Chapter II

ECONOMICS OF WATER RESOURCES: A SURVEY

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Water is far from a simple commodity,
Water's a sociological oddity,
Water's a pasture for science to forage in,
Water's a mark of our dubious origin,
Water's a link with a distant futurity,
Water's a symbol of ritual purity,
Water is politics, water's religion,
Water is just about anyone's pigeon,
Water is frightening, water's endearing,
Water's a lot more than mere engineering.
Water is tragic, water is comical,
Water is far from the Pure Economical.
So studies of water, though free from aridity,
Are apt to produce a good deal of turbidity.

Kenneth Boulding (1964)

1. Introduction and overview

This chapter reviews the application of economic concepts to the study of the consumption, supply, and allocation of water resources. Water management poses a wide array of issues for the economist, since few commodities are so pervasively involved in human economic activities. To an important degree, the location and intensity of economic activities depends on the availability of water for drinking, for agricultural and industrial production, for sanitation and waste assimilation, for transportation and for aesthetic and recreational benefits.

Water is said to be the only substance which exists in all three physical states—solid, liquid, gas—within the normal temperature range found on the earth's surface. Via the process known as the hydrologic cycle, the earth's water

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inventory is continually being transformed among the three states. No form of life on earth can exist without water. Water is a nearly universal solvent.

Enormous quantities of water are available; the earth's estimated stock exceeds tens of trillions of gallons per capita. Although only a tiny fraction of this amount is readily usable by humans—because most is too salty, in frozen or vaporous form, or simply in the wrong place—the world's fresh water supply is plentiful relative to present consumption patterns [Baumgartner and Reichel (1975)]. A "water problem" exists when water is not found in the proper quantity and quality at the appropriate place and time.

Objective and scope

Our aim is to direct attention to the more significant of the economic aspects of water resource management. Due to space limitations, we will concentrate on the approaches to policy evaluation, including both project appraisal and the assessment of incentive structures for water users. The emphasis is on the U.S. experience. Matters dealing with water quality and recreation are treated elsewhere in this volume, and are largely ignored here.

Section 2 reviews those characteristics of water resource systems that serve to set them apart from other resources, with particular reference to the attributes which serve as the basis for public intervention. It also describes the nature of the interventions which have been made, and emphasizes the need for evaluating them in terms of their objectives. This is followed, in Section 3, by a survey of cost–benefit concepts and procedures as they have been applied in the water resource planning area. Special attention is given to the measurement of economic benefits. The remaining sections survey several important policy issues relating to water allocation and development, including irrigation planning, floodplain management, interbasin transfers, pricing and allocative institutions.

2. Characteristics of water resource systems and patterns of supply and use

This section treats a number of specific characteristics of water and its use which are relevant to the economics of water and public intervention into water allocation. It also surveys water supply and water use patterns. [See also, U.S. Water Resources Council (1978).]

2.1. Water supply and use

Fresh water for human use may be found in surface water (open bodies of water such as streams or lakes) or groundwater (from subsurface zones in which water is found in voids in sands, gravels, etc.). Water generally is categorized among the
renewable (flow) resources, although certain groundwater deposits are more usefully analyzed with concepts applicable to the non-renewable (stock) resource case.

The unique characteristics of water consumption mentioned above necessitates particular care in understanding what precisely is meant by water "use". Conventional terminology distinguishes between offstream and instream uses [Solley, Chase, and Mann (1983)]. Offstream uses are those requiring withdrawal or diversion from a ground or surface water source. Examples include crop irrigation, industrial water use for cooling or cleaning, and municipal water supply for consumption, cleaning and waste removal. Several factors are involved in measuring the amount of water "used" in an off-stream activity. Withdrawal refers to the amount of water diverted or pumped from the source of supply, while consumption, cleaning and waste removal. Several factors are involved in measuring the amount of water "used" in an off-stream activity. Withdrawal refers to the amount of water diverted or pumped from the source of supply. Delivery means the amount of water received at the point of use, while release is the amount returned to the hydrologic system from the point of use. With consumptive use, water is no longer available because it has been evaporated, transpired, incorporated into products, or otherwise removed from the water environment. Return flow is that amount that reaches a ground or surface water source after release and thus becomes available for further use. Conveyance losses are waters lost in transit from pipe, canal, or other conduit by leakage, seepage, or evaporation. In certain cases, losses may be available for reuse, in which case they may be included as return flows.

Generally speaking, consumptive use plus conveyance losses plus return flows sums to withdrawal. Withdrawal and consumption are the two principal concepts by which water "use" is measured. However, use categories differ greatly in the quantity and quality of their return flows, and hence on the further usability of the non-consumed portion. A full evaluation of water use, therefore, must consider both quantity and quality dimensions.

Non-withdrawal (instream) uses are those uses requiring no diversions from ground or surface water sources. Examples include hydroelectric power generation, maintenance of streamflow or water supplies to support fish and wildlife habitat or aesthetic values, dilution of wastewaters, freshwater dilution of saline water bodies, and right-of-way provision for inland waterways navigation. A number of unresolved conceptual difficulties remain in quantitatively measuring non-withdrawal uses since the waters are neither withdrawn nor consumed. Those issues arise mainly in cases where the tradeoffs between instream and offstream uses are being assessed.

Table 11.1 summarizes estimates of water withdrawals and consumption for the United States in 1980. The major withdrawals of water are for industrial and irrigation uses, accounting for 51 percent and 40 percent, respectively. Since most industrial use is for thermoelectric power plant cooling, which is relatively non-consumptive, this category accounts for only 8 percent of national consumptive use. Irrigation water, which is about 55 percent consumed, accounts for a dominant 82 percent of total water consumption.
Table 11.1
Withdrawal and consumption of fresh water in the United States, 1980
(by source and category of use).

<table>
<thead>
<tr>
<th>Withdrawals (millions of gallons per day)</th>
<th>Groundwater</th>
<th>Surface water</th>
<th>Total</th>
<th>Consumptive use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigation</td>
<td>60,000</td>
<td>90,000</td>
<td>150,000</td>
<td>83,000</td>
</tr>
<tr>
<td>Self-supplied</td>
<td>11,600</td>
<td>179,000</td>
<td>191,000</td>
<td>8,200</td>
</tr>
<tr>
<td>industrial</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rural use(^a)</td>
<td>4,400</td>
<td>1,200</td>
<td>5,600</td>
<td>3,900</td>
</tr>
<tr>
<td>Public supplied(^b)</td>
<td>12,000</td>
<td>22,000</td>
<td>34,000</td>
<td>7,100</td>
</tr>
<tr>
<td>Total</td>
<td>88,000</td>
<td>290,000</td>
<td>378,000</td>
<td>102,000</td>
</tr>
</tbody>
</table>

\(^a\) Rural use includes domestic and livestock uses.
\(^b\) Public supply is water withdrawn for all other uses by public and private water suppliers.
\(^c\) Excludes 171,000 mgd of saline water withdrawn primarily for thermoelectric power plant cooling.


Consumption patterns in other countries will, of course, vary by climate and degree of development. Irrigation represents the major consumptive use of water in the world, as in the United States.

2.2. Characteristics of water resources: The rationale for intervention

The logic of economics emphasizes private resource allocation decisions if the conditions required for a smoothly functioning market system exist. These conditions involve both the nature of goods being traded and the characteristics of the markets within which the trades occur. In brief, these conditions are that there must be perfect competition in the private factor and product markets. Competition, in turn, requires that: (1) Each industry in the economy exhibits increasing costs; (2) all goods and services produced and traded must be exclusive; (3) goods which exhibit jointness in supply, such that one individual's consumption does not diminish any other individual's use of the good (public goods) are absent; (4) all buyers and sellers must have full knowledge of all the alternatives available to them and the characteristics of these alternatives; (5) all resources must be completely mobile; and (6) ownership rights are clearly attached to all goods and services to be traded in the economy.

Physical and economic attributes of the water resource

On several scores, either water as a commodity or the markets in which water is actually bought and sold fail to meet the requirements listed above. In fact,
markets in water are "rudimentary" and unorganized in that there is no regularity of procedure, intermediaries, or location [Brown et al. (1982)]. Several factors account for this situation. Some of these are related to the difficulties in defining "water use", as discussed above. Extending and modifying Bower's (1963) approach, some of the primary characteristics of water which account for the inadequacy of water markets can be listed as follows.

**Mobility** – Water tends to flow, evaporate, seep, and transpire. These attributes present problems in identifying and measuring the resource. Consequently, the exclusive property rights which are the basis of an exchange economy are difficult to establish and enforce.

**Economies of large scale** – Scale economies are evident in water storage, conveyance, and distribution. Therefore, water supply often provides the preconditions for a classic natural monopoly and, hence, water is generally supplied publicly or under regulation.

