – although not unanimous view of philosophers – is that neither extrinsic nor intrinsic values are necessarily absolute. When values conflict, as they often do, a dilemma arises. In such cases, the only apparent solution is to make a practical judgement of how to compromise the competing goals (Maclean, 1993). Morgan and Henrion (1990, p. 27) describe a widely used method, called the *approved process* approach, which, roughly speaking, requires all relevant parties to observe a specified set of procedures or observe a concept of due process to estimate a policy's impacts on relevant measures of value. Any decision reached after an appropriate authority balances the competing values under the specified procedures is deemed acceptable. Standard water planning manuals (both the US Water Resources Council's *Principles and Guidelines*, 1983, and the Organisation for Economic Co-operation and Development's (OECD's) *Management of Water Projects*, 1985 – although neither acknowledge the underlying philosophical premises – appear to reflect an approved process approach. Both manuals call for a determination of environmental impacts (intrinsic values) to be balanced against human (economic and social) welfare (extrinsic value) considerations. Both manuals emphasize the display of impacts; the ultimate resolution or balancing of conflicting values is assumed to take place at the political, rather than the technocratic level.

The economic values discussed in this chapter are extrinsic (instrumental), in that they reflect people's assessment of a policy proposal's contributions or decrements to human welfare. These economic benefits will be appropriate to either a stand-alone economic analysis or as part of a more general multi-objective or approved process approach.

4. ECONOMIC CRITERIA FOR RESOURCE ALLOCATION AND VALUATION

Although the objectives of improving the distribution of income, enhancing environmental quality and attaining other non-market goals are important, the analysis here pertains exclusively to the objective of economic efficiency in the development and allocation of the water resource. There are two major reasons for this: first, under conditions of increasing scarcity and growing competition among water users, economic efficiency remains an important social objective and efficiency values have viable meaning in resolving conflicts; second, efficiency values provide a valuable means of assessing the opportunity costs of pursuing alternative objectives.

4.1 The Pareto Principle and Economic Efficiency

Economic efficiency may be defined as an organization of production and consumption such that all unambiguous possibilities for increasing economic well-being have been exhausted. Stated somewhat differently, economic efficiency is an allocation of resources such that no further reallocation is possible that would provide gains in production or consumer satisfaction to some firms or individuals without simultaneously imposing losses on others. This definition of economic efficiency (termed Pareto optimality) is satisfied in a perfectly functioning competitive economy. Abstracting from the mathematical elegance found in textbook expositions (for example, Just et al., 1982) and abstracting further from the time consideration in outputs and inputs of economic activities, Pareto optimality can be expressed quite simply in terms of the attainment of: (1) economic efficiency in production of goods and services; (2) economic efficiency in distribution of goods and services; and (3) resource allocation in a manner consistent with consumer preferences. Pareto efficiency is said to occur when the marginal benefits of using a good or service are equal to the marginal cost of supplying the good.

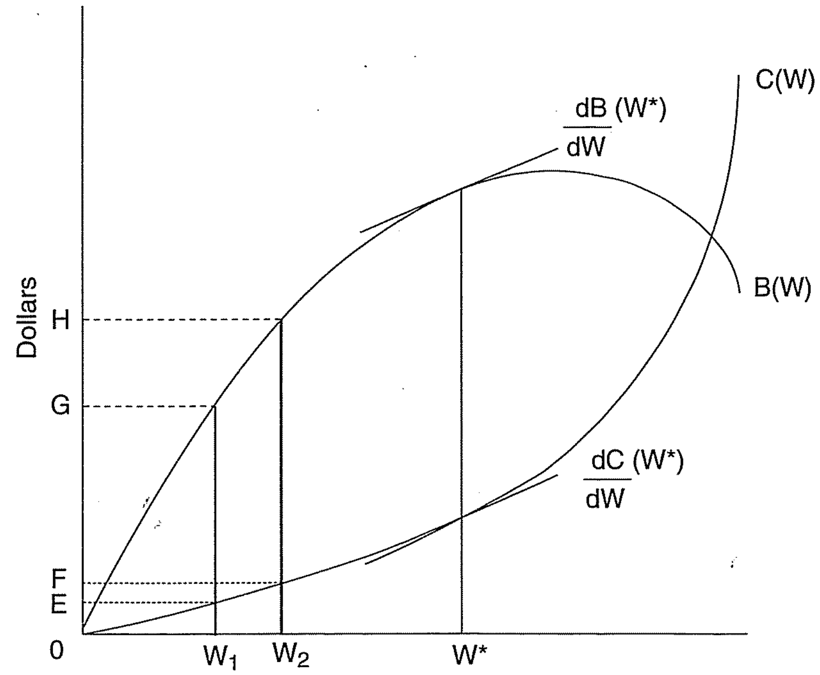
Pareto optimality rests on several central value judgements (Mäler, 1985). The first of these is the judgement that individual preferences count; the economic welfare of society is based on the economic welfare of its individual citizens. Second, the individual is the best judge of his/her own well-being. The third, highly restrictive, value judgement is that a change that makes at least one person better off while no one else becomes worse off constitutes a positive change in total welfare.

4.2 From Theory to Practice

Translating from the welfare economics theory to benefit–cost practice requires further steps. Because in a complex modern society, few policy changes that improve welfare for many would avoid lowering welfare of some individuals, few proposed changes would meet the strict Paretian standard of making no one worse off. However, welfare theorists circumvented this problem with the *compensation test*: if gainers could compensate losers and still be better off, the change would be judged an improvement. In practice, compensation is often impracticable; identifying and compensating all adversely affected parties is expensive and time-consuming. Hence, the compensation test becomes a test for a *Potential* Pareto Improvement (PPI). If gainers could *in principle* compensate losers, the change is deemed acceptable, whether or not the compensation actually takes place. Also, rather than evaluating all possible allocations in a continuous function framework, benefit–cost analysis typically examines fairly large discrete increments of change to assess whether the move is in the direction of Pareto efficiency. An action that generates incremental benefits in excess of incremental costs is termed Pareto-*superior*, because it leads to a condition superior to the *status quo ante*.

Following Smith (1986), Figure 2.1 illustrates the comparison of Pareto-efficiency and benefit–cost criteria. The curve denoted B(W) is a representation of aggregate benefits (that is, consumer or producer surplus) of alternative levels of water services (W), while C(W) represents the associated aggregate costs. These curves measure social welfare or aggregate utility and cost. Their general forms reflect the conventional assumption that benefits increase at a decreasing rate with increased output and costs increase at an increasing rate. The Pareto-efficient solution is at W* – the maximum vertical distance between B(W) and C(W). At W* the marginal benefits equal the marginal costs.

However, rather than seeking a full optimum solution, benefit–cost analysis (CBA) in practice typically considers whether a change from given



Source: After Smith (1986).

Figure 2.1 Comparison of Pareto-efficiency and benefit–cost criteria

conditions would represent a desirable shift. In Figure 2.1, such a change is represented by moving from W_1 to W_2. The conventional CBA test compares the aggregate increment in benefits (GH in Figure 2.1) with aggregate incremental costs (EF). If incremental benefits exceed incremental costs, as they are drawn to do in Figure 2.1, then the change is termed a Pareto *improvement*. Any act or policy judged a Pareto improvement would be recommended as preferable to the existing situation.

5. ECONOMIC VALUATION IN THE ABSENCE OF MARKET PRICES

Water management policies can have widespread effects on the quantity of water available, its quality, and the timing and location of supplies for both in- and off-stream uses. In general, these impacts have an economic dimension, either positive or negative, which must be taken into account in policy formation. Specifically, the decision process (resolution of conflicts) requires the identification and comparison of the benefits and costs of water resource development and allocation among alternative and competing uses.

Beneficial and adverse impacts to people are abstract and often ambiguous concepts. As noted earlier, mainstream economists treat values as extrinsic, and propose to measure impacts in terms of satisfaction of human preferences. To transform the concept of welfare into a single metric, the suggested measuring rod is that of money (Rhoads, 1985). A person's welfare change from some proposed improvement is measured as the maximum amount of money a person would be willing to forgo to obtain the improvement. Conversely, for a change that reduces welfare, the measure is the amount of compensation required to accept the change.

The economic evaluation of projects or proposals is based on balancing the predicted beneficial against the adverse effects generated by the proposal. *Benefits* are the 'good' or 'desired' effects contributed by the proposal, while *costs* are the 'bad' or 'undesired' impacts. This balancing of costs against benefits is called *cost–benefit analysis* (CBA). (For detailed treatment of the overall approach to CBA – particularly as applied to environmental and natural resource problems – the reader is referred to the extensive literature in that field, for example, Boardman et al., 2001; Dinwiddy and Teal, 1996; Johansson, 1993; Pearce, 1987; Zerbe and Dively, 1994.)

In applied CBA, the terms benefit and cost are assigned a narrow technical economic interpretation. The prices used in CBA are interpreted as expressions of *willingness to pay* (WTP) for a particular good or service by individual consumers, producers or units of government. Direct benefits are willingness of beneficiaries to pay for project services or policy impacts. Direct costs are willingness to pay for the forgone alternatives, or to avoid any adverse effects. In what follows, changes in producer surplus and consumer surplus, respectively, are accepted as the pertinent measures of willingness to pay or to accept compensation.

5.1 The Need for Shadow Prices

Howe (1971) has classified policy impacts into four categories that are paraphrased below:

1. Impacts for which market prices exist and market prices reflect scarcity values.
2. Impacts for which market prices may be observed, but such prices fail to accurately reflect true social values, but they can be adjusted to more accurately do so.

3. Impacts for which market prices do not exist, but it is possible to identify surrogate market prices.
4. Impacts for which market prices or surrogate prices are not meaningful.

The second and third cases are most typical in benefit–cost analysis for water resource planning; in these instances the prices employed (adjusted or estimated prices) are called *shadow prices* (or sometimes *accounting prices*).

Benefits and costs must be expressed in monetary terms by applying the appropriate prices to each physical unit of input and product. Three types of estimates are employed. Primary sources of the prices used for CBA are the result of observing the market activities. However, in the second type (often the case in water planning) it is necessary to make adjustments to observed market prices (for example, when agricultural commodity prices are controlled by government regulation or when minimum wage rates are set above market clearing prices). Finally, in many cases, it will be necessary to estimate prices that do not exist at all in any market (such as the value of water used for wetland preservation).

5.2 Defining Shadow Prices: The Willingness to Pay Principle

Whatever the source, the prices used in CBA are interpreted as expressions of *willingness to pay* or *willingness to accept compensation* for a particular good or service by individual consumers, producers or units of government. This presumption is obvious for market prices, since the equilibrium market price represents the willingness to pay at the margin of potential buyers of the good or service. For non-marketed goods, WTP also is the theoretical basis on which shadow prices are calculated. The assertion that willingness to pay should be the measure of value or cost follows from the principle that public policy should be based on the aggregation of individual preferences. Willingness to pay represents the total value of an increment of project output, that is, the demand for that output.[2] Willingness to accept compensation (WAC) is an important welfare measure in some contexts. Willingness to accept compensation is the payment that would make an individual indifferent between having an improvement and forgoing the improvement while receiving the extra money. Alternatively, it is the minimum sum that an individual would require to forgo a change that otherwise would be experienced. (Applied measurements of WTP and WTAC under the same conditions often find that estimates are not equal, in apparent conflict with economic theory. Various plausible explanations have been offered, both by economists and psychologists, but the issue seems to be unresolved. See Freeman, 2003, for further discussion.)

Therefore, *benefits* are defined as any positive effect, material or otherwise, for which identifiable impacted parties are willing to pay. *Costs* are the value of the opportunities forgone because of the commitment of resources to a project, or the willingness to pay to avoid detrimental effects. (Critics of certain applications of CBA from within the ranks of economists, observing that WTP is dependent on the existing distribution of income, properly caution against any unquestioning application of the technique for public investment decisions. However, few water policy initiatives would change the distribution of income enough to cause significant shifts in willingness to pay for benefits.)