**Variability in supply** – Water supply is variable in time, space, and quality. The annual cycle of precipitation and streamflows prompts storage reservoirs to smooth out supplies. At the extremes of the probability distributions of availability, the unlikely event yields problems (floods, drought) which may be most economically solved when undertaken by public entities. Flood mitigation, for example, typically has public good characteristics.

**Solvent properties** – Plentiful supply and solvent properties create a capacity for assimilating and absorbing wastes and pollutants. Managing the assimilative capacity of the hydrologic system is, in essence, the allocation of a collective good, one that exhibits non-rivalry in consumption. It is this characteristic of water which requires the introduction of quality as well as quantity in the definition of use.

**Sequential use** – A given river may be tapped by many and varied entities as it flows from upper watershed to eventual destination in sea or sump. Only rarely is water fully consumed by any particular user. The "return flows" from upstream users may be reduced in quantity and degraded in quality, creating many problems for subsequent downstream interests, problems which require complex allocative institutions for solution.

**Complementarity of outputs** – Closely related to the previous point is the fact that some water may be used for more than one purpose. A reservoir can store water for flood control, irrigation, power generation, municipal demands, and recreation. Private ownership may capture only a part of these complementarities.

**Bulkiness** – Water is a "bulky" commodity, in that value per unit weight tends to be relatively low. Therefore, costs of transportation and storage tend to be high relative to economic value at the point of use, and the extensive transportation network developed to transport more valuable liquids (e.g. petroleum) is found only to a limited extent for water. This characteristic, combined with the relative costliness of enforcement of property institutions noted above, yields situations where the optimal property structure is the "commons" or open access.
Conflicting cultural and social values—Even where economic productivity might be best served by market allocations, alternative goals may oppose the result dictated by pure willingness to pay. Boulding (1980, p. 302) notes that "the sacredness of water as a symbol of ritual purity exempts it in some degree from the dirty rationality of the market". Market-induced shifts of water to energy or household uses which would alter flows or dry up streams are judged on the degree to which the natural environment or the existing social structure (i.e. the family farm) are affected. For such reasons, some cultures proscribe water allocation by market forces.

2.3. Public intervention in water resource allocation

2.3.1. The rationale for public intervention

Where markets are thin or absent, or where the demands or supplies revealed to markets capture only a portion of the full social costs of benefits, or when the commodity (water) in some role has public good characteristics, public intervention may allocate resources more efficiently. Public intervention may take a variety of forms: regulations (to provide for regularity of water use and to protect a given function of water—e.g., recreation—against present and future competing demands; public investment in structures to protect against damages from flooding (a public "bad") or to provide infrastructure (for example, navigable water courses); or public ownership and operation to produce services jointly produced with other water related outputs (for example, hydroelectric power or municipal water supply). Collective action of these forms appears in a wide variety of combinations to serve a wide variety of objectives.

A number of facets of this issue, and the complexity involved, can be easily illustrated. Averting flooding through constructing a flood control dam yields a public good—when one downstream resident is protected from flooding, all downstream property owners are automatically protected. The provision of the dam may be socially worthwhile in that the social benefits may exceed the costs of building and maintaining the dam, but the private sector would fail to undertake the provision of flood control because of the difficulty of recovering costs from downstream beneficiaries. Similarly, some of the other "outputs" of water resource development may have public good or externality characteristics. These may be improved boating and picnic facilities created by the reservoir behind a dam, or beneficial side effects of a more reliable river channel or hydroelectric power potential created in constructing a flood control dam.

When goods involving these spillover effects are present, the efficient resolution often involves production by the public sector. Even in those cases where production is left in the private sector, public action may be necessary either to
ensure the socially optimum amount of production or to correct for undesirable inefficiencies.

Thus, if the social benefit of these non-marketable services exceeds the cost of providing them, which it often does, and if the development of the river by a private firm precludes the development of these other purposes, which it often does, then private development of the stream denies society the benefit of these worthwhile yet external or spillover benefits. Multipurpose development by a government agency will permit society to enjoy the benefits of those products.

The converse of this may exist if private development imposes significant spillover costs. This is the case with proposals to construct hydroelectric or flood control dams which would flood out sites valuable for wilderness experience, scenic beauty, and other environmental values. In such a case, collective action may be required to keep a private project from being undertaken. It should be noted that this same conclusion would hold if the “developer” were a public agency rather than a private firm.

However, as Castle (1978) and Wolfe (1979) contend, government interventions may also “fail”, so that combinations of market and non-market resource allocation mechanisms may yield the most appropriate solution in an imperfect world.

Finally, we can agree with Kelso (1967) who observes that while “water is different”, the general public perception ascribes peculiarities to water that go far beyond any idiosyncrasies that can be objectively identified. Water policies and institutions are often out of touch with the realities of a world in which water is increasingly scarce. Even though water has special attributes, its allocation is an economic problem, and policies and institutions for its management should be designed to achieve economically efficient and equitable allocation.

2.3.2. The nature of public intervention in the water sector

Water management strategies may be distinguished according to several basic characteristics [White (1971)]. One characteristic concerns whether the water allocation decision is made by public or private sector decision-makers. Second, the project or program may be single-purpose or multiple-purpose. Third, the means employed may be distinguished as to whether one or more techniques or means are considered in providing project or program outputs. Structural or engineering approaches were the main forces of early policy, but non-structural or institutional means for solving water problems are receiving increasing attention. Finally, strategies may be judged according to a single criterion, such as economic efficiency, or multiple objectives, which may include the distribution of income or other social goals.

Federal intervention in the development and management of water resources in the United States dates from 1802, at which time the Corps of Engineers of the
U.S. Army was established. From the first Corps appropriation of $75,000 in 1824—"for the removal of snags, sawyers, planters and other impediment of that nature" from the Ohio and Mississippi Rivers—public intervention, almost exclusively by the Federal government, has grown to enormous proportions. In the provision of irrigation water in the west, however, Federal legislation has also shaped the nature of ownership rights and market trading of water. Below, we briefly describe the nature and history of the public intervention in water resources in the United States. [See also Holmes (1972, 1979).]

2.3.3. Flood control

Although protection against flooding was one of the most recent water-related activities of government, it has firm economic rationale. A swollen watercourse has "public bad" characteristics—when flooding occurs, no downstream property owner or watercourse use is immune from damage. Conversely, an investment designed to reduce flooding, for example, a dam and reservoir, will automatically reduce damages from flooding for all downstream users. The Federal government has constructed numerous control reservoirs and dams, as well as undertaking river bed straightening and deepening and levee and revetment construction in areas subject to inundation.

Most Federal flood control expenditures prior to 1936 were administered by the Mississippi River Commission, mainly in response to the disastrous flood of 1927. The Congress in 1936 for the first time assumed nationwide responsibility for flood control, an activity which until then had been viewed as a local government responsibility (except for the Mississippi River). "Flood control on navigable waters or their tributaries is a proper activity of the Federal government." While flood control absorbed a relatively small share of Federal water resource expenditures in the period prior to 1945, during the post-war period, the flood control program became the major peacetime function of the Corps of Engineers. The Department of Agriculture, through its Soil Conservation Service, had the mission of reducing agricultural flood damages upstream of the large Corps installations on the major rivers. About one-half of total damages were agricultural. The expenditures of the Agriculture Department consisted of comprehensive soil conservation and land treatment activities and small storage projects in agricultural watersheds.

2.3.4. Navigation

Public investments in the inland waterway system have the same economic rationale as public infrastructure investments in transportation in general—the
opening of undeveloped regions, the enabling of trade and communication among regions, and the provision of capital intensive right-of-way (with public good aspects). Water investments, historically, had a further purpose of stimulating a traffic mode which could effectively counter the monopoly power and preemptive practices of the railroads. The Federal navigation program has been the domain of the Corps of Engineers, and has been focused historically on the Great Lakes ports and inland waterway system. In the past two decades, however, activities have concentrated on the Mississippi and Ohio Rivers, ocean harbors, and coastal rivers.

The inland waterway program consists of a wide variety of project types—dams designed to regulate flows to navigable depths, dredging and straightening watercourses to permit barge transportation, the construction of canals where no natural watercourse exists, the construction of Great Lake and ocean port facilities, and the maintenance of all of these.

2.3.5. Hydroelectric power

Public production of electric power is largely a post Second World War phenomenon. With few exceptions, electric power generation is a secondary purpose of projects the primary function of which is to provide flood control, irrigation or navigation services. The hydroelectric generation function has been justified as an economical by-product of irrigation, flood control and navigation projects. The Corps of Engineers is responsible for only about 20 percent of the public hydroelectric capacity in the United States; the primary construction agencies are the Tennessee Valley Authority (over one half of the capacity) and the Bureau of Reclamation which has provided hydroelectric generation as part of a number of large irrigation projects in the western states. While the Corps of Engineers and Bureau of Reclamation have been responsible for project construction, the power is marketed through special agencies in the Department of Interior with a cost recovery mandate.

2.3.6. Irrigation

The irrigation program began with the Reclamation Act of 1902, which authorized the Bureau of Reclamation of the U.S. Department of Interior to build irrigation projects. The reclamation program is confined to the 17 western states (plus Alaska), and is financed by sales of public lands, beneficiaries of projects (which are required to pay some share of the costs), the sale of electricity and general appropriations. While the Bureau of Reclamation is responsible for construction of the projects and the arrangement for reimbursement, management and maintenance is turned over to user-managed irrigation districts.
The economic rationale for irrigation investments is one of the most tenuous of the Federal water resource activities. Three reasons have been suggested: (1) the infrastructure, regional development rationale, (2) the need for eminent domain rights in order to secure water rights and land rights for project construction, and (3) the massive initial capital requirement that creates a barrier to private or local provision. However significant these may have been in the west in the early part of the century, they are of questionable import now.

2.3.7. Other water resources purposes

In addition to the interventions described above, a range of other public activities involving the provision or use of water have been undertaken by the public sector. Here these will simply be mentioned.

Water pollution control. The Federal role in water pollution control was trivial before 1960, and modest until 1966. During the early 1960s, these activities were under the supervision of the Department of Health, Education, and Welfare (HEW) and included: data collection and dissemination, research, administration of pollution control grants to state and local governments and industry, and enforcement procedure) of the water pollution control act. The economic rationale for this intervention is clear: reducing or preventing spillover costs on downstream water users from the discharge of effluents.

During the decade of the 1960s, the organizational arrangements for pursuing water pollution control changed substantially, culminating in the creation of the Environmental Protection Agency (EPA) in 1970. The functions of the pollution control offices (and the appropriations granted them to support these functions) were expanded to include: extended enforcement powers, establishment of water quality standards for all watercourses (including the setting of criteria and a plan to implement the criteria), and (after 1970) the setting of effluent standards and the enforcement of the standards on both municipalities and states. Throughout the entire period, the strategy of the Federal government was basically two-pronged: the setting and enforcement of regulations (standards) and the provision of subsidies to accelerate pollution control activities.

Municipal and industrial water supply. The provision of water to municipalities and industrial users has been a long-standing by-product of the Reclamation program. Beginning in the 1960s, however, such deliveries and contracts became more important than in earlier periods, but remained but a small fraction of irrigation water deliveries.

Recreation. As with the water supply function, the Federal provision of recreation services has also grown, again largely as an economic by-product of activities whose basic purpose was flood control, navigation, or irrigation. The various agencies have accepted this function, and implemented it by the construc-
tion of parks and recreation grounds adjacent to reservoir facilities and the provision of access to and the regulation of water based recreation activities.

2.4. The objectives of public intervention in water resource allocation

The prime requisite for evaluating public interventions in the water resources area is an explicit statement of the objective toward which the resource development decision is focused. The benefits attributable to use of a resource have meaning only in relation to the objective, and are measured as the contribution of the resource to the objective function [Marglin (1962)]. Discerning the objectives of public interventions in the water resources area is difficult as the principal public sector decision makers often fail to articulate any clear purpose for their decisions. Nevertheless, the statements and actions of policymakers do seem to point rather systematically to the interaction of two objectives which guide public interventions: (1) economic efficiency and (2) regional economic aid or income redistribution.

From the very inception of Federal government activity in both the development of navigation facilities and flood measures, some emphasis has been placed on the degree of economic efficiency of the projects to be constructed. While tangible evidence of such concern is found earlier, the Congress in 1936 further reaffirmed and clarified this position by requiring that, for such projects to be authorized, benefits must exceed costs, "to whomsoever they may accrue". Since that time all water resource projects have been evaluated by the evolving methods of benefit–cost analysis.

While concern with economic efficiency is of long standing in the history of water resource development in the United States, other criteria have also been explicitly recognized, in particular, income distribution and regional development. The concern with the multiple objectives to be served by public water resource developments is reflected in both the writings of scholars in this area and in official government documents.

In an early statement (1952), the Bureau of the Budget's Circular A-47, discussing the criteria to be applied by the executive office in the review of project reports, placed great emphasis upon economic efficiency in defining concepts to be included as benefits and costs. Also, however, "the efficiency of the program or project in meeting regional...needs" is stated as a further criterion. The "Green Book" [Federal Interagency Committee on Water Resources (1958)], while again heavily emphasizing the necessity of total annual benefits exceeding estimated annual costs, explicitly noted the importance of regional development as a public water policy objective.
This growing recognition on the multi-dimensional nature of the social welfare function in planning for water resources was extended in Senate Document 97 [U.S. Congress (1962)] and was formalized in the Water Resources Council's *Principles and Standards*, in 1973. The 1973 *Principles* established four accounts on which evaluation was to be based – national economic development (economic efficiency), regional development, environmental quality and social well-being. These categories were maintained in the documents of the Water Resources Council's (1979) revisions and extension, while procedures for measuring beneficial and adverse impacts were refined.

The U.S. Water Resources Council's (1983) *Principles and Guidelines* retained the same four-account classification with some minor changes in nomenclature and procedure. This document returns the emphasis to the national economic development objective while requiring plans to be consistent with environmental protection.

In sum, then, the focus on economic efficiency – the existence of project benefits in excess of costs – in water resources has been fundamental and persistent. However, a basic and growing tension between this efficiency goal and other objectives – largely, regional development or income redistribution – exists. [See Eisel et al. (1982) and Castle et al. (1981) for more detailed discussions of the evolution of Federal evaluation procedures.]

3. Benefit–cost analysis for water resources systems

3.1. Conceptual basis

The prevailing technique for evaluating public investments and policies in the water resources area is benefit–cost analysis. This approach assumes that economic efficiency is the relevant objective for public water resources interventions. Procedures for estimating the benefits and costs of a non-marketed commodity such as water can be interpreted as efforts to simulate hypothetical market outcomes. The basic concept of "benefit" underlying such estimation is *the amount a rational and informed user of a publicly supplied good would be willing to pay for it*. Costs represent the forgone value of goods and services displaced by a project. [See one of the general texts on cost–benefit analysis, e.g. Pearce and Nash (1981), Mishan (1976) or Gittinger (1982) for more general treatments of the subject.]

Willingness to pay, which reflects the user's willingness to forego other consumption, is in turn, formally represented by a demand curve relating the quantity of a good taken at a series of alternative prices. [The producer's demand for an input is given by the marginal value product (MVP) for that input.] The value of additional units decreases as the quantity consumed increases. The
negative slope of the demand curve follows from the principles of diminishing marginal utility of consumers and diminishing marginal product for producers. The measurement of willingness to pay should be designed to be consistent with market prices.

Krutilla and Eckstein (1958) presented a conceptual framework for analyzing multi-purpose river basin investments. Marglin (1962) formalized the model, and extended it to more complex cases where demands are interdependent and budget constraints apply. A net benefit criterion function, representing the present value of the streams of future benefits and costs, is maximized. [See Herfindahl and Kneese (1974) for a succinct summary.] Marglin's summary provided the basis for developing interdisciplinary computer simulations models [Maass et al. (1962), Hufschmidt and Fiering (1966)], which played an influential role in the subsequent development of the water resource planning literature.

While computer simulations may employ the model of optimal resource allocation, various simplified formulas are employed to measure project worth at the field level. These include the net present value, the benefit cost ratio and the internal rate of return. Any text on cost benefit analysis describes their computation, use and limitations [James and Lee (1971), Gittinger (1982)].

3.2. Problems in measuring the economic impacts of water resources interventions: Conceptual issues

There are a number of conceptual issues relating to the general question of measuring the impacts of water resource interventions, to which we now turn.

3.2.1. "With or without" principle

This rule asserts that benefits and costs are to be measured as increments which would occur with the project or program as compared to without. Adherence to the rule assures that measured benefits (or costs) are solely due to the program or project, rather than measures of changes between before the project as compared to after, some of which would have occurred autonomously even in the absence of the program.

3.2.2. The accounting stance

In the theoretical construct of the market system, a private accounting stance is presumed. Individuals are motivated to act in accordance with gains and losses as each perceives them, and pursuit of private objectives (such as maximizing utility or profits) is assumed to occur independently of gains and losses occurring elsewhere in the system. When the responsibility for an allocation decision rests
with a public agency, an alternative criterion may be appropriate. In the water
resources literature, two major alternatives to the private perspective are found
(i.e. alternative "objective functions" or "accounting stances"). These reflect the
viewpoints, respectively, of regional planning authorities (river basin or state) and
the Federal government [Howe (1971, ch. 2)].

Regional and national accounting stances differ from private financial analysis
in that social rather than private benefits and costs are incorporated into the
analysis. Ideally, the national accounting stance should attempt to utilize social
opportunity costs and values for all inputs and outputs, whether they are correctly
or incorrectly priced by the market mechanism, or not priced at all. All externali-
ties should be identified and incorporated into the measures.