5.3 Economic Surplus and Measures of Benefit

Economists base the concept of economic value on a decision framework within which rational individuals make the best use of resources and opportunities. The framework assumes that the individual members of the economy react systematically to perceived changes in their situation. Such changes can include – in addition to the quantity and quality of the water resource of primary interest here – prices, costs, institutional constraints and incentives, income and wealth.

Figure 2.2 illustrates the concepts of economic (producer's or consumer's) surplus under marketed commodity conditions. The curve denoted MBw in Figure 2.2 is a familiar demand curve, reflecting the maximum amount of the commodity W that consumers would be willing to take at alternative price levels. The demand curve slopes downward to the right, reflecting the desire for consumers to take more of the commodity W only as the price declines. The inverse demand curve (in which quantity is the independent variable and value is the dependent variable) can also be interpreted as the marginal willingness to pay for alternative quantities, so it is conventionally labelled in cost–benefit analysis, as in Figure 2.2, a *marginal benefit* (MB) function. *Consumer's surplus* is defined as the area above the price: it represents the difference between the maximum users would be willing to pay and what they would actually pay under a constant price per unit. The supply curves S_1 and S_2 represent a non-marginal shift in supply functions, such as from a project that increases the supply of some productive factor, such as water for crop irrigation.

Consumers enjoy two forms of gain: a decrease in unit price from P_1 to P_2 and an increase in available output (from W_1 to W_2). Producers also see a gain, from expanded output, but their price goes down. The area in Figure 2.2 circumscribed by the points P_1ABP_2 represents the gain in surplus enjoyed by consumers. With the change from W_1 to W_2, producer

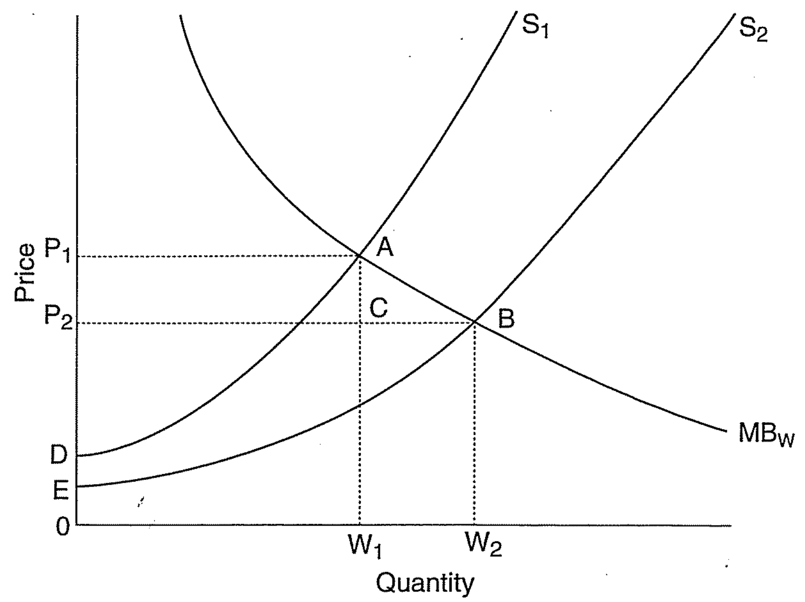


Figure 2.2 Price and quantity effects and change in economic surplus from non-marginal shift in supply of water

surplus changes from P_1AD to P_2BE. The net increase in economic surplus, the sum of gains and losses to producers and consumers, is DABE.

The economist reading the above paragraphs will note that the measures shown are for the ordinary *Marshallian* concept of demand and consumer surplus. More precise welfare measures, called Hicksian measures, are often reported in the applied welfare economics literature (Just et al., 1982). The Hicksian *compensating* version refers to the amount of compensation (received or paid) that would return the individual to his/her initial welfare position. The *equivalent* version refers to the amount of money that must be paid to the consumer to make him/her as well off as they could have been after the change. Whether to aim for the Hicksian formulation depends on the individual case. Marshallian demand functions are sometimes easier to estimate. Moreover, when purchases of the good or service in question accounts for only a small part of the household budget, it has been shown that the Marshallian measure is often a quite close approximation to the Hicksian measure. (See Freeman, 2003, for a more complete analysis.) For the case of water resources, which for the most part makes up a small fraction of consumers' budgets, the differences among the measures are probably smaller than the errors that occur in econometric estimation of the functions, so the Marshallian approximation will usually be acceptable in practical applications.

Figure 2.3 portrays a case frequently applicable to non-market valuation applied to water resources (Randall, 1987, ch. 13). It represents an increase in the availability of a non-priced water use from W_1 to W_2. Perfectly inelastic supply curves S_1 and S_2 shift from W_1 to W_2. The curve MB_w, as before, shows the downward sloping marginal benefit function. The area under MB_w between W_1 ('without change') and W_2 ('with change') represents the economic surplus attributable to the changed water supply. This area is that bounded by the points W_1ABW_2. It is this area that the economic analyst is attempting to measure in non-market valuation of changes in water and environmental amenities.

Note that the curve MB_w can, in addition to representing consumer demand, also portray the demand from producers. In the latter interpretation, MB_w is the producers' marginal value product (MVP) function, the marginal net return to increasing level of input. (See Johannson, 1993, s. 5.1, for a formal derivation of these properties of producers' welfare.) This

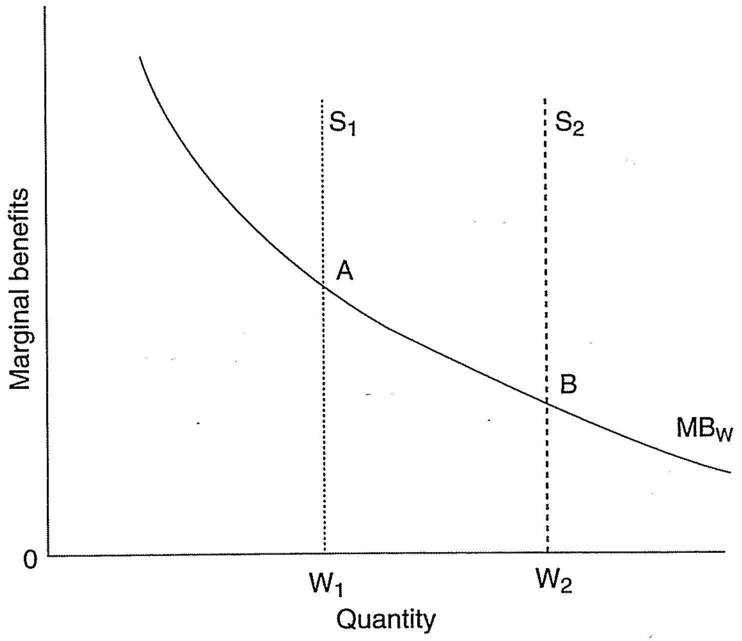


Figure 2.3 Change in economic surplus from non-marginal change in water supply

interpretation is, in fact, more applicable to valuation purposes than the producer's surplus depicted in Figure 2.2 (that is, the area above the supply curve S and below the price line). Also, in parallel with the Hicksian adjustment for income effects to consumer surplus measures, a corresponding adjustment for cost-minimizing allocation of other inputs or technology is appropriate for producer surplus measures (Johannson, 1993).

To recapitulate, the economic value of a non-marketed resource is measured by the summation of many users' willingness to pay for the good or service in question. Willingness to pay is a monetary measure of the intensity of individual *preferences*. Therefore, we can say that *economic valuation is the process of expressing preferences for beneficial effects or preferences against adverse effects of policy initiatives in a money metric.*

5.4 Opportunity Costs: Measuring Forgone Benefits of Reduced Water Use

Increasingly of interest are measures of opportunity costs of water resources. Opportunity costs are the benefits forgone when a scarce resource is used for one purpose instead of the next best alternative. When evaluating trade-offs of proposed reallocations, one needs a measure of the benefits of the proposed new use as well as the reduction of benefits associated with reduced water use in the sector currently benefiting. Hence, opportunity costs are conceptualized as the reverse of incremental benefits. Returning to Figure 2.3, a measure of opportunity costs would be the area under MB_w from, this time, W_2 to W_1. This is the same area as described before; in Figure 2.3 that bounded by the points W_1ABW_2. (Randall, 1987, Figure 13.5 conceptualizes this point more elegantly in a framework jointly accounting for increments or decrements of natural resource use.)

6. OTHER CONCEPTS USEFUL FOR APPLIED ECONOMIC EVALUATIONS RELATING TO WATER

A number of additional concepts are important for applied economic evaluation in water resource management. *The general point is that there is no single economic value of water. What is being measured is the welfare change associated with some policy-induced change in the attributes of the commodity*. It is important to keep clear what are the specific attributes of the situation and decision in question. A number of these issues are discussed in this section.

6.1 The With–Without Principle

The *with–without* principle holds that policy appraisal should contrast the 'state of the world' as it would be with the policy to the 'state of the world' as it would be without the policy. An important implication of the principle is that project evaluation is not adequately accomplished by comparing conditions before the project with conditions after its implementation. Many changes in the world from 'before' to 'after' would have occurred without the project, so such effects should not be credited or charged to the project.

The with–without principle directs the analyst to measure the impacts according to the status of the economy with the public intervention as compared to without the intervention. The intent is to identify only the impacts that are clearly associated with the project or programme, and not include as impacts any changes in the economy that would have occurred even without the project. Therefore, regional growth that would be due to private sector investment, or to other public projects should not be included in project impact measures. Project evaluations that measure impacts by comparing *before* with *after* the intervention are likely to overstate project impacts.

6.2 Accounting Stance

The *accounting stance* is defined here as *how* benefits, costs or other impacts are priced or counted in a cost–benefit analysis. The primary distinction is between *private* and *social* accounting perspectives, which differ as to how benefits and costs are measured. The private accounting stance measures impacts in terms of the prices faced by the economic actors being studied. In contrast, the social accounting stance draws on social prices (adjusted or shadow-priced so as to account for taxes, subsidies or other public interventions). The distinction between private and social accounting stances has seen most application in the case of agricultural water use, since many nations intervene in both commodity or input markets relating to agriculture. However, the analyst performing a social analysis may wish to use shadow prices for inputs such as labour, energy or capital in other contexts.

Although the terms *financial analysis* and *economic analysis* are used for the same distinction in some CBA manuals, particularly those from the World Bank (for example, Gittinger 1982), that terminology is avoided here. This is because these terms seem to me to be ambiguous and quite confusing to non-specialists, economists and non-economists alike. The methods termed financial analysis and economic analysis both employ

the same basic economic techniques. The main difference is that they use different prices. Hence, the terminological distinction between private and social prices seems to capture the essential point.

6.3 Scope

Although this terminology is not in general use, the *scope* of a cost–benefit analysis is defined here as the geographical area or political entity or subdivision within which benefits, costs or other impacts are counted. A project or policy may have impacts that are confined to a local area, or they may extend to the nation or even internationally. For example, the economic benefits of an irrigation project may be confined to a local area. Some of the conventional direct costs of construction and operation might be met by water users (or taxpayers) in the project area, but part of the cost might be provided by the national government, so impacts would spread nationwide. Other costs, particularly indirect or external costs, such as forgone electric power generation or lower water quality imposed on downstream water users, will accrue well beyond the borders of the area benefited, but need to be accounted for in a full economic evaluation. Indirect benefits outside the project region can also occur. For example, interception of flood waters by irrigation or power reservoirs may yield benefits far downstream. Thus, both benefits and costs could extend well beyond the geographic area where direct benefits occur.

Ideally, the scope should be as encompassing as possible; real impacts should be accounted for no matter how far away or in what political jurisdiction they may occur. For example, indirect costs of water projects in upstream regions adversely affecting downstream neighbours (such as the forgone costs of depleting water) or indirect benefits (such as by intercepting flood waters) should be assessed. However, in practice, the choice of scope must be made on pragmatic grounds, balancing the gains in accuracy against the increased costs of spreading a wider net. Most national planning agencies suggest a national scope wherever possible, but in practice, few analyses give consideration to interests in downstream states or nations.

6.4 Long-run versus Short-run Values

Because policy decisions relating to water entail a range of cases, from major long-lived capital investments to one-off allocations in the face of immediate events such as droughts, it is often important to distinguish carefully between long-run and short-run values. The distinction relates to the degree of fixity of certain inputs, and is particularly important for cases in which water is a producers' or intermediate good, such as in irrigation, industry and hydropower.