3.2.3. The equimarginal principle

The marginal benefit represents the contribution of an incremental unit of good
or factor to a specific objective function and is defined by the first derivative of
the total benefit function. As was shown above, it is the net marginal benefit
function which is of primary importance for purposes of efficiency analysis in
water resource development and allocation. For the development case, economic
efficiency requires that development be undertaken to the point of equality
between the marginal value of the output and its marginal cost. For the realloc-
ation decision (i.e. the allocation of constrained water supplies among competing
uses), economic efficiency is achieved when net marginal benefits per unit of water
are equal for all uses. This latter proposition is familiarly known as the equimargi-
nal principle.

3.2.4. Long-run versus short-run value

A fourth conceptual distinction is that between short- and long-run value. This
distinction is related to the degree of fixity of certain resources and is especially
important where commodities are used for further production (i.e. intermediate as
opposed to final goods), as is typical with respect to water.

The rational producer's willingness to pay for an increment to water supply is
equivalent to the increase in the net value of output attributable to the added
water. The distinction between short-run and long-run value is that in the short
run, where some inputs associated with water use are fixed, estimates of increases
in the net value of output can appropriately ignore the sunk costs of the fixed
resources. However, in the long run, all costs must be covered.

3.2.5. Physical interdependence and economic impacts

The above discussion points to a major problem which increases the difficulty of
evaluating the benefits and costs of using water. A specific water use cannot, in
most cases, be viewed in isolation from potential alternative utilizations. The typical river basin will contain several alternative uses for water and one use may affect others through any or all of the quantity, quality, time, and location dimensions. The benefits from a particular increment of water supply in a given river system is the sum of the value of the marginal product in the initial use and the value of the return flow in all subsequent uses. In a system context, the sum is net of the positive and negative effects which are engendered elsewhere or subsequently in the system [Hartman and Seastone (1970), Butcher, Crosby and Whittlesey (1972)].

3.2.6. Appropriate measure of use

Formally, the valuation problem posed by physical interdependencies in water use is that of specifying the unit of measure of the variable representing quantity of water. In certain situations (e.g. complementary products such as recreation), evaluation of water resource development decisions may not require a measure of value per unit of water “used”. This is true so long as a use is not competitive with another.

Another problem is posed by instream utilization. While navigation, recreation, power generation, and waste load assimilation do not withdraw or consume water in the usual hydrological sense of these words (evaporation and seepage aside), instream uses clearly can foreclose other economic uses at a particular location and at later times. The “with and without” principle will provide guidance in such instances.

For cases involving withdrawal use, some unit measure of use is clearly required for the evaluation of alternative uses. The choice of the appropriate measures of use is typically between the withdrawal versus the depletion (consumption) concepts. D’Arge (1970) contended, for example, that the selection of the appropriate variable depends on the interdependencies existing among users and on the availability of benefit estimates. He concluded that consumption is the relevant variable for public planning purposes.

Most economists seem to prefer to measure use in terms of withdrawal, since that is what the individual private user must pay for. Moreover, conventional measures of consumption, in terms of evaporation may be misleading for economic analysis from a social perspective. As examples, return flows may so degrade in quality as to be unusable or return flows percolating back to the groundwater table in deep aquifer situations may not be available for reuse in any reasonable planning horizon.

3.2.7. Economic benefits related to location, quality, and time

Site productivity refers to the economic value of water used at a particular geographic location for a specific class of use. The costs of transporting this bulky
commodity are such that the derived economic value of water in the stream will be considerably less than at the point of use. The factors which influence the physical productivity of water at a particular location for each type of use also affect the economic value. Examples of these factors include soil and climatic characteristics affecting the physical productivity of irrigation water or aesthetic characteristics of a particular site which influence the value of water for recreation. The productivity of water is also dependent upon the degree of investment in other resources used in conjunction with water, such as the height to which a power dam is constructed or the investment in efficient water application systems in irrigation.

Temporal variability in demand can significantly affect benefit estimates. The variation may extend from the very short run to the long run. The most important case stems from seasonal variation such as shifts found in demand from agriculture, navigation, recreation, and waste load assimilation. Also, secular trends in population, income, and technology have a long-run impact on the demand for water.

Water must frequently undergo some form of processing (filtration, chlorination, pressurization, etc.) prior to use. Thus, there will be differences in willingness to pay for the raw (unprocessed) water as compared to the benefits of water of suitable quality for a specific use.

To sum up, specifying strictly commensurable shadow prices for alternative uses of water requires that benefits per unit of water be conceptually equivalent in terms of time, location, and quality. [Flinn and Guise (1970) and Howitt et al. (1982) present sophisticated modeling efforts which incorporate these distinctions.]

3.3. Techniques for determining the direct economic impacts of water resources interventions

Five broad approaches for measuring the benefits of water resources interventions may be identified [Young et al. (1972), Gray and Young (1984)]. These include: (a) observation of transactions relating to water, (b) derivation of value from a statistical demand function, (c) residual imputation and variations, (d) alternative cost valuation and (e) user surveys. (Where certain costs of water development projects are not correctly reflected in market prices, these techniques are also applicable to the measurement of such costs.)

3.3.1. Market transactions relating to water

Because of the physical, economic, and institutional characteristics of water, market transactions for water are rare. However, they do exist and in such cases the observed price must be carefully interpreted. The least complex has been termed the “irrigation water rental market” [Anderson (1961)]. The owner
maintains the title to the perpetual annual stream of water supplies but sells the right to receive the water for a specified period of time. The observed prices in rental markets are based on private, short-run demands and may be of limited utility in evaluating long-term public investment or reallocation decisions.

Transactions in permanent water rights are not common, largely because of institutional constraints designed to avoid third party effects [Ditwiler (1975)]. Observed transaction prices of transfers between similar uses are conceptually correct measures of the long-term private value of the resource in that purpose. However, interpretation of these derived values must be done with care if public shadow prices are needed. Also, the appropriate price is that for the right to a perpetual series of annual flows, and not the price of a unit volume of water. In order to derive the value of a unit volume, an appropriate capitalization formula, with the proper interest rate, must be applied to the price of the right. Will the private sector exhibit the same rate of discount, risk aversion, time horizon or price expectations as would be selected by the public analyst? Gardner and Miller (1983) have illustrated this approach with data from the Northern Colorado Water Conservancy District, while Brown et al. (1982) have studied markets for water rights in New Mexico. The cyclical price variations observed by Gardner and Miller are consistent with the hypothesis that the market price of water rights can be affected by the same imperfect forecasts of inflation or urban growth rates as are markets for precious metals, real estate, or common stocks.

The value of water rights has also been estimated indirectly where the right is transferred as a part of a real property transfer. Statistical regression analysis applied to a sample of such transactions characterized by variation in water supply per unit of land permits inferences to be drawn as to the capitalized value of the water right. Freeman (1979, ch. 6) presents a detailed review of the problem of employing property values to study the benefits of non-marketed goods and services, particularly with respect to environmental quality. (See also Chapter 15 of this Handbook.)

A second type of observed transaction in water is that in which water supplies in withdrawal uses are sold under an “administered” price system. In this case, the public agency or utility which supplies water may sell it at a specified price through a metered system. The consumer is free to adjust consumption to reflect the marginal valuation of water use at the specified price. Statistical analysis of cross-section or time-series data pertaining to the consequent relationship between consumption and price can be used for inferring the value of water to the final user [Howe (1982), C.E. Young et al. (1982)].

3.3.2. Benefit estimates from econometric production functions

The classical approach to estimating values of non-marketed commodities is to estimate the demand function for the good in question. Water is often an intermediate good, in which case the demand function is the marginal value
product function, the first derivative of the production function in value terms. Use of econometric production function estimates is most common in valuing water in irrigation use, where numerous field experiments have studied crop response to water application and other factors [for example, Hexem and Heady (1978)]. The general approach is to derive a schedule representing the short-run value of the marginal product under the experimental conditions.

Cobb–Douglas type functions may be fitted to farm account data with irrigation water as an explicit variable have been employed in estimating long-run marginal value productivity. A major problem in such cases is obtaining an accurate measure of water applied. Extrapolation, of course, must be done with caution. Moreover, the derived value may not be suitable for social cost–benefit analysis if commodity market interventions or unemployment are present. Ruttan (1965) and Beattie et al. (1971) have applied the approach to aggregate irrigation and production data.

In industries other than irrigated agriculture, a scarcity of the data necessary to estimate demand or production relationships, together with the fact that water accounts for a very small portion of production costs, has generally forced analysts to turn to alternative estimating procedures.

3.3.3. Residual valuation approaches

Residual imputation achieves the task of shadow pricing by allocating the total value of output among each of the resources used in a single productive process when water is used as an intermediate good. If appropriate prices can be assigned to all inputs but one, then the residual of the total value of product is imputed to the remaining resource [Heady (1952)].

The residual imputation technique is based upon two major postulates: (1) the market prices of all resources, except the one to be valued, are equal to the returns at the margin (value of the marginal product), and (2) the total value of output can be divided into shares such that each resource is paid according to its marginal productivity and the total value of output is completely exhausted (Euler’s Theorem). Consider a simple example where three factors, capital, labor, and water, are used in the production of a single output \( Q \). The problem is to impute a value to the water resource. By Euler’s Theorem:

\[
TVP_Q = VMP_L \cdot L + VMP_K \cdot K + VMP_W \cdot W
\]

(1)

where \( TVP_Q \) is the total value of output \( Q \), \( VMP_i \) represents the value marginal product of any resource, \( i \), and \( L \), \( K \), and \( W \) refer, respectively, to quantities of labor, capital, and water employed. Substituting according to the first postulate and rearranging, we have

\[
TVP_Q - P_L \cdot L - P_K \cdot K = VMP_W \cdot W.
\]

(2)
Eq. (2) is solved for $VMP_w$ to estimate $\hat{P}_w$, the desired shadow price of water.

The postulates cited previously are satisfied by production functions homogeneous of the first degree and optimizing producers in competitive markets. The Cobb–Douglas function, which implies constant returns to scale, satisfies Euler’s Theorem and has been used in empirical estimation of marginal value products.

Residual imputation is subject to limitations which should be recognized by the user. First, if input variables are omitted, inadvertently or otherwise, the residual will be overstated. Second, distortions of either input or output prices will lead to a distorted residual estimate. Lastly, this procedure is most applicable to estimating the value of water in production processes (such as irrigated crop production), where the water resource is a substantial contributor to total product. In industrial uses, where the contribution of water rarely represents more than 1 or 2 percent of total value of product, the difficulty in properly shadow pricing the other factors, particularly capital, management, and risk-bearing, leads to highly uncertain estimates of a residual value of water.

Mathematical programming procedures can be employed to derive imputations of the value of water which are theoretically similar. Burt (1964) pioneered this approach with application to irrigation water, deriving a long-run net benefit function from parametric variation of a water supply constraint in a linear programming (LP) model of a California agricultural region. Depending on the definition of the objective function, long-run or short-run value estimates are obtained. Numerous others have used LP models to impute short-run values to irrigation water, in which case the residual is the return to land, management and fixed investments, in addition to water.

The “Change in Net Income” method (hereafter abbreviated to CINI) is related to the residual valuation approach. This model defines the increment in net producer income associated with adding water to a production process as willingness to pay for the incremental water. The approach is that adopted for valuing irrigation water benefits by the U.S. Water Resources Council (1979). Assign $X_i$ to represent production inputs and $Y_j$ refer to products, and let the subscripts 0 and 1 attached to the input and output variables refer, respectively, to values without and with investment or program adding to water supply. The water resource is designated $X_1$. Assuming that the factor prices ($P_{x_i}$) and product prices ($P_{y_i}$) are unaffected by the investment, the change in net income $\Delta Z$ associated with a discrete addition to water supply per unit of time is:

$$\Delta Z = Z_1 - Z_0 = \left( \sum_{i=1}^{m} Y_{1i}P_{y_i} - \sum_{j=2}^{n} x_{1j}P_{x_j} \right) - \left( \sum_{i=1}^{m} Y_{0i}P_{y_i} - \sum_{j=2}^{n} X_{0j}P_{x_j} \right). \quad (3)$$

The second term in (3), in effect, represents the annual net returns to the fixed land resources in the “without” project situation.
The unit value of water may be obtained by dividing the expression in equation (3) by the incremental quantity of water (i.e. $\Delta X_1$).

The CINI approach requires the same assumptions of the residual imputation procedure, namely, that resources be optimally allocated, that factor and product prices correctly reflect social values, and that all inputs be properly represented in the calculations.

A number of studies have attempted to measure the value of water from a regional perspective employing regional inter-industry models. Such studies typically employ a concept of "value added", or more generally, of income of primary resources per unit of water withdrawal as a criterion for allocating the resource.

What we term here as the "value-added approach" has certain key similarities to the residual approach described above, but it also has important differences. Although its practitioners have presented it as an appropriate method for valuing an unpriced resource such as water, this interpretation can be accepted only under very limited conditions. The important difference between the value added and the correct residual approach lies in the definition of value added. Since value added is generally an aggregation of the basic inputs to production, the residual in this case includes not only the contribution of water to the value of output, but the contribution of all primary resources. Attributing the value added to water implicitly assigns a zero shadow price to the other primary resources and thus ignores the fact that resources other than water are scarce. Assigning zero opportunity cost to other primary resources by implicit assumption is questionable, and tends to result in water value estimates which greatly overstate the true contribution of water to net regional output. The value-added imputation process can lead to conceptually correct results only if (1) extreme care is taken to disaggregate value added so that the contribution of all other primary resources is empirically identified and deducted from value added or (2) if the assumption that the opportunity costs of the other primary factors is zero is verified. A number of well-known studies by regional economists have used this method, and their results are subject to this critique [i.e. Wollman (1963), Lofting and McGauhey (1967), d'Arge (1970), and Bradley and Gander (1968)].

3.3.4. Alternative cost

The fourth major technique of value estimation discussed here is based on the concept of "alternative cost". Alternative, in the alternative cost context, refers to a substantively different means of accomplishing the same project purpose. Willingness to pay is limited to the cost of the most likely economically feasible alternative. The definition is deceptively simple because there are a number of possible alternatives, including private alternatives to public projects, public
alternatives to each component of dual purpose projects, and so on. [See Herfindahl and Kneese (1974, pp. 267–270), for a more detailed exposition.] The technique is applicable to cases in which a private alternative (e.g. a railroad system for commercial transport) to a public development (e.g. navigation for the same purpose) exists. Maximum willingness to pay is determined by the cost of the least expensive alternative.

The approach is attractive since in many cases estimation of a demand schedule is very difficult, if not impossible. However, complexities arise in the situation in which neither alternative need be built to a fixed scale. Then the demand schedule must be estimated for the output range between the private level of output and the public level of output (assuming demand is not totally inelastic) of the private alternative represents the upper limit of willingness to pay (benefits) for the public alternative.

The primary advantage of the alternative cost method is that, for cases in which demands are difficult to obtain, estimation of maximum willingness to pay can be accomplished without estimating demand functions. In those situations where the output of each of two alternatives is water, as in the case of private development of groundwater for irrigation versus public supply, the least cost alternative can represent a legitimate estimate of the social value of water. In some situations, e.g. transportation, power production, and waste treatment, estimation of direct benefits to water, as contrasted with total project benefits, is a two-step process. First, the alternative cost of accomplishing a given purpose must be estimated. Second, a benefit per unit of water must be imputed, usually by deducting from the alternative cost the associated costs (an application of the residual technique described above).

3.3.5. User surveys

The final category concerns methods for determining the demand for water when no exchange transaction or diversions for production occurs, that is, when the “use” activity involves neither consumption nor diversion. In such cases, usually associated with recreation and aesthetic enjoyment of water in natural surroundings, water has a public or collective good character. Here, analysts have come to rely on user surveys to derive estimates of the value of the recreation experience, and more particularly, of the value of the contribution of environmental resources, such as water, to that experience [Knetsch (1974)]. Two general lines of approach can be identified – the expenditure function approach, and the income compensation approach.

The expenditure function approach relies on market-generated price and quantity data where the quantity of a non-rival good is an argument in the demand for some private good. Under certain conditions regarding the demand relationships,
an empirical estimate of the benefit for the non-rival commodity can be derived. The well-known Clawson–Knetsch travel cost method and land-value approaches to valuing amenities are examples.

The income compensation function approach derives from the Hicksian model of monetary equivalent measures of welfare impact. Willingness to pay is defined as the area under the Hicksian compensated demand curve. Since the indifference surfaces of the theoretical model are not directly observable, various approaches to estimation have been developed. These mainly depend on a “direct asking” (contingent valuation) approach to estimating changes in economic surplus. Freeman (Chapter 6 of this Handbook) develops these issues in detail, and we do not treat them further.

3.4. Social cost measurement

For the most part, water project appraisal proceeds on the assumption that the relevant markets reasonably accurately reflect the costs of factor services and intermediate goods employed by the public sector. In smoothly functioning markets, wage rates and the prices of material and equipment adequately measure the opportunity cost of resources. Some possible exceptions to these presumptions are noted here.

3.4.1. Underutilized resources

The existence of unemployed and underutilized resources must be recognized in any attempt to estimate the true social cost of a water resource project. The opportunity cost of underutilized resources is less than the market price, since little forgone production occurs if such resources are utilized.