A rational producer's willingness to pay for water will be based on net rents or returns to the input. In the short run, where some inputs are fixed, the estimate of the net increase in the value of output can ignore as sunk the cost of the fixed inputs. In the long run, where input costs must all be covered, these costs cannot be ignored. Therefore, we would expect that for the same site and production processes, values estimated for short-run contexts would be larger than values for the long run. Similarly, domestic water users exhibit different responses in the short versus the long run. Price elasticity of demand is less (in absolute value) in the short run when decisions are constrained, than in the longer-run decision context, when adjustments to shortages are possible. Accordingly, willingness to pay in the short-run planning situation is typically higher than in the long-run case.

However, most public water policy decisions involve situations where the long-run context is appropriate. Failure to observe this distinction has caused many non-specialists to erroneously use short-run measures for long-run decision contexts, thereby attributing too high a value to water uses. However, important cases occur – such as drought planning – where short-run values are appropriate.

6.5 Appropriate Measure of Water 'Use'

To assign an economic value to water, one must express it as a monetary value per unit water volume or quantity used. To the frequent confusion of non-specialists, several measures of water use are commonly found in the technical water literature. Moreover, at least one of the hydrologic terms for water use is the same word, but with a narrower meaning as that often adopted by economists. The need for different measures arises because, first, some water is typically lost between the water source and the water user, and second, because some additional amount of the water taken by the user is returned to the hydrologic system, where it sometimes is available to produce further human benefit.

Three measures of water use are possible candidates in an economic valuation. These are: *withdrawal*, *delivery* and *depletion*. Withdrawal refers to an amount of water diverted from a surface source or removed from a groundwater source for human use. Delivery is the amount of water received at the point of use (home, farm or factory). Withdrawal differs from delivery by the amount of *conveyance losses* to the point of use. That is, withdrawal minus conveyance loss equals delivery. (Conveyance losses are typically significant in water delivery systems. Losses of up to 30 per cent are not

unusual in agricultural delivery systems, many of which often are of simple earthen construction and not sealed with impervious materials. Although urban water delivery systems are usually more efficient, losses of this magnitude or even higher may also be found in domestic water supply systems in developing countries. (See Nickum and Easter, 1994.) Depletion (often termed *consumptive use* or simply *consumption* by hydrologists) is a measure of water use referring to that portion of water withdrawn from a source that is made unusable for further use in the same basin. Depletion or consumptive use mainly occurs via evaporation and transpiration, but also may be due to contamination or drainage to a saline sink. Those who are not specialists in hydrology tend to use 'consumption' broadly as a synonym for 'use', so the term 'depletion' is suggested for the technical concept.

Next, almost all off-stream human uses of water *release* some water back to the hydrologic system. In urban settings, this may take the form of sewage discharges. In agriculture, a considerable amount of water is typically lost as drainage water, either through seepage into a groundwater system or overland flow via drainage ditches. *Return flow* in the technical water literature is a measure of that portion of water withdrawals which returns to the hydrologic system still usable for human purposes. Return flows comprise both conveyance losses and releases back to the hydrologic system. Thus, withdrawal minus return flow equals depletion.

The choice of withdrawal, delivery or depletion as the measure of water use will depend on the purposes at hand. For valuing off-stream uses, the quantity variable most often used is the amount *delivered* to the user. Alternatively, the measure may be the amount depleted. Economic values per volume of water will likely differ greatly, depending upon which measure is chosen. For the economist interested in predicting user behaviour in response to changing prices or entitlements, the delivery measure is often more appropriate, because that is the measure upon which water users base their allocation decisions. Hence, willingness to pay is usually conceptualized as of the point the firm or household receives the water. However, for river basin planning exercises, the net amount of water depleted in a particular use is the relevant measure, since that is the amount not available for further use downstream. Where necessary to consider quantities depleted, valuation can be made in terms of deliveries and adjustments to express benefits per unit depleted can be subsequently made.

Turning to non-depleting or in-stream uses, none of the above variables are precisely relevant. One must take any change in form, timing or location as a measure of water use. In the case of evaluating in-stream versus off-stream uses, incorporating a hydrologic model that can adjust for all these interdependent factors becomes an important aid.

6.6 Commensurability of Place, Form and Time: At-site versus At-source Values

Marketed economic commodities are priced according to spatial, quality and temporal attributes, and shadow pricing of water should follow similar rules. For example, another economically important liquid, petroleum, is always priced in terms of grade, location and date of delivery. A look at a daily newspaper's business pages reveals that prices for crude oil at the point of production are less than the cost per unit volume of refined gasoline (petrol) in bulk at some specified distribution point, which is in turn much lower than the price of gasoline at the local retail station. These considerations lead to a need for analysts engaged in comparative water valuation exercises to be careful to assure that the chosen measure of water value is *commensurable* in terms of a common denominator of place, form and time.

Water falls among the commodities which economists call 'bulky.' This means that the economic value per unit weight or volume of water tends to be relatively low. (For example, retail prices for water delivered to households are typically in the range of US0.0005–0.0008 per litre or about US$1.0 to $1.5 per ton, much less than other liquids important in contemporary life, such as petrol (gasoline), milk, soft drinks or beer. In crop irrigation, much of the water applied may yield direct economic values – profit net of costs of other inputs – of less than US$0.04 per ton.) Bulky commodities tend to exhibit high costs of transportation per unit volume, so that costs of transporting them become an increasingly important part of the total cost of supply. In the case of water, this point implies that water values are often highly site-specific.

Consider now the aspects of location and form. Because of its low value at the margin, capital and energy costs for transportation, lifting and storage tend often to be high relative to economic value at the point of use. Therefore, water at different locations may have widely differing values, and moving the commodity from one place to another frequently may become uneconomical due to conveyance costs. Thus it may be important to distinguish between *at-site* and *at-source* values, a consideration inadequately recognized in the water valuation literature. As the terms indicate, at-site values represent willingness to pay at the point of use or delivery, while at-source values measure willingness to pay at some point in the hydrologic system where water is withdrawn. At-source values are derived values that are sometimes called values for 'raw' or 'untreated' water. At-site values differ from (exceed) at-source values by whatever costs are required to transport, store, treat, and deliver the water from source to site. By convention in water supply project evaluations (but not by necessity) water supplies for off-stream uses are usually valued in at-site terms, and the storage and delivery costs are included in the total costs of providing water to users. In contrast, evaluations of intersectoral water allocations should use at-source values for each sector, so that the comparisons among sectors – be they producers' or consumers' uses and off-stream or in-stream – are in commensurate terms. Water in its raw (untreated) form in a river – or even in a reservoir or canal – is a distinctly different commodity than water delivered (perhaps after treatment and under pressure) to a farm, business or residence, and comparisons of value in alternative uses must recognize that point. Comparing values among uses is best performed with the comparisons made in terms of raw water supplies at some specified point of diversion. (Booker and Young, 1994, represents an early example of a class of combined hydrologic-economic models in which demands are initially expressed in at-site terms and which account for return flows and delivery costs so that in the final analysis both economic and hydrologic variables are expressed in at-source terms.)

Also, because of the variations in demand over the seasons of the year, the value will – other factors being equal – change with time. In many places, water has little value for irrigation in winter, but it may be quite useful at that time for power generation or industry.

7. SPECIFIC CASES OF ECONOMIC EVALUATION OF WATER RESOURCES ISSUES

In a river basin management context, the principal opportunities for economic welfare enhancement, and hence the need for measures of water value, are, first, investments in capturing, storing, delivering and treating new water supplies and, second, reallocation among water-using sectors. Other examples where marginal values of water might be useful include: optimal groundwater basin policy (for example, Provencher and Burt, 1994; Young, 1992) and pricing and cost recovery for investments in water supply systems. Of most interest are the cases of investment and reallocation decisions, discussed below in more detail.

7.1 Evaluating Investments in Additional Water Supplies

Consider now a simple framework (Equation 2.1) that shows the conditions for economic feasibility of a potential investment in water supply from the point of view of the private investor. All benefit and cost elements in the models presented below are assumed to be expressed in annual equivalent terms, employing a consistent interest rate and planning period and reflecting the same general price level.

$$DB_p > DC_p \tag{2.1}$$

where the symbols represent the following concepts: the subscript p denotes the private perspective; DB_p is direct private user benefit (willingness to pay for the initiative) and DC_p is the direct private cost. Direct benefit reflects the economic value of the physical increment in production due the increment in water supply. Direct costs are the costs of bringing the water supply to the user. Equation 2.1 asserts simply that the contemplated investment is economically feasible if, from the private investor's perspective, direct benefits exceed direct costs. The private investor is assumed to ignore any uncompensated indirect benefits or costs received by or imposed on third parties.

Turning next to evaluation of the impacts of an investment from the public or social accounting stance and national scope, three types of adjustments and additions should be made to Equation 2.1. First, benefits and costs are adjusted for subsidies or other government-induced market distortions. For example, crops produced with the aid of government support programmes – such as cotton or rice in the southwestern United States – would be valued at lower price levels, derived from estimated free market prices (which task is a challenge itself). Costs would similarly be adjusted for public subsidies (such as low-cost credit or energy) or penalties (for example, minimum wage regulations). On balance, these adjustments usually make the social net benefit of added water less than the private net benefit.

The terms new in Equation 2.2 are IB, representing indirect (real external) benefits, SB denoting secondary (pecuniary external) benefits, IC standing for real external costs and SC denoting secondary external costs. The other adjustments needed for a shift to the public accounting stance are to incorporate monetary estimates of any external effects, both real and pecuniary. These steps are represented in Equation 2.2, in which direct benefits and costs are expressed in social prices (adjusted for market price distortions, denoted by introducing a subscript s) and external impacts (both real and pecuniary) are incorporated in the formula. The Potential Pareto Improvement (PPI) hypothesis to be tested is:

$$\text{Is } (DB_s + IB + SB) > (DC_s + IC + SC)? \tag{2.2}$$

In words, is the sum of the present values of direct, indirect and secondary benefits greater than the sum of present values of direct, indirect and secondary costs?

Secondary benefits, the multiplier effects arising from increased purchases of production inputs and consumption goods when a project comes into operation, are typically concentrated in the project region. Secondary benefits are normally measured with specialized economic techniques (such as regional interindustry models). Regional models of this type simulate the effects of an increment of resources on the regional economy. Secondary costs (SC) are the pecuniary benefits forgone when a public investment draws funds (via taxes) from the economy at large. Secondary costs typically spread throughout the national economy and are very difficult to measure. As remarked in section 2 above, the conventional economic wisdom (embedded in public planning manuals and texts in CBA – for example, Boardman et al., 2001) is that from the national accounting stance, secondary or pecuniary costs are at least as large or larger than secondary benefits. Hence, the two effects offset each other and, except in special cases, secondary economic impacts can be ignored for national investment planning purposes.[3] Indirect costs and benefits, the other class of external effects, are real impacts and should be incorporated into evaluations adopting a public accounting stance. Indirect benefits are not often economically important in the context of water investments, but indirect costs are typically very significant. Examples of indirect costs of water withdrawals include reduced downstream water supplies or adverse effects on water quality downstream for off-stream (irrigators, industries, households) and in-stream (hydroelectric power plants, recreational water users and fish and wildlife habitat) water users.

In implementing this PPI test, economic valuation or shadow pricing will be required for the terms B_{it} and D_{jt}. (Of course, the PPI test can be also expressed in the alternative, but largely equivalent forms of benefit–cost ratios or internal rates of return. See for example, Gittinger, 1982, for discussion.)

7.2 Evaluating Proposals to Reallocate Water among Sectors

Another likely welfare improvement opportunity is for reallocating water among use sectors. The hypothesis (for a Potential Pareto Improvement) to be tested is: can a reallocation from sector i to sector j yield incremental gains to sector j in excess of the forgone benefits in the ith sector?

In applied cases, the hypothesis of sub-optimal 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 PPI test can be expressed by developing measurements for two conditions (Young, 1986).