Early writers [Eckstein (1958), McKean (1958)] acknowledged the problem, particularly with regard to labor, but were skeptical of attempts to forecast unemployment over the long interval between project planning and construction or the even longer period of the operating project's lifetime. Haveman and Krutilla (1968) initiated efforts to develop empirical measures of the opportunity costs of underutilized labor. A response function was formulated which relates the probability of drawing from a pool of idle resources to the unemployment rate in that pool. Adopting an a priori hypothesized form of the response function, they concluded that the true social cost of projects were some 5–30 percent less than monetary costs (based on employment data from 1957 to 1964). Significant regional variation was found in the appropriate adjustment factor. They and others note, however, that for appropriate measurement of the social cost of labor, it is not sufficient to measure the “before” and “after” labor force status, but that “with” and “without” conditions must be compared. The latter is
particularly difficult to achieve, particularly given the prospect for labor migration from other regions.

Federal evaluation procedures regarding underutilized resources have varied rather widely. Senate Document 97 [U.S. Congress (1962)] encouraged accounting for project construction period and operating period unemployment, and permitted recognition of indirect and induced employment effects. The U.S. Water Resources Council’s (1973) Principles and Standards limited consideration of underutilization to only the construction or installation period, a practice continued in the (1979) and (1983) revisions.

We close this topic by calling attention to a rather different approach. Johnson and Layard (1982) adopt a general equilibrium framework, and show under plausible assumptions that the social opportunity cost of unemployed labor can exceed the wage rate.

3.4.2. Opportunity costs of non-marketed resources

Market prices may be biased or absent in the case of lands used for project sites. Recreational benefit forgone from reservoir construction is an example. If the site is publicly owned, no budget outlay for its purchase is required, but non-marketed alternative (e.g. recreational) uses may be sacrificed. (If the land is purchased, the higher private discount rate, an aversion to risk and differing price expectations on the part of private land market participants may imply an assessed value which diverges from that derived from evaluations from a social accounting stance. Particularly in instances where an irrigation project inundates some farm lands to develop other farm lands, the opportunity costs of the site should be assessed with the same discount rate, commodity prices and production costs as are the benefits of the development.)

Finally, the opportunity cost of the water itself must not be ignored. As water economies mature and the resource becomes increasingly scarce, the potential forgone values will rise. Since relative economic values and institutional arrangements both act to protect household and industrial demands, the problem arises mostly with instream uses. Hydropower benefits forgone can be very high when irrigation water is diverted high in a river basin [Whittlesey and Gibbs (1978)]. Recreational uses requiring instream flows are only beginning to be protected by legal rights [Daubert and Young (1981)].

3.5. Other benefit–cost analysis issues

We treat briefly below a number of long standing economic issues which have pervaded evaluations of public interventions in the water field.
3.5.1. The discount rate

Around the mysteries of finance
We must perform a ritual dance
Because the long-term interest rate
Determines any project's fate:
At two percent the case is clear,
At three, some sneaking doubts appear,
At four, it draws its final breath
While five percent is certain death.

Kenneth Boulding (1964)

A long-standing issue in applying benefit-cost analysis in the water resources area concerns the rate of interest to be used in the discounting of future streams of benefits and costs. Until 1969, official procedures manuals stipulated that "average long-term interest rates that will prevail over the life of a project are considered the proper basis for discounting future benefits and costs". The long-term government bond rate was taken as the measure.

This rate was rationalized as follows. First, it is claimed that the rate of interest conceptually appropriate for use by the Federal government is the social cost of capital, i.e. "...the risk-free return expected to be realized on capital invested in alternative uses". Second, because the government can borrow funds at the going long-term government bond rate, it is claimed that this rate is an accurate estimate of the social cost of capital. Critics of this procedure have argued that because of the difference between lender's and borrower's risk, the rate on long-term government issues is less than the social opportunity cost of capital [Eckstein (1958)]. Also, due to the effect of taxes, the actual bond rate may fall far short of the real opportunity cost of capital as determined by its pre-tax value in an alternative use. (Offsetting these biases in recent years has been the effect of inflationary expectations and heavy government borrowing in increasing the nominal cost of capital to the government.)

The appropriate conceptual basis for the discount rate to be used by the public sector has been long-debated in the economics literature. Depending on the perspective taken, a case can be made for any of the following concepts: (1) the social rate of time preference [in conjunction with a cut-off benefit-cost ratio to reflect opportunity costs (Marglin (1968), Eckstein (1958))]; (2) the opportunity cost of displaced private spending, [Haveman (1969), Harberger (1968)]; and (3) the before tax rate of return on corporate investments [Stockfisch (1982)].

In 1968, H.P. Caulfield, Director of the Water Resource Council, proposed a formula approach to determining the discount rate on federal water resources investments. After Congressional hearings, the Water Resources Council announced that the new formula was to be based on the yield rate for long-term government bonds. An immediate 4.625 percent rate was established (in comparison to the 2.5–3.5 percent rate in effect during the 1950s and 1960s) and the much higher yield rate was to be approached from this level by not more than one
quarter percent per year. In fiscal year 1984, the rate used by the agencies, based upon this formula, had risen to 8.125 percent. This rate has come to closely approximate the real opportunity cost of displaced private spending which is preferred by many economists. However, the conceptual basis on which the water resources rate is based – the nominal cost to the Treasury of borrowing – is little different than that on which the pre-1970 rate was based.

The debate in economics on the appropriate concept and magnitude for discounting public investments has continued but there is still little consensus on the correct concept and size of the discount rate. Nevertheless, most economists would agree that the cost of Treasury borrowing is not an appropriate conceptual basis and that, in the analysis, the opportunity cost of alternative activities displaced by the public activity and its financing must be considered. A range of other issues pertinent to the choice of the discount rate have not been resolved, however. These include: (1) the appropriate consideration of future generations, (2) the inclusion of risk and uncertainty considerations in the discount rate, and (3) the relationship of the appropriate public discount rate to macroeconomic policy. These issues are discussed fully in Lind (1982).

3.5.2. Inflation and benefit–cost analysis

The worldwide experience with inflation in the seventies raised questions regarding the treatment of inflation when performing B/C analyses. Price and interest rate data used in such investigations often reflect inflationary expectations. The major conclusions of the literature on this subject [Howe (1971), Hanke et al. (1975)] is that consistency is required in the treatment of prices and interest rates. In other words, either real or nominal prices and interest rates must be considered in making projections. (The Water Resource Council procedures continue to violate this precept by appealing to nominal interest rates – the yield rate on long-term government bonds – while employing real prices in forecasting benefits and costs.) It is recommended that real values be employed since the forecasting of nominal price trends over the long lifetime of a water project is a formidable task. Hanke and Wentworth (1981) extend the analysis to cases in which relative prices are expected to change over the life of a project. (The writers would add a note of caution on projecting changing relative prices. Analysts who in the 1970s confidently adjusted relative prices of food or energy in response to perceived permanent scarcity scenarios for these commodities have seen supplies rebound and real prices in the 1980s fall to well below earlier forecasts.)

3.5.3. External and secondary effects

Effects internal to a water project are those which can be captured, priced, and sold by the decision-making or project entity (or which must be paid for, in the
case of costs). External effects, then, are uncompensated side effects, and can be positive or negative.

External effects can be classified as technological or pecuniary. The former refer to changes in real production or consumption opportunities imposed on third parties, and generally involve some physical interaction among the parties. Because technological externalities are real and represent welfare changes, public project planning should take them into account. Pecuniary impacts (usually called “secondary” or “indirect” economic effects) are those reflected in changes in incomes or prices caused by shifts in supply or demand. Pecuniary externalities are likely to represent income distribution rather than allocative effects, and their inclusion would amount to double-counting.

The need to explicitly consider real effects on third parties in benefit–cost evaluations is clear and presents no serious conceptual difficulties. Whether positive or negative, such impacts can be measured, in principle, by methods of non-market valuation discussed above in Section 3.3. In practice, of course, serious difficulties in measuring external costs and benefits abound.

Pecuniary spillovers present more of a problem. The conditions under which pecuniary externalities are properly included in measures of water project benefits have been the subject of a long and controversial history. McKean (1958) and Eckstein (1958) remain the definitive analyses. The main problem has been a focus by planning agencies on secondary benefits (which are largely registered in the project locality), while secondary costs (which are likely to be spread across the national economy, and often represent the elusive potential returns to alternative public investments) are not given equal consideration.

Howe and Easter (1971, pp. 26–27) present a most accessible summary of the issues. They note that in a properly functioning economy with fully employed resources, a new investment project yields no net benefits beyond its own net income. Any expansion in related activities is offset by a fall in activity and profits elsewhere, while potential alternative investment projects could be expected to have similar indirect effects. However, with departures from the competitive model—including (a) the presence of long-term unemployment of resources, (b) immobility of resources, and/or (c) the existence of economies of large scale in related industries—real national secondary impacts may occur.

Two final remarks are in order. Even though the pecuniary (or secondary) impacts of water projects are likely to be balanced out elsewhere in the national economy, that is not to downplay their economic and political importance to affected regions [Kimball and Castle (1963)]. Much of the political motivation for public water projects represents an attempt to capture such regional effects, which in many cases are reflected in large gains in real property values. Second, much analytic effort has gone into forecasting regional income gains, often with the use of Leontief input–output models. The changes thus projected remain income transfers, and should not be labeled as “benefits” or treated as real income gains.
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Kelso et al. (1973) and Bell et al. (1982) are empirical measurement efforts which avoid the possible pitfalls in projecting secondary impacts.