The first condition is that the benefits (both direct and indirect) to the municipal sector exceed the sum of: (forgone direct benefits to the selling sector plus forgone indirect benefits to the selling sector plus forgone indirect benefits to the hydropower sector). Condition 1 can be written (assuming all benefit and cost expressions are in present value terms, employing a consistent planning period and price level):

$$DB + IB > FDB + FIB + FIB + TC + CC \qquad (2.3)$$

where:
DB: direct economic benefit (value) to receiving sector
IB: economic benefit to indirectly affected sector(s)
FDB: forgone direct benefit (value forgone) in source sector
FIB: forgone benefit in indirectly affected sector(s)
TC: transactions costs (for information, contracting and enforcement)
CC: conveyance and storage costs
A further condition is that the direct forgone benefits in irrigated agriculture be the least-cost source of water for the purchasing sector:

$$FDB + FIB + TC + CC < AC \qquad (2.4)$$

That is, condition 2 asserts that the sum of direct and indirect foregone economic benefits and the transactions and conveyance costs should be less than the cost of the next best alternative water source.

Economic analysis of both issues – as well as the other resource allocation and cost recovery problems mentioned in the introduction – require the estimation of incremental or marginal benefits of changes in water supply or use. The overall challenge is critically to examine methods for estimating the various manifestations of incremental benefits.

This discussion has focused on measuring benefits of increments or decrements of water supply. To this point, the analysis has abstracted from two other important dimensions of water supply – water quality and supply reliability. These are taken up in the next two subsections.

8. THE BENEFITS OF IMPROVED WATER QUALITY

The quality of water, of course, also influences its economic value. Water in natural environments is never perfectly pure. Humankind uses water bodies as sinks for disposal of numerous wastes from production and consumption activities. The extent to which micro-organisms, and dissolved or suspended constituents are present varies greatly, and in sufficiently high concentrations 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 issues. For the important cases of degradable effluents – those that are transformed after discharge into receiving waters – the detrimental effects depend on the nature of downstream water uses, the distance downstream, temperature, rates of flow and the quality of receiving waters. Willingness to pay for water quality improvement is usually assumed to reflect damages to subsequent water users. The damage function is a measure of the effect of the concentration of pollutants on the utility or costs of receiving entities. Benefits are the damages avoided from a given project or regulative policy.

The framework for conceptualizing the benefits of water quality improvement can be readily derived by extending the model developed earlier for increments of water supply. All other factors (prices, incomes, technologies, and so on) held constant, an improvement in quality of water for either producers or consumers will shift the demand or marginal benefit curves to the right. The increment in producers' or consumers' surplus accruing to the change will be the appropriate measure of benefits of an improvement in water quality. (See Spulber and Sabbaghi, 1998, ch. 2, for a rigorous exposition. A more advanced formulation, with application primarily to groundwater contamination is found in Bergstrom et al. 2001.)

A related example responds to the need for measuring economic damages from releases of harmful materials into public water bodies. This issue has increasingly come into prominence in the USA in response to the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980 (see, for example, Kopp and Smith, 1993).

9. THE BENEFITS OF IMPROVED WATER SUPPLY RELIABILITY

The degree of certainty with which supplies are available, in addition to its quantity and quality, is another important factor influencing the willingness to pay for water. Domestic, industrial and agricultural water demanders all place a higher value on reliable water supplies than on supplies with high risk of availability. At least two cases can be envisioned for which the potential for changed reliability might have value. The major source of water supply unreliability comes from normal hydrologic risk; reflecting the inevitable swings in precipitation and runoff. (For individual users, hydrologic variation may be exacerbated by the institutional arrangements for sharing shortages. Where the rule for allocating shortages is a priority – first in time/first in right – system, high priority users may be little affected while low priority classes experience more than proportional fluctuation.)

Another problem is the short-term lack of reliability of water supply systems, due to either inadequate capacity or to breakdown. Some Third World cities, for example, lack sufficient capacity to be able regularly to deliver water to all customers on demand. A policy of rotating supplies among different geographic sectors of the city's system may serve as a rationing method. In such cases, even customers with piped residential connections are unable to obtain water on demand throughout the full 24-hour day, or even are unable to obtain some water every day (Nickum and Easter, 1994).

Increasing reliability comes at increasing costs, so trade-offs are necessary between cost and risk. Conventional technical risk analysis as applied to water supply reliability selects a risk level roughly reflecting the potential severity of adverse effects, and designs projects to satisfy the selected degree of risk (Renn, 1992). Reliability standards typically vary among use classes: for reasons of health, sanitation and, implicitly, willingness to pay, water supply reliability is usually set higher for domestic supplies than for irrigation.

The technical approach treats all affected areas and parties equitably, but it ignores economic efficiency considerations. Under technical reliability standards, investments to improve reliability may not be subjected to systematic comparison of costs of improved reliability with the expected losses averted. Therefore, large expenditures may sometimes be made which have little prospect for a corresponding reduction of damages. In contrast, the economic approach goes beyond the identification of the probability of some adverse event to the measurement of the disutility of such events to humans.

Howe and Smith (1994) developed a model for assessing reliability and apply it to the case of municipal water supply. Of interest here is how they formulate a function reflecting the economic benefits of reliability to compare with costs of achieving reliability. They defined the 'Standard Annual Shortage Event' (SASE) as a drought of sufficient severity and duration that certain specified restrictions on water use would be put in place. (Howe and Smith's case study was for cities in the semi-arid western United States, so the hypothesized drought-induced restrictions were on summer, outdoor water usage for lawns and gardens.) Here, the discussion abstracts from the optimization model formulated by Howe and Smith to focus on the marginal economic benefit of improved reliability. System reliability, R, is defined in terms of probability (P) of occurrence of the SASE:

$$R(SASE) \equiv 1 - P(SASE) \tag{2.5}$$

Next, a *loss function* L(SASE), is introduced, which represents the reduction in economic value accruing if the SASE were to occur. The desired economic measure, the *marginal benefit of improved reliability*, is given by the incremental reduction in expected losses (denoted E(L)):

$$\delta E(L)/\delta R \tag{2.6}$$

Howe and Smith implement their model empirically with a contingent valuation survey. Griffin and Mjelde, 2000 represent a more recent endeavour at valuing water reliability, one that illustrates the problems of empirical measurement of willingness to pay for uncertain outcomes. Valuing reliability has received relatively little attention, but more effort on this topic is clearly warranted.

10. UNCERTAINTY AND SENSITIVITY ANALYSIS

Estimating benefits for long-run water investment or allocation decisions by its nature requires forecasting the behaviour of a number of economic, hydrologic technological and social variables for a many-year planning period. Because of the limited predictabilities in these factors influencing water management decisions, no analyst can expect to be fully accurate in such a situation. It is desirable that some recognition of uncertainty be incorporated into benefit analysis. Basing a plan simply on best-guess projections may bring about an unwarranted degree of confidence in the results.

A number of formal treatments of uncertainty are applicable to evaluation of water investment and allocation decisions (for example, Morgan and Henrion, 1990). The techniques recommended in these sources – usually based on estimating objective or subjective probabilities of occurrence of key variables – are typically used in evaluating flood risk reduction measures and may be used by academic researchers. However, adoption of such formal techniques will often require too much in the way of analytic expertise and study resources to be useful under many actual planning conditions.

A more practical alternative for acknowledging uncertainty is to use 'sensitivity analysis'. The effect of (sensitivity to) important variables on the estimated value of water is determined by varying one element at a time to determine the sensitivity to erroneous forecasts (Gittinger, 1982). For example, a study of the economic benefits of irrigation should test for sensitivity to assumptions about future crop yields, crop prices or production costs. The cost of capital, represented by the interest or discount rate, is an important variable of uncertain value, and sensitivity to its potential values often should be tested. A sensitivity analysis cannot reduce the risk of a given plan. Sensitivity analysis does not change the facts, but shows the impacts of incorrect assumptions regarding key parameters.

A variation on sensitivity analysis is the 'switching value' test. The switching value test investigates how far a key element in the analysis would need to change in an unfavourable direction before benefits fell below zero.

11. CONCLUDING REMARKS

The economic valuation of goods and services whose prices are in some way distorted or for which markets do not even exist is an important aspect of environmental and resource economics. Economists recognize that people value things – including many important services of the earth's water supply – that they do not purchase through a market or that they may value for reasons independent of their own purchase and use. Further, not everything that reduces utility – such as pollution – is adequately costed in markets. Although economists are sometimes equated with Oscar Wilde's cynic (who 'knows the price of everything and the value of nothing'), environmental economists in fact spend much of their professional efforts attempting to estimate the public's value (often called a shadow price) for non-marketed goods and services.

This chapter has reviewed the conceptual framework for estimating economic efficiency benefits of decisions relating to water supply, allocation and quality. The modern economic paradigm assumes that values of goods and services rest on the underlying demand and supply relationships that are usually, but not always, reflected in market prices. Economics is not just the study of markets but, more generally, it involves the study of preferences and human behaviour. The prices used in cost–benefit analyses are interpreted as expressions of willingness to pay for a particular good or service by individual consumers, producers or units of government. Direct benefits are willingness of beneficiaries to pay for project services or policy impacts. Direct costs are willingness to pay for the forgone alternatives, or to avoid any adverse effects. The numerous techniques developed for applied non-market valuation of water are based on these principles.

Much of the applied non-market valuation literature has dealt with water resources in one or another of its many ramifications, but there is not yet any single publication that brings all these disparate methodologies together for all types of water uses. Moreover, although many of the resource valuation techniques, particularly on the topic of environmental quality, have been subject to critical scrutiny and testing, some important areas of water valuation have received less attention. Particularly for the intermediate or

producers' goods derived from water – such as crop irrigation, hydroelectric power and industrial and commercial water use – procedures for empirical applications of valuation techniques appear to be less developed and seem to have received less application and critical confrontation. An important next step will be to extend the applied paradigm to meet that challenge.

NOTES

1. The term 'value' takes on a narrow meaning in economics, referring to money measures of changes in economic welfare (Freeman, 2003, p. 7). 'Economic benefit' and 'economic value' will be used interchangeably here to refer to positive welfare changes resulting from investment projects or policy initiatives.
2. Some authors, unfortunately, in addition to this broad meaning, use 'willingness to pay' to refer to a specific type of non-market valuation study which directly questions people on their valuations for environmental changes. To avoid ambiguity, these specific techniques would best be identified by the name of the relevant elicitation process – that is, 'contingent valuation'.
3. Regional models have occasionally been used, incorrectly in my view, to measure direct economic benefits according to a 'value added' concept. See Young and Gray (1985) for a critique.

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3. Water as an economic good

J. Briscoe

1. THE THEORY OF WATER AS AN ECONOMIC GOOD

There is an emerging consensus that effective water resources management includes the management of water as an economic resource. The Dublin Statement of the International Conference on Water and the Environment, for example, states that 'water has an economic value in all its competing uses and should be recognized as an economic good'. But there is little agreement on what this actually means, either in theory or in practice. This chapter provides a simple framework for unbundling the different components of water as an economic resource, provides some data on critical variables and discusses the policy implications.

The idea of 'water as an economic good' is simple. Like any other good, water has a value to users, who are willing to pay for it. Like any other good, consumers will use water so long as the benefits from use of an additional cubic meter exceed the costs so incurred. This is illustrated graphically in Figure 3.1(a), which shows that the optimal consumption is X*. Figure 3.1(b) shows that if a consumer is charged a price P^1 which is different from the marginal cost of supply, then the consumer will not consume X*, but X^1. The increase in costs (the area under the cost curve) exceeds the increase in benefits (the area under the benefit curve) and there is a corresponding loss of net benefits called the 'deadweight loss'.

But what about groups of users, how is welfare maximized for the group and society as a whole? The simple logic of Figure 3.1 applies in the aggregate – for society as a whole, welfare is maximized when:

- water is priced at its marginal cost; and
- water is used until the marginal cost is equal to the marginal benefit.

So far so good, but what actually do we mean by 'benefits' and 'costs', how are these dealt with in different water-using sectors and what are the implications? These issues are explored in the next section of this chapter.

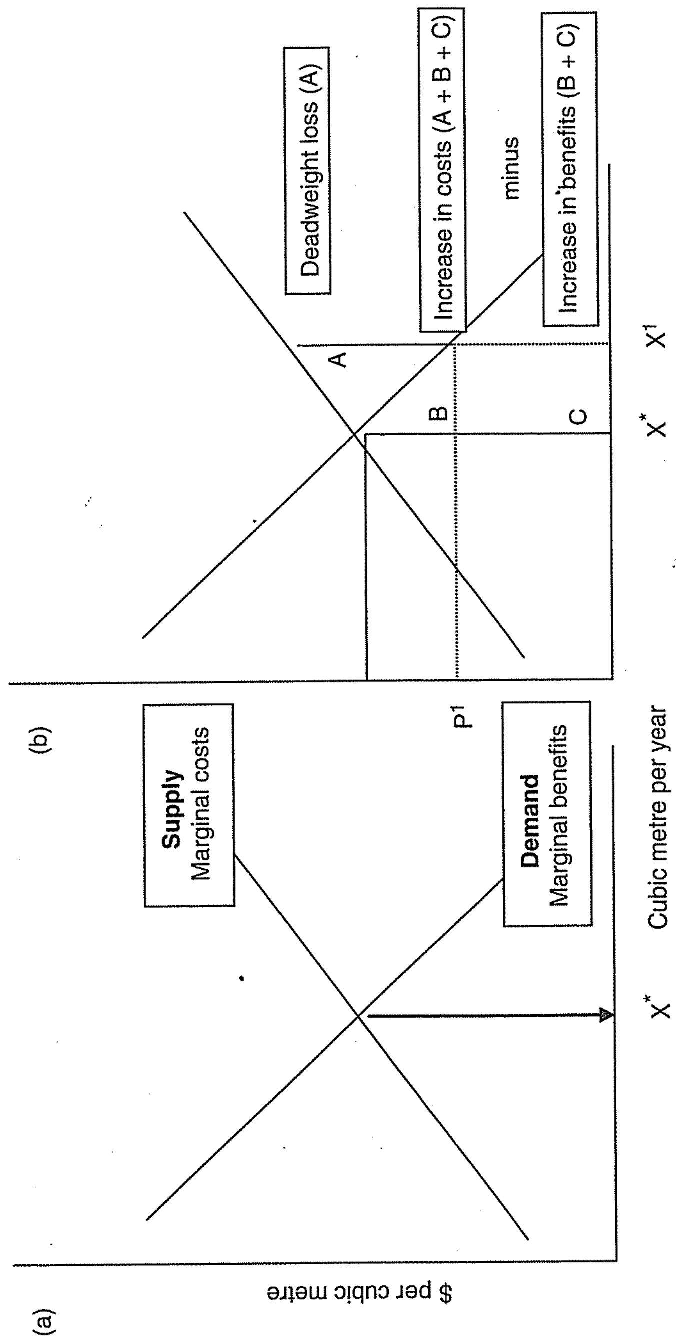


Figure 3.1 Optimal consumption and deadweight losses if water is underpriced

2. THE VALUE OF WATER

The value of water to a user is the maximum amount the user would be willing to pay for the use of the resource. For normal economic goods which are exchanged between buyers and sellers under a specified set of conditions, this value can be measured by estimating the area under the demand curve. Since markets for water either typically do not exist or are highly imperfect, it is not simple to determine what this value is for different users of water. A hodgepodge of methods are used to estimate the value of water in different end uses (Gibbons, 1986). These methods include:

- estimating demand curves and integrating areas under them;
- examining market-like transactions;
- estimating production functions and simulating the loss of output which would result from the use of one unit less of water;
- estimating the costs of providing water if an existing source were not to be available;
- asking (with carefully structured 'contingent valuation' questions – Arrow et al., 1993; Griffin et al., 1995) how much users value the resource.

What is the point of estimating these values, given the crude and inexact nature of the estimates, and given that the value of water varies widely depending on factors such as the use to which it is put, the income and other characteristics of the user, the location at which it is available, season and time, and quality and reliability of the supply? Most certainly these 'ball-park estimates' can never, and should never, be used to make technocratic decisions on allocations and prices (as has sometimes been proposed). But examination of the values which emerge from these estimates do show some striking and remarkably consistent themes which have major implications for policy. To illustrate these themes, it is useful to work with some actual values. Figure 3.2 summarizes some data (presented by Moore and Willey, 1991) from the western United States, where most valuation work has been done. Other compilations (for example, in Gibbons, 1986) show similar patterns in terms of the relative value of water in different uses.

Conclusions which emerge from Figure 3.2 (note the log scale on the Y axis) and consistently in similar studies and in meta-studies which draw together large amounts of available data include the value of water for:

- irrigated agriculture;
- hydropower;
- household purposes;

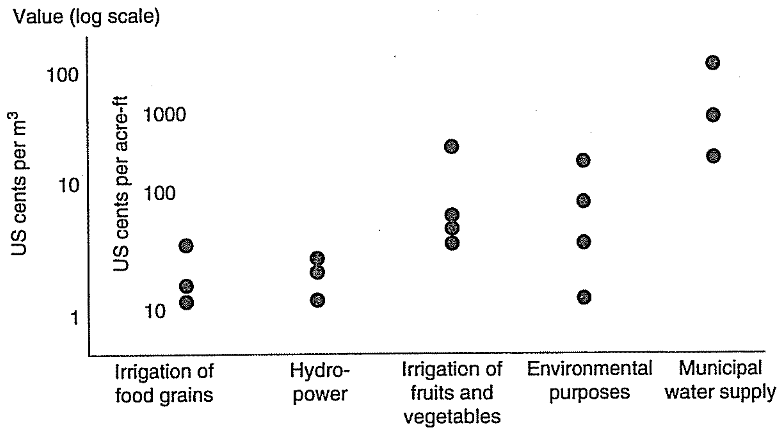


Figure 3.2 Typical market and non-market values for water in the western United States

- industrial purposes; and
- environmental purposes.

2.1 Value of Water in Irrigated Agriculture in Industrialized Countries

It is, first, important to note that irrigated agriculture accounts for a large proportion of water use, especially in many water-scarce areas. The value of water for many low-value crops (such as food grains and fodder) is universally very low. Where reliable supplies are used on high-value crops, the value of water can be high, sometimes of a similar order of magnitude to the value of water in municipal and industrial end uses.

2.2 Value of Irrigation Water in Developing Countries

The picture in developing countries is similar. Consider the case of India. In western India (Shah, 1993) groundwater is exploited by private farmers and is provided in a timely and responsive fashion to users (the farmers themselves and others to whom they sell the water). The water is used on high-value crops (including fruits, vegetables and flowers). The value of water, as reflected in active and sophisticated water markets, is high (typically around US 5 cents per cubic metre). In public (mostly surface) irrigation systems in the same country, the quality of the irrigation supply is poor, food grains are the major crop produced, and the value of water is typically only about 0.5 cents per cubic metre (World Bank, 1994a), orders of magnitude lower than in the private groundwater schemes. Similar very large and persistent differences are found in publicly run irrigation schemes throughout the developing world.[1]

2.3 Value of Water for Hydropower

The short-run values for water in hydropower in industrialized countries are typically quite low, often no higher than the value in irrigated agriculture (Gibbons, 1986). Long-run values are even lower. Whether hydropower is an economic proposition depends greatly on particulars – of the economy, of the power sector and of the water sector. Where water is abundant and there are few competing uses, hydropower is likely to be economically viable; where water is scarce (and therefore competition high), the case for hydropower is less clear-cut.

In developing countries the demand for power is growing very rapidly. Although energy conservation is important here (as it is in industrialized countries), large capacity expansion is inevitable and essential. It has been argued (Goodland, 1996) that the high environmental costs of alternatives (especially fossil-fuel based generation) means that hydropower is a particularly attractive alternative in many developing countries. Interestingly, data suggest that the environmental costs – as measured by flooded area per kw and number of oustees per kw – are substantially smaller for big dams than smaller dams (less than 100 megawatts of installed capacity).

It is frequently argued that hydropower is a non-consumptive use and therefore does not impose costs on others. It is this notion which has, for instance, been behind the creation of two separate categories of water rights – 'non-consumptive' and 'consumptive' – in Chile (Gazmuri and Rosegrant, 1996). What is evident – in Chile and elsewhere – is that the situation is not so simple. By modifying flow regimes and the timing of water to downstream users, hydropower installations can impose major costs on other users (Briscoe, 1996b). The key issue is not consumptive or non-consumptive use, but the costs imposed on others by a particular use of a resource.

2.4 Value of Water for Household Purposes

This value is usually much higher than the value for most irrigated crops. Not surprisingly, the value for 'basic human needs' and for household uses is much higher than the value for discretionary uses (such as garden watering). An important finding (similar to that emerging from the irrigation data) is that people, even poor people in developing countries, value a reliable supply much more than they value the intermittent, unpredictable

supplies which are the norm in most developing countries (World Bank Water Demand Research Team, 1993).

2.5 Value of Water for Industrial Purposes

This value is typically of a similar order of magnitude to that of supplies for household purposes.

2.6 Value of Water for Environmental Purposes

The value of water for environmental purposes such as maintenance of wetlands, wildlife refuges and river flows also vary widely, but typically fall between the agricultural and municipal values, as shown for the western United States in Figure 3.2. In developing countries, most similar work has been done on the value of mangrove swamps (in El Salvador, Malaysia, Indonesia and Fiji), which are critically dependent on inflows of fresh water. These data, too, show quite high values (primarily due to the off-site impacts on fisheries) (Lai, 1990).

Before discussing the policy implications of these remarkably consistent findings, it is relevant to summarize a related area of work on the economic value of water, which also has major impacts for policy. There is a substantial literature assessing how users react to changes in the price of water. The concept used is that of 'elasticity', with the measure being defined as the percentage change in use of water for each percentage increase in the price of water. Once again, there is a striking consistency to the findings (and to their import for resource management, as discussed later). Figure 3.3 presents some values (again from Gibbons, 1986) which do not purport to be universal, but which illustrate consistent findings in the literature.

In assessing data on elasticity, it is necessary to clear up a confusion generated by a piece of economic jargon. When the price elasticity of demand is less than -1.0 (that is, when the percentage change in consumption is less than the percentage change in price) then economists say 'demand is inelastic with respect to price'. The common-sense (but erroneous) interpretation is that demand is not reduced as prices change. In fact, as long as price elasticity is negative, demand is reduced when prices increase.

An obvious omission from Figure 3.3 – the lack of estimates of the price elasticity of demand in irrigated agriculture – needs to be explained. This is best done with reference to the place where it has been most studied – the western United States. In the western USA the price elasticity of demand for irrigation water is low. The reason for this low elasticity is not that farmers do not respond to prices (as is often inferred), but rather because users' reactions to price changes depend on the original price and

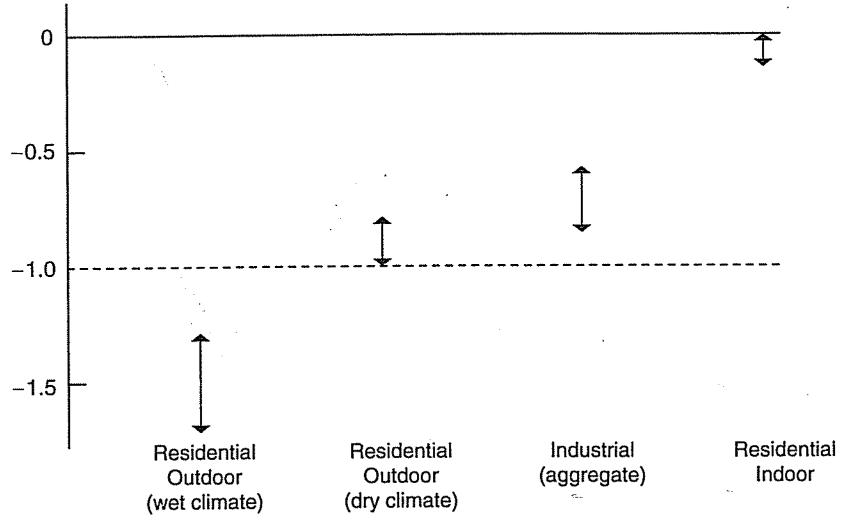


Figure 3.3 Range of price elasticities of demand for water in the United States

because irrigation water costs are held artificially low (Gibbons, 1986). In California, for example, where water is priced at $3 per thousand cubic metres, a 10 per cent price increase causes a 5 per cent decline in water use, whereas where water is priced at $14 per thousand cubic metres, a 10 per cent price increase results in a 20 per cent drop in use (Rogers, 1986).