3.5.4. Risk and uncertainty

Risk and uncertainty attached to outcomes—either positive or negative outcomes—are generally viewed as undesirable from an individual point of view. Individuals are generally thought of as "risk averse". Production and consumption decisions made in the face of uncertainty are generally less effective than when knowledge is relatively certain [Dorfman (1962)]. Extrapolation of these points to project evaluation implies that risky investments—those in which benefit and cost streams are largely uncertain or risky—are less desirable than interventions with equivalent expected values of benefits and costs, but less risk or uncertainty. The implication is that risk and uncertainty is a cost, and this cost should be reflected in the evaluation of projects.

Existing evaluation procedures used by water investment agencies, as well as the academic literature, reflect this conclusion. A number of approaches to reflecting risk and uncertainty have been proposed, including: (a) conservative "rules of thumb", (b) sensitivity analysis, (c) probability analysis, and (d) decision-theoretic models. The "rules of thumb" are devices for penalizing riskier proposals, and include (1) limiting the period of analysis, (2) introducing direct and specific safety allowances, (3) the inclusion of a risk premium in a single discount rate (where uncertainty is unrelated to time), and (4) appraising benefits conservatively. No longer does the project appraisal literature [Mishan (1976)] or the U.S. Water Resources Council Guidelines (1983) recommend these approaches. They do, however, advocate sensitivity analysis, which is a reworking of the analysis for alternative values of the parameters which are thought likely to affect the feasibility determination.

The probabilistic approach generally relies on formal assignment of probabilities to uncertain outcomes, and compares the expected value of benefits with the expected value of costs. Flood control evaluation rests on this procedure. As discussed in the section on appraising flood control investments, many have questioned whether maximizing expected value of net benefits is an appropriate criterion. [See, for example, Kunreuther (1978), Heiner (1983).] Assigning probabilities to water flows is reasonably straightforward and the subject of a large literature. However, estimating probabilities for economic and political factors (prices, population, productivities) is only in its infancy. This, and the large computational load for serious probabilistic analysis has limited its application in practice to the flood control field.

Decision theoretic approaches [Dorfman (1962), Mishan (1976)] hold promise, but have seen little application beyond the theoretical level as yet.
A refinement of the expected value approach adopts Bernoulli's insight that individuals do not necessarily value uncertain prospects by their monetary expectation. The expected utility approach assumes that expectation is the appropriate decision criterion, but that individual attitudes toward risk should be reflected in the analysis. Risk aversion by individuals is hypothesized, so that highly risky projects have a certainty equivalent which is less than the expected monetary value [Dorfman (1962)].

Arrow and Lind (1970), however, have contended that it is not correct to presume that risk and uncertainty in benefit and cost streams are always socially costly. Depending upon (1) the entire portfolio of national investments, (2) the correlation between the benefit and cost streams of projects and the overall returns to the assets in the economy, (3) the existence of contingency claims markets, and (4) the extent to which the risk and uncertainty is spread over impacted individuals, it may be appropriate to ignore individual project risk in public project evaluation. The implication is that a risk-free discount rate should be used. Fisher (1973) has pointed out, however, that the theorem applies only to private goods, but not in the important cases where the goods provided are non-exclusive and non-rival (public goods). Pearce and Nash (1981) note some additional limitations.

The risk of dam failure is an aspect of water project appraisal that has been conspicuously ignored in federal water planning procedures. Experience has proven that dams do fail, so that siting dams above areas of large population must be studied with extra care. However, due to philosophic controversies over the concepts to be employed and the reluctance of water management agencies to admit publicly the possibility of failure, official planning guides do not yet address the issue. [See Baecher et al. (1980) for a discussion.]

3.5.5. Multiobjective appraisals

Conventional cost–benefit analysis has been criticized on the ground that economic efficiency was not the only criterion by which water projects should be judged. In a previous section, we have outlined the rise (and partial decline) of multiple objective planning procedures by the federal establishment in the United States. This development was paralleled by a burst of interest in formal evaluative procedures in the technical literature. Marglin (1962) and Freeman (1969) provided theoretical formulations incorporating additional objectives (such as regional income) into water planning models. Cohon and Marks (1975) Goicoechea et al. (1982), and Chankong and Haimes (1983) survey and appraise the various quantitative techniques proposed for formally solving multiobjective problems. Major and Lenton (1979) incorporate multiple objectives into a river basin planning exercise, while Gum et al. (1982) treat a water quality problem.
Relatively few economists have chosen to explore this topic. Many appraise it as merely an attempt to justify unsound public investments under the guise of broader criteria. (Some efforts in multi-objective evaluation have suffered from inadequate care in specifying objectives, identifying trivial physical impacts as their objectives rather than employing measures representing legitimate public goals.) Others doubt the ability of government “decision-makers” to provide quantitative tradeoffs among social objectives. Those economists holding this latter view tend to focus efforts on predicting the allocative and distributive consequences of water policy proposals, and recommend that the political system resolve the conflicts (as is provided in the federal planning procedures of the past decade). Haveman (1965), Gardner (1966), Infanger and Butcher (1974), and Miller and Underwood (1983), represent instances of measurement of distributive impacts of water-related programs and projects.

3.5.6. Ex post evaluation

The application of economic analysis to public spending decisions has its longest history in the water resources area. Yet, in contrast to many other program areas, analysis has been almost exclusively ex ante in nature. As a result of this singleminded attention to ex ante analysis, water resource planners have not had access to ex post information required to (1) determine if project evaluation techniques are biased, and if so, in what direction and to what extent, (2) revise evaluation methodologies so as to improve their reliability, and (3) gain information on the production functions on which project evaluations rest.

Several obstacles to meaningful ex post evaluation exist in the water area [Haveman (1972)]. The primary barrier, in addition to data problems, concerns the “with–without” framework of benefit–cost analysis. An ex post evaluation of the before–after sort is of no use in efforts to improve evaluation procedures. If, for example, the flood losses actually prevented by a project were estimated and used as a basis for judging the benefits produced by the project the appraisal would implicitly indicate that the prevention of damage to property induced into the floodplain by the project constituted a benefit attributable to the project.

Second, substantial conceptual and empirical problems are involved in appraising the performance of investment projects whose output depends on a stochastic process. When an investment has afforded protection against the occurrence of a probabilistic event, such as a flood, it has, in effect, a value that is analogous to insurance.

Finally, for most water projects, the bulk of expected project benefits occur in the later years of the project’s life. In such cases, the analyst would find it most difficult to judge the efficiency of the investment on the basis of its output stream until it has matured.
In the primary water resource agencies the correspondence of actual costs with \textit{ex ante} estimates has been explored periodically. In the 1950s a pattern of major cost overruns was uncovered; later cost analysis has been found to be far more accurate [Hufschmidt and Gerin (1970)].

Very few \textit{ex post} appraisals have been undertaken. Haveman (1972) developed a framework for \textit{ex post} evaluation of flood control, navigation, and hydroelectric project purposes, and undertook preliminary \textit{ex post} analyses in each area. The study concluded that, “there is a serious bias incorporated into agency \textit{ex ante} evaluation procedures, resulting in persistent overstatement of expected benefits” (p. 111).

\textit{Regional growth impacts}. Another analytic thrust can be interpreted as a type of \textit{ex post} appraisal. This is represented by the several studies which use econometric techniques to test the hypothesis—fundamental to much of public water policy—that water resource development does in fact yield significant regional economic growth impacts. A number of such analyses have utilized cross-sectional census data from one or more census periods and regressed various indices of growth (income, production, etc.) against expenditures for water development projects. Lewis et al. (1973) review the conceptual issues. Both Cichetti et al. (1975) and Fullerton et al. (1975) studied multi-state regions in the southwestern United States, but failed to identify statistically significant regional growth measures for federal irrigation projects. Howe (1976) surveys both the econometric and descriptive evidence from river basin developments on several continents, reporting rather mixed findings. The evidence at hand suggest caution is advised in projecting large and assured regional growth impacts from water projects.

\textbf{3.5.7. Optimal sizing, timing and sequencing of water supply projects}

This section calls attention to the related issues of optimal timing and sizing of projects. The sizing of water projects has often been based on hydrologic and engineering considerations. Size has tended to be made as large as possible, until the point where incremental cost rises sharply. This, however, ignores the likelihood of diminishing marginal net benefits. The conditions for optimal sizing of a project in a static and deterministic framework are achieved by the familiar equating of marginal costs and marginal benefits [Marglin (1962), Herfindahl and Kneese (1974)].