The major point that emerges from the (quite large) literature on the price elasticity of water demand is that, in developing and developed countries alike, the price elasticity is significantly negative, meaning that users react to price increases by reducing demand. A second important point is that the price elasticity is, as common sense would suggest, related to the price level – the higher the price, the greater the elasticity. Obvious and commonsensical as these findings may be, they contradict a large body of folklore about 'non-responsiveness to prices' in the water profession.

Before concluding this discussion of 'value', it is relevant to focus on the issue of the 'value' of waste water treatment, or the 'value' of environmental quality. The usual approach to this has been to assume that it is impossible to assess this value and, instead, to promulgate standards (by type of treatment required, quality of effluent stream, or quality of the receiving stream). This is often perceived as a way of 'getting round' the issue of value. As was shown in a seminal work by Harold Thomas (1963), setting of a standard is equivalent to imputing a value for the resource. As will be discussed later, there are institutional arrangements for setting

standards which violate (at great cost) this understanding, but there are also institutional arrangements which provide practical and proven methods for taking these values into account implicitly in setting standards.

3. THE COST OF WATER

So much for the value side of the equation – what of the cost side? In thinking about 'the cost of water' it is first necessary to acknowledge that there are two different types of costs incurred in providing water to, say, a household or a field. The first (obvious) cost is that of the constructing and operating the infrastructure necessary for storing, treating and distributing the water. In this chapter this is referred to as the 'use cost'. The second, less obvious, cost is the 'opportunity cost' incurred when one user uses water and, therefore, affects the use of the resource by another user. For example, greater abstraction of water by a city might affect the quantity and quality of water available to downstream irrigators, thus imposing costs on these users.[2]

3.1 Use Cost

In discussing 'use costs', it is first necessary to define three concepts. First is the concept of 'historical costs'. Consider the example where a water board constructs a reservoir from which it supplies water to its customers. What should the board charge its customers for the service provided by the reservoir? Frequently, the charging system mimics the mortgage payers of a homeowner – the board charges its users that which is necessary to pay for the remaining portion of the debt incurred in financing the dam. This is known as 'historical cost' pricing. The second, less intuitively obvious concept is that of 'replacement cost pricing'. Accountants will argue that the value of the asset (the dam in this case) is not correctly measured by its historic costs (which are often heavily distorted by government intervention), but rather the cost that would be incurred in replacing the asset. The analogy here is that of the housing rental market. If a homeowner has paid off his or her mortgage, he or she does not charge a tenant nothing – rather, he or she charges a rental fee that reflects the replacement cost of the asset. The third concept is that of marginal cost. Economists argue that when someone is thinking about using a bucket of water, they should not be told (through prices) what it costs to produce that water but, rather, be told the cost that will have to be incurred if capacity needs to be expanded to produce another cubic meter of water (Turvey and Warford, 1974). Where cost curves are relatively flat, the distinction between the former (average costs) and the latter (marginal costs) is unimportant. When costs are falling (as happens where there are economies of scale, for instance in treatment plants), marginal costs are less than average costs. For raw water, however, the situation is just the opposite, because the closest, cheapest sources are those which are used first. The cost curve for raw water, then, is almost always rising, and marginal costs are greater than average costs.

3.2 Opportunity Cost

It is obvious that measuring the opportunity cost of water is a difficult task. It needs a systems approach and a number of more or less heroic assumptions about real impacts and responses to these. What can be said with certainty is that:

- Opportunity costs are related to value in a non-transitive way. That is, if a city and an irrigation district lie on opposite banks of a stream, the opportunity costs imposed by abstraction by the high-valued user (the city) will be much lower than the opportunity costs imposed by abstraction by the low-value user (the irrigation district).
- Opportunity costs increase substantially as the water in a basin becomes more 'densely used' (both in quantity and quality terms) and are, therefore, substantially higher, all other things being equal, in arid, heavily used basins.
- The existence and imposition of opportunity costs can give rise to conflicts amongst users, unless there are institutional mechanisms for recognizing these costs and for ensuring that these are taken into account by users (on which more later in this chapter). Such conflicts are, of course, not a new phenomenon – the etymology of the word 'rivals', originally meant 'one living on the opposite bank of a stream from another' (Oxford English Dictionary, 1971).

4. THE BALANCING OF VALUE AND COSTS

The overall 'economic cost of water', therefore, comprises two separate components – the use cost and the opportunity cost. It is useful to maintain and deepen this disaggregation in thinking about how the idea of 'the cost of water' is understood, and how this understanding frames the public, political and theoretical discussions of water management. In doing this, it is instructive to recognize that there are a variety of ways in which the use cost and opportunity cost are perceived, and how different institutional arrangements mean that users are faced with different vectors of 'use' and 'opportunity cost'.

In exploring these relationships it is useful to first define the 'golden standard', namely, that combination of use and opportunity costs which ensure that users take the full economic costs of using water into account. As illustrated in Figure 3.4, a user faces the full economic cost when he or she (a) has to pay a 'use cost' which corresponds to the marginal financial cost of supplying the water to him or her and (b) incurs an opportunity cost which reflects the value of water in its best practical alternative use. This combination of 'use cost' and 'opportunity cost' is shown in the upper right-hand corner of Figure 3.4.

So much for theory, what about practice? This varies by sector and by country. A few examples will illustrate the general situation.

4.1 Urban Water Supply in Industrialized Countries

Practice in urban water supply in industrialized countries deviates from 'the economic optimum' in two ways, which are significant in theory, but of little importance in practice. Regarding 'use charges', water utilities in industrialized countries are generally operated on commercial or quasi-commercial principles (World Bank, 1994b), and recover the full average financial costs (level III in Figure 3.4) from users. There are two reasons why few utilities operate at level IV (the economic optimum).

First, although there are negative economies of scale for raw water, there are positive economies of scale for the major civil works, which account for much of urban water supply costs. Accordingly, marginal costs may not be different from (and may actually be less than) average costs. Second, setting tariffs to cover average costs is a simple, transparent process, which mimics that of commonplace financial transactions. A corollary is that the (small) economic benefits of moving to marginal cost pricing have to be weighed against the (large) administrative and governance costs of dealing with a system which 'defies common sense' for most customers.

Urban water tariff setting also deviates from the economic optimum in that the opportunity costs of water are often not visible to the utilities (except in well-functioning water resource management systems, two of which are described later in this chapter). In any case, these opportunity costs are, from the point of view of urban water supplies, usually very small relative to the financial costs of abstracting, transporting, treating and distributing water. For the urban water sector Figure 3.4 would usually look like a 'tall L', as shown in Figure 3.5.

The 'tall-L' shape for urban water arises both because the value of raw water for municipal uses is typically (as shown in Figure 3.2) an order of magnitude higher than the value of the next best use, and because the costs of raw water constitute only a minor part (typically less than 20 per cent)

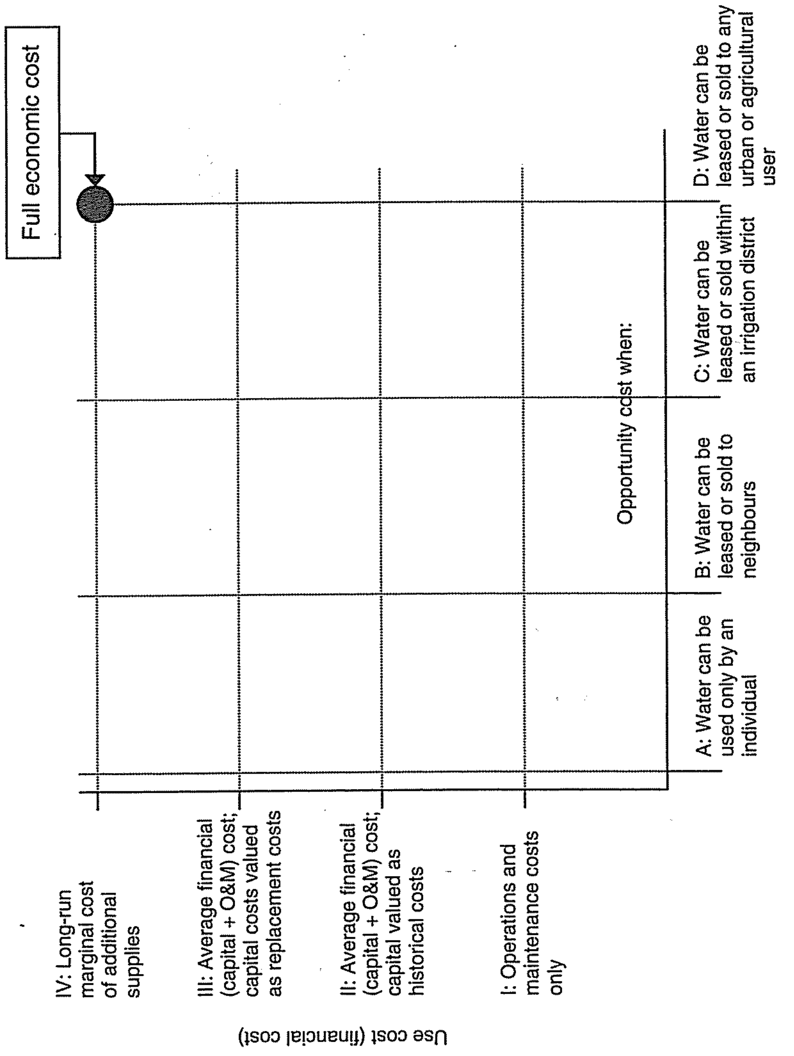


Figure 3.4 Schematic representation of the definitions of use cost and opportunity cost

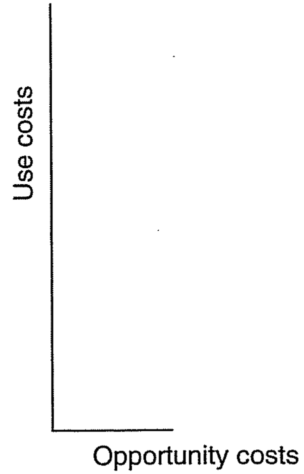


Figure 3.5 The relative magnitudes of use costs and opportunity costs for urban water supply

of the cost of water as delivered to the customer. The bottom line then is that, although opportunity costs are often not taken into account, the 'tall-L' shape of Figure 3.5 means that, in practice, urban water supply pricing in industrialized countries deviates little from the economic optimum.

4.2 Urban Water Supply in Developing Countries

In developing countries the situation is quite varied and generally quite different from that in industrialized countries. The first difference comes on the cost side. Many cities in developing countries are growing rapidly. In many cities incomes are also increasing and industrial demand is growing. The net result is that the demand for municipal water is often growing very fast and new sources have constantly to be found. A consequence is that the costs of urban supplies from new sources are growing rapidly – in current World Bank financed projects the cost of a cubic metre of raw water for a city is typically two to three times greater (in real terms) than was the case in the last project (World Bank, 1992). In terms of Figure 3.4, this means that the difference between marginal (level IV) costs and average (level III) costs are typically substantially greater for developing countries than for industrialized countries. Unfortunately the story does not stop there. Urban water supplies in most developing countries have been financed but of general revenues. In many cases these costs are fully subsidized, with the utility responsible only for operation and maintenance costs (level I).

In other cases the costs are computed in historical terms, which typically greatly undervalue the assets of the utility.

With regard to opportunity costs, the situation is similar to that in industrialized countries – they are not taken into account, but are also usually small relative to real financial costs. In a typical case in India, for instance, average financial costs ('use costs') are about US 50 cents per cubic metre, whereas the opportunity cost of water (for irrigation of food grains) is about 0.5 cents per cubic metre, a difference of two orders of magnitude.

The important challenge for urban water utilities in developing countries, is, therefore to:

- reduce costs by more efficient operation, which increasingly means substantial involvement of the private sector (Serageldin, 1995; World Bank, 1994b); and
- raise tariffs from their very low levels, which typically cover less than one-third of costs (World Bank, 1992). Worrying about opportunity costs they impose – the short leg on the L in Figure 3.5 – is not a priority problem for urban water utilities in developing countries.

4.3 Privately Financed Irrigation

The great distinction here is not between industrialized and developing countries, but rather between publicly and privately financed irrigation schemes. In most countries private irrigators bear the full financial costs of the schemes they construct and thus implicitly face financial costs at level III in Figure 3.4. In a number of countries this is not the case, with subsidies substantially reducing the financial costs incurred by private irrigators.[3]

Private irrigators seldom face any opportunity costs for the water they use. Where groundwater is used, this has led to the unsustainable pumping of aquifers, sometimes on a huge scale, such as the Ogallala aquifer in the United States (Rogers, 1986). Where surface water is used, this is often in the context of a 'prior appropriation' water doctrine, which implicitly encourages the ignoring of opportunity costs.

4.4 Publicly Financed Irrigation

Public irrigation systems throughout the world share several striking characteristics. First, as has been documented in countries as different as the United States (Bradley, 1996; Worster, 1992; Reissner, 1986), and India (Wade, 1986), they have been enormous sources of political patronage. Typically these investments have been subsidized almost completely by the

state. In most developing countries charges have been much lower than those required even to pay for operations and maintenance costs (World Bank, 1995). In Bihar in India, for example, water charges are not sufficient even to cover the costs of collection (Rogers, 1992).

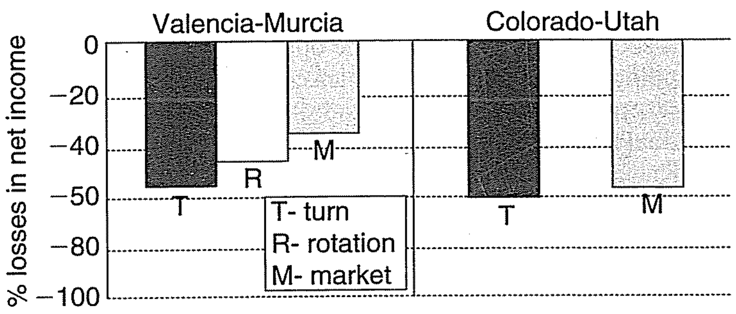
The issue of 'recovering the costs of operations and maintenance' has been the focus of much debate in the irrigation community. This is an important debate, first, because the associated issue of ensuring that systems are maintained and provide a good-quality service to users such as farmers is obviously appropriate and central to improving irrigation performance. This issue thus deservedly occupies centre stage in reviews, such as a recent one by the Operations Evaluation Department of the World Bank (1995). An important finding from such reviews is that the supply side of this question is at least as important as the demand side. It has been shown repeatedly that cost recovery in irrigation systems makes little positive difference unless the revenues so collected are applied to improving the quality of service received by the farmers. Where these revenues go to a central treasury (as is frequently the case), there is little improvement in irrigation performance if 'costs are recovered'.

The 'opportunity cost' axis is an important and subtle one in canal irrigation systems (the dominant technology in public irrigation districts). A typical situation is one in which users are charged a small amount (often zero) for the 'use cost', but where they do take account of one restricted measure of the opportunity cost of the resource. The best-known example of this is the rotational rationing system of north India (the so-called 'waribandi system'). As students of the system have pointed out, in this setting water is often the limiting production resource. Each farmer, therefore, faces an 'opportunity cost' which influences the way in which he uses that resource. While this is true (and is often neglected in criticisms of such systems) it should be observed that the opportunity cost varies considerably depending on 'alternative uses' which come into play. In the waribandi system, the 'opportunity cost' is essentially that of the opportunities which the individual farmer forgoes on another (non-irrigated) field, assuming he has one. The 'opportunity cost' would evidently be greater if all farmers in a particular distributory were included, since it is the value placed by the highest alternative use which defines the opportunity cost.[4]

Similarly, if it were possible (as is increasingly the case) to transfer the water among a wider universe of potential users of that water (which will usually include other farmers, and may include neighbouring towns and industries), then the 'opportunity cost' would be greater still. While 'the best alternative use' needs to take into account location and the hydraulic connections possible between users, it is certain that the restrictive 'opportunity cost' implicit in rationing systems (like waribandi) will often represent large underestimates of the true opportunity costs and will therefore mean that farmers are facing both use and resource costs which represent substantial underestimates of the true costs. Under such circumstances, as explained earlier, deadweight losses are likely to be substantial.

The magnitude of these losses has been estimated in a seminal assessment of different irrigation systems in Spain and the United States. Maass and Anderson (1978) did simulation analyses of the effects of different water allocation procedures on the economic impact of water shortages. In the 'turn' system, farms are served in order of location along the canal. When water reaches a farmer, he takes all he needs during the period, before the next farmer is served (a procedure followed in Valencia). In the 'rotation' system each farm has a reserved time in which to irrigate in each period, but the water delivered in this time varies on each rotation depending on the flow in the ditch (a procedure followed at the time of the study in Fresno, Utah and Murcia.) In the 'market' system, all water users bid each period for the water used to irrigate their crops and the water is allocated to the highest bidders (a procedure followed in Alicante). As shown in Figure 3.6:

- the market system is far superior in terms of overall productive efficiency; and
- the differences between the market system (which incorporates the opportunity costs within the command area) and the turn and rotation systems (which do not incorporate these opportunity costs) is large.



Source: After Maass and Anderson (1978).

Figure 3.6 *Relative efficiency of different American and Spanish water management procedures when water to an irrigation district is reduced by 10 per cent*

A relevant aside is to note the effects of different water management regimes on the distribution of losses amongst farmers when there are shortfalls in water availability. The standard measure for inequality is that of the Gini coefficient – as shown in Figure 3.7. The Gini coefficient is:

- zero when losses are equally distributed equally across the land; and
- unity when all losses are concentrated in a single farmer.

As shown in Figure 3.8, in both Spain and the United States, the market system was markedly superior to the turn and rotation systems in terms of

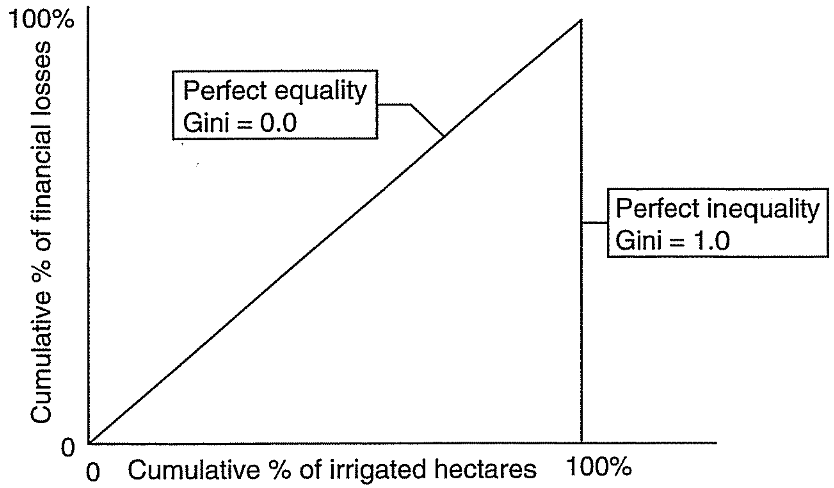


Figure 3.7 *Measures of equality – the Gini coefficient*

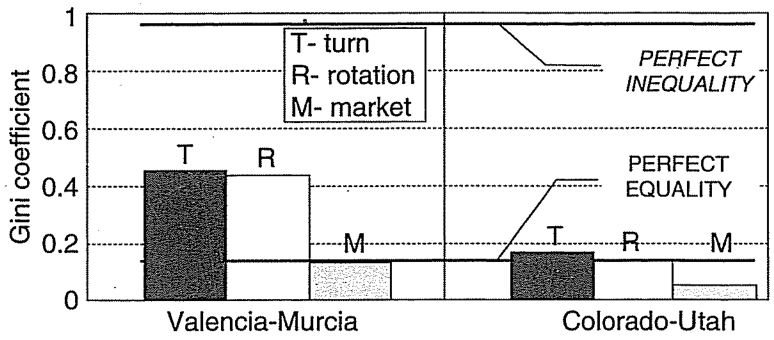


Figure 3.8 *The equity of different water allocation systems*

the equity of distribution of the losses resulting from a water shortage. As pointed out by the authors,

> although it is a doctrine of many welfare economists that procedures that rank high in efficiency will do poorly in distributing income equally among beneficiaries, while procedures that do well in distributive equality will be inefficient . . . this conventional wisdom does not apply to a wide variety of conditions in irrigated agriculture. (Maass and Anderson, 1978, p. 391)

4.5 The Implications for Irrigation vis-à-vis Urban Uses

In summary, when considering the relative magnitudes of the use cost and opportunity cost of irrigation, the situation is almost exactly the opposite of that pertaining for urban water supply. Financial costs of irrigation systems are usually much lower (per unit of water) than they are for urban water, and opportunity costs are much higher, both absolutely and relatively, as shown in Figure 3.9.

Ignoring opportunity costs is thus a matter of minor practical importance when it comes to the economic management of urban water supplies, but a matter of huge practical significance when it comes to irrigation. As illustrated schematically in Figure 3.10, the shape for irrigation is a 'flat L' in contrast to the 'tall L' in Figure 3.5 for urban water supply.

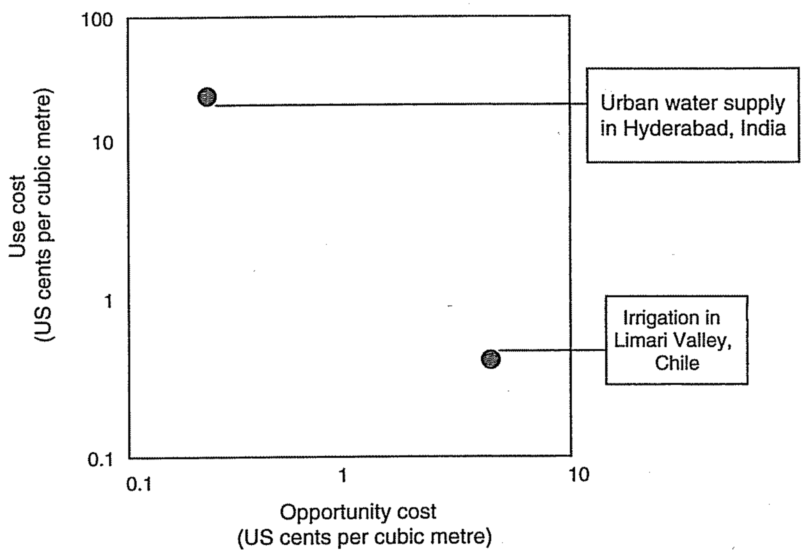


Figure 3.9 Illustrative values of use and opportunity costs for urban supply and irrigation opportunity costs

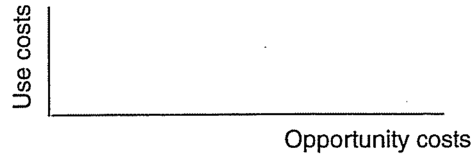


Figure 3.10 The relative magnitudes of use costs and opportunity costs for irrigation

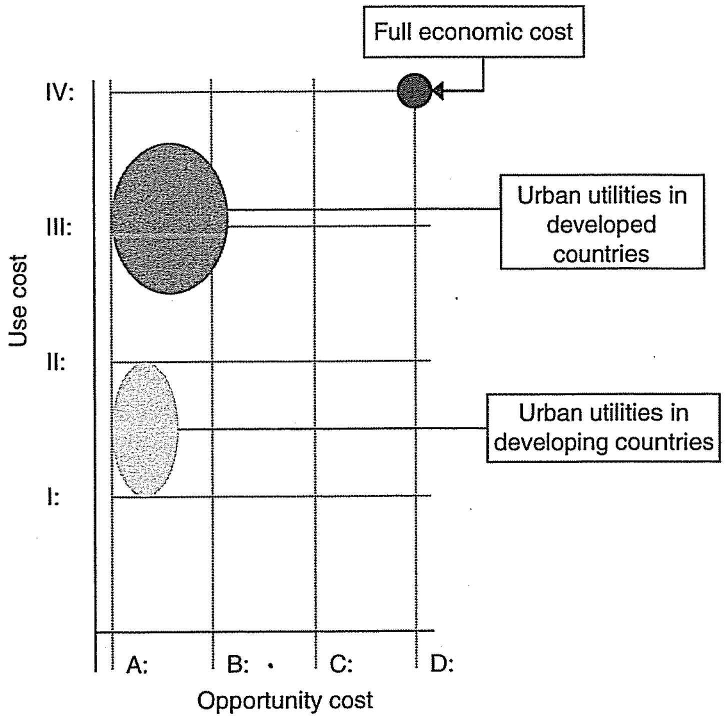


Figure 3.11 Schematic representations of deviation from economic pricing for urban water supply

Finally, it is instructive to return to the graphical format developed in Figure 3.4 to summarize the issues on use and opportunity costs as they pertain to different water using sectors. Figures 3.11 and 3.12 provide a schematic representation of how the management of different water using sectors deviate from the economic optimum.