In the face of growing demand for project output, net present value of returns may actually be increased by postponing a project even though it might be found feasible for an immediate start. This will be the case if, roughly speaking, net benefits are growing at a percentage rate larger than the rate of interest. Herfindahl and Kneese (1974, p. 202) discuss the issue and Gittinger (1982, pp. 381–383) describes some simple tests for determining when to start a project.
Marglin (1963) presented one of the earliest formal attempts to deal with the problems of investment sequencing. Most of the recent contributions have come from the engineering and operations research literature. Moore and Yeh (1980), for example, apply a dynamic programming approach to a case study in which price-sensitive demand, a marginal cost pricing rule and an objective of economic efficiency are incorporated into a model for expansion of regional water supply capacity.

4. Evaluations of selected public water policy issues

Local, regional, and national government entities are involved in numerous water supply and management programs. We cover only the most significant in terms of public expenditures in the United States—natural hazard mitigation, water transportation and irrigation.

4.1. Natural hazards: Floods and droughts

Extreme climatic or meteorological events, such as floods or droughts may cause significant economic damages and have been a major preoccupation of water-related public policies.

4.1.1. Structural approaches to floodplain management

 Provision of flood control is one of the major water resource activities in the federal government's portfolio. These activities often involve levee construction, channel improvement, and reservoir construction. In these cases, the purpose is to erect some man-made structure which will confront natural probabilistic events—the chance of a discharge of $x$ volume occurring in any given year in any flood plain—and alter the impact of these events when they occur.

Several outputs from flood protection projects can be distinguished:

(1) the reduction of crop damage from flooding;
(2) the reduction of property damage from flooding;
(3) the reduction of non-crop output losses due to flooding; and
(4) increasing in the productivity of land and improvements on the floodplain.

Optimal flood control programs will minimize the sum of the costs of the protection program plus the costs of damage avoided. In Figure 11.1 the steps required to empirically estimate the present value of both crop and property damages averted are depicted and related sequentially to each other [see also James and Lee (1971), Haveman (1972), Herfindahl and Kneese (1974)]. These components of the empirical estimation process correspond to the method utilized.
by federal water resources agencies. As can be inferred from the figure, analyses of hydrologic conditions, forecasts of the physical performance of the installation, estimates of crop distribution patterns, seasonal planting patterns, flood-free crop yields and value components, and forecasts of "factors of increase" without the project are essential components of the estimated annual benefits resulting from the reduction of flood damage to crops due to the flood control project. Similarly, estimation of the benefits of averting damage to property required estimates of stream hydrology, property values of the floodplain, project performance, and factors of increase without the project.

Within a smoothly functioning economy operating at full employment, there are several additional benefits from flood protection investments beyond crop and property damage aversion. These include the reduction in output losses due to destruction of a crucial input or the temporary reduction or cessation of production. While these benefits are not properly considered direct project outputs, a net willingness to pay for them does exist. These benefits result from a reduction of production losses associated with activities not experiencing direct physical damage from flooding.

One of the outputs of a public flood control investment may be an increase in the productivity of floodplain land because of the reduced incidence of flooding.
For example, because of reduced flood incidence, an entrepreneur may find it profitable to shift floodplain land from low-net-yield pasture to high-net-yield agricultural commodities or to a factory site. In principle, this output is the net reduction in cost (or increase in net earnings) experienced by the occupants of the land because of the flood reduction services of the investment other than flood damage reduction. In the water resource literature, the value of this physical output is known as "land enhancement benefits".

Estimation of benefits in this productivity improvement category is difficult. In this case, the analyst must identify the increment to, and the composition of, economic activity that would have taken place on the floodplain in the absence of the investment, and compare this value with the actual increment to, and the composition of, economic activity occurring on the floodplain due to increased real productivity of floodplain land. Through this procedure, the investment-induced productivity increase of floodplain land can be estimated. Stated alternatively the analyst's task is to distinguish between (1) changes in the level and composition of economic activity on the floodplain attributable to productivity increases of floodplain land induced by the public investment, (2) changes in economic activity resulting from the natural growth of the area without the project, and (3) changes in floodplain economic activity attributable to inadequate or erroneous information about the extent of increased protection afforded the floodplain by the investment. Having isolated that component of changed economic activity attributable to investment-induced increases in land productivity, the analyst must estimate the increase in net earnings of these induced activities [see Lind (1967)].

These procedures for valuing flood protection benefits are fraught with both practical and conceptual problems. Here, only the primary of these will be mentioned.

(1) Flood protection benefits are "public goods" requiring demand functions to be added vertically.

(2) The willingness to pay benefits are based on the assumption that floodplain occupants are rational and fully informed. Substantial evidence exists to suggest that they do not act on the expected value concepts which dominate this area [see White (1964), Kates (1970)].

(3) If floodplain decisions are not made on this basis, non-optimal floodplain usage will result, both without but especially with flood protection. This will result in actual damages (and damages averted) being quite different than those predicted on the basis of expected values. (This perception has led to a de-emphasis on structural protection measures, and more emphasis placed on land use control, or mandatory flood insurance.)

(4) The benefits from land value enhancement have been disputed by several economists, who have argued that, generally speaking, land quality is a continuum, and that because land quality equivalent to that on the floodplain is available, land enhancement benefits are non-existent [Lind (1967)].
(5) It has been claimed that projected changes in land value can capture all of the benefit components described above. This is true, but only under a very restrictive set of conditions, including competitive markets in long-run equilibrium, no shifting of benefits outside of the floodplain, and fully informed floodplain decision makers operating on unbiased estimates of expected values [See Haveman (1972)].

Recent contributions include Cochrane’s (1981) survey of the state of the art of flood loss simulation. He examines the potential for using these methods in developing nations. Cochrane and Huszar (1983) studied urban storm drainage practices, finding in a case study that application of engineering rules of thumb (e.g. “protect to the 100 year event”) yielded excessively costly mitigation programs. Milliman (1983) surveys the economic literature on flood hazard mitigation and sets out priorities for economic research.

4.1.2. Non-structural measures for floodplain management

White (1964) led in advocating a shift away from strictly structural solutions to floodplain problems. Krutilla (1966) proposed flood insurance to shift the cost of risk-bearing toward the individual floodplain occupant. Floodplain zoning, flood forecasting and post-disaster relief policies have received extensive discussion, in light of the failure of the federal flood insurance program to live up to expectations [U.S. Congress (1979)]. The theoretical model of expected utility maximization hypothesizes risk-aversive behavior and suggests that affected individuals would be willing to pay more than an actuarially fair premium to protect against loss. Kunreuther (1978) demonstrates, with field and laboratory studies, that for relatively rare events which may cause high losses, such as floods, this hypothesized behavior is not observed. [See also Heiner (1983).] This finding may support compulsory insurance and regulations of land use and construction practices [Sorkin (1982)].

4.1.3. Drought impacts and their management

Drought is a condition of moisture deficit sufficient to have an adverse effect on plants, animals and ultimately man [Warrick (1975)]. Water managers attempting to mitigate drought impacts may modify demand, augment water supply, or select a combination of the two approaches. An optimal plan minimizes the sum of mitigation costs and drought losses. As with floods, the economic literature stresses the problems of measuring economic damages from moisture shortages, and treats both structural and non-structural approaches to drought mitigation. Musgrave and Lesueur (1973) questioned the usefulness of large dams as drought mitigation measures in Australia, and proposed market-like procedures which would encourage scarce water supplies into the highest valued uses. The research agenda developed at the Harvard Water Program [Maass et al. (1962),
Hufschmidt and Fiering (1966) brought the field of stochastic hydrology together with economic analysis, and initiated concern with formally measuring loss or damage functions due to water shortages. Russell et al. (1970), developed two sets of loss functions: one corresponding to an *a priori* model of drought impact; and the other based on an *ex post* estimate of actual damages, both for the Massachusetts drought experience in the 1960s. Millan (1975) extended this tradition in a theoretically and empirically rigorous study of the upper Colorado River Basin in the western United States. An interindustry model of the economic region was adapted into a linear programming format to measure both direct and indirect economic impacts of variations in water supply. The major water-using sectors were each represented by several production activities designed to represent a range of adjustment to water shortage. The overall simulation model, in addition, incorporated advanced procedures for modeling the hydrologic system of the basin.

A number of studies cited in the subsequent sections on crop irrigation and on allocative institutions reflect attempts to model the impacts of water shortages [Anderson and Maass (1971), Dudley et al. (1972), Daubert et al. (1984), Angelides and Bardach (1978)].

### 4.2. Water transportation

Public provision of right-of-way and public improvements to existing rights-of-way for waterborne commerce are important water resource investment activities. They can in concept, be accurately evaluated by the “least-cost alternative” technique. The partial equilibrium presumption is that the nation requires a certain origin–destination movement of goods, and that the objective is to achieve this movement at the lowest resource cost to the nation. (The fixed origin–destination presumption, of course, is questionable.) The provision of transportation infrastructure, and the pricing (cost-recovery) procedure which accompanies it, will cause shifts in the location of both producers and consumers and, hence, changes in both the origin–destination pattern and the total volume of commerce requiring transportation