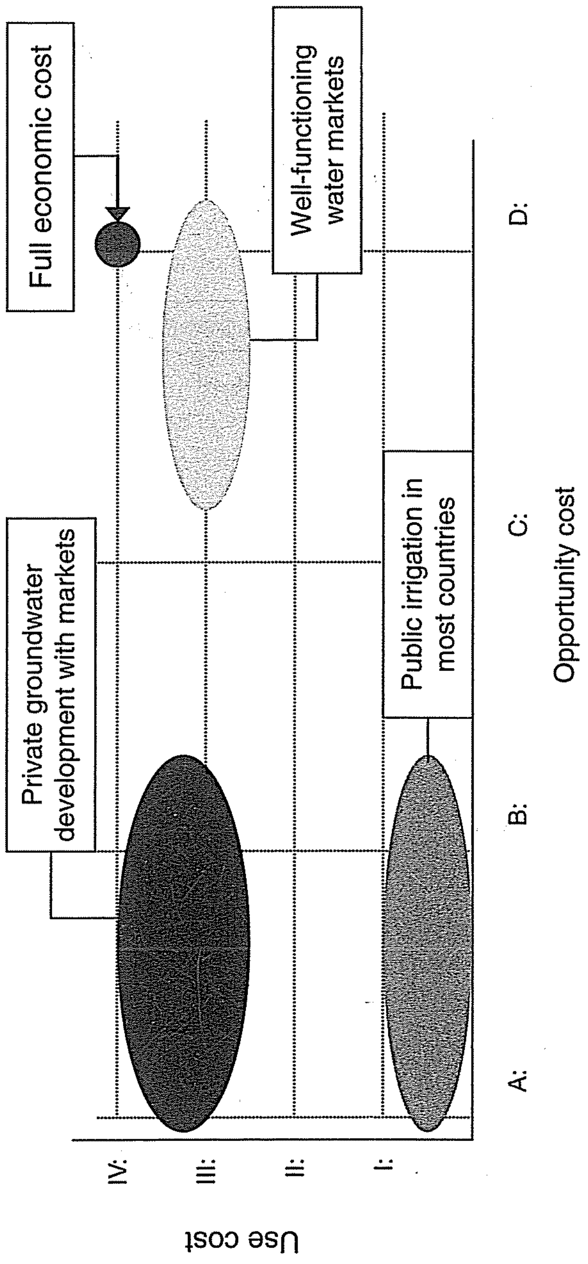


Figure 3.12 Schematic representations of deviation from economic pricing for irrigation

5. EXAMPLES OF GOOD PRACTICE

5.1 Where Water Quality Management is the Principal Challenge – the Ruhr/French Model

Probably the most widely admired water resource management model is that which was developed in the Ruhr Basin in Germany in the early part of the twentieth century, and subsequently adapted on a national scale by France in 1964. The evolution and details of the Ruhr and French experiences have been described elsewhere (Cheret, 1994; Ruhrverband, 1992; Serageldin, 1994). The core elements of this system are:

- management of the basin by a policy-making 'water parliament', comprising all important stakeholders in the basin, supported by a high-quality technical agency; and
- the extensive use of negotiated abstraction fees and pollution charges.

How does the economic value of water come into play in the Ruhr/French type of system? With regard to use costs the answer is simple: the users pay the full financial cost of the infrastructure required to deliver water to them. The way in which the model deals with opportunity costs is more important and less obvious. Abstraction fees are set through a negotiation process. If there is a shortage of water and a potential user without access wants water (or an existing user wants more water), then that user's voice will be heard in the parliament in pushing for higher abstraction prices so as to bring supply and demand into balance. In economic terms this 'next best use' is precisely what is meant by 'opportunity cost'. On the quality dimension (of dominant importance in industrialized countries), the operation of the basin agency is similar: the costs imposed on others in the basin are revealed in both the work of the technical agency and in the course of negotiations, and pollution fees accordingly set in part to take account of these 'externalities'.

On the one hand, then, opportunity costs do come into play in decisions on prices. On the other hand, this expression is indirect and muted by a complex administrative process. As a result, the signals on opportunity cost in such a system do not have the desired specificity and flexibility. While administratively set prices in these systems are affected by opportunity costs, they cannot mimic a market, which, as described in the next section, automatically differentiates by location, quality, season and other complex and changing variables.

5.2 Where Water Scarcity is the Principal Challenge – Experience with Water Markets

In arid areas of the world the foremost water resources management problem has long been that of allocating scarce water among competing uses and users. A wide variety of approaches have been taken, and are taken, to this problem.

In the twentieth century, the most common approach has been a combination of 'first come-first served' (known as the 'prior appropriation doctrine' in the western United States (Worster, 1992)), and the augmentation of supplies through massive investments and allocation of the additional water on political grounds. The problems with such an approach has become manifest throughout the world – the financial costs are enormous, precious water is wasted on low-value activities, while high-value uses cannot secure adequate supplies, and environmental destruction and degradation are the norm (Postel, 1992; Reissner, 1986; Worster, 1992). Recently there has been a surge of interest in the use of water markets as a means of performing this allocation function in an efficient and consensual fashion.

Water markets have a long history both informal, as documented by Shah (1993) for groundwater in Western India, and formal, most notably in Spain (Maass and Anderson, 1978). There have been major developments in Australia (Dudley, 1994), and innovative proposals on the use of markets to solve international water disputes in the Middle East (Fisher, 1994). Most of the attention, however, has been focused on the western United States, where, a wide range of water markets have developed (Saliba and Bush, 1987), with some sophisticated developments (such as the recent development of electronic water markets for the huge Westlands Water District in the Central Valley of California (Zachary, 1996).

In the context of the present discussion of the economic management of water, it is instructive to concentrate on a single, much discussed case, that of the water markets in Chile. The key policy decision in Chile was the separation of land and water rights in 1981 and the simultaneous encouragement of trading of water without restriction. The water market is a brilliant conceptual solution to the enduring problem of reconciling practical and economic management of water. On the one hand, 'common-sense pricing' suggests that the water management unit charges users for the use costs – the investment and operating costs incurred in storing and delivering the water to the user (it is this which is done by users' associations who operate water systems at various levels in Chile).

The problem arises because these financial costs are much lower (often an order of magnitude) than the opportunity cost.[5] The existence of a water

market means, however, that behaviour is not driven by the financial cost of the water, but rather by the opportunity cost. If the user values the water less than it is valued by the market, then the user will be induced to sell the water. This is the genius of the water market approach: it ensures that the user will in fact face the appropriate economic incentives, but de-links these incentives from the tariff (which is set on 'common-sense' grounds).

In well-regulated river basins in arid areas of Chile, the water markets function as one would wish: within a particular area water is traded from lower-value uses to higher-value uses. Prices are responsive to both temporary (seasonal) scarcity as well as longer-term scarcity and trading is quite active. Two comments are appropriate here. First, it is evident that no administrative mechanism, even the very good Ruhr and French systems, can mimic water markets in transmitting information on opportunity costs in such a flexible and specific way. Second, it is important to note that water markets are not a simple panacea. The major challenge facing water resources managers in Chile is more effective basin-level management, which will both complement and enhance the workings of the water markets (see Briscoe, 1996).

From the perspective of the economic management of water, a critical issue is the 'breadth' of the water markets, with the dictum being 'the less restrictions there are on water trades, the more the true opportunity cost will come into play'. In Chile, where water can (and is) traded from agriculture to towns, a farmer who owns water rights faces the full opportunity cost of the resource. In many instances (such as the water market of Alicante, and the large market in the Northeast Colorado Water Conservation District) there are specific, and sometimes absolute, prohibitions on the sale of water to non-agricultural users. In such situations, the opportunity costs are obviously truncated, with important resulting distortions in the economic signals.

6. CONCLUSIONS

In this chapter, an attempt was made to develop a framework for thinking about management of water as an economic resource and to assess the policy implications in light of available empirical evidence.

Three principal conclusions emerge from the discussion. First, economic development and environmental sustainability in many countries depend on considering water as a scarce resource, and using economic principles for its management. Second, the challenge is particularly great with respect to irrigated agriculture, which is, simultaneously, the largest user of water in many countries and the sector which is managed (in most places) least like an economic resource. Third, while it is clear that the distance between the 'bad' bottom left-hand corner of Figure 3.4 and the 'good' top right-hand corner is great (particularly for irrigation), there are also examples of good practice which show that change is possible and how it can be effected. Finally, it is important to acknowledge that the idea of 'water as an economic good' is but one of a triad of related ideas which will increasingly shape the way in which societies are organized (and water managed) in the twenty-first century. These ideas are:

- broad based participation by civil society in decisions (including those on water management) which were previously often treated as the province of technocrats alone;
- the hegemony of the market model of development, and the corresponding move to using market-like and market-friendly instruments for managing all elements of the economy (including water); and
- the emergence of the environment as a major focus of concern.

NOTES

1. A comprehensive review of World Bank-financed irrigation schemes (World Bank, 1995) showed that food grains were the predominant crop in 90 per cent of such schemes.
2. Technically speaking, the 'opportunity cost' is defined as the value of the water in its highest value alternative use.
3. Subsidized energy prices for water pumping is widely practiced, from the United States to India. While it has been, or is being, phased out in many countries, in some – India is a prime example – farmers benefit from large subsidies for irrigation pumping.
4. This is confirmed by the fact that, although not formally sanctioned, limited water markets – often involving only neighbours – exist in waribandi-like systems.
5. In the Limari Basin, in Chile, for example, the use cost is about 0.5 cents per cubic metre, and the opportunity cost about US 5 cents per cubic metre.

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4. Appraising flood control investments in the UK

D.W. Pearce and R. Smale

1. INTRODUCTION

The UK government has generally assumed the role of financing flood defence and coastal protection (hereafter just 'flood protection'), but just how much should government spend? For any given budget constraint, appraisal procedures used by the government ministry responsible, the Department for the Environment, Food and Rural Affairs (DEFRA) make use of cost-benefit analysis (CBA) as part of an overall 'scoring and weighting' procedure to assign priority to different schemes. But the size of the budget constraint should itself be determined by a comparison of the social returns to flood protection and the social returns from alternative uses of that money. This chapter focuses primarily on the second question, that is, what is the appropriate size of the flood protection 'budget'? Economic analysis would suggest that if there are higher social returns from expanding the existing budget than the returns on other uses of the money, then flood protection should be expanded. This may amount to changing the 'return period', that is, the probability of a flood in any given time period, so that risks are lowered relative to current design standards and effective current risks.

We argue that:

- on the basis of the appraisal procedures currently used by DEFRA, there are extremely high net benefits from increased flood protection;
- benefit–cost ratios from added expenditure appear to be rising, rather than falling as might be expected;
- existing appraisal procedures understate benefits because of the general omission of categories of benefit not covered by property damage, and because of several conceptual factors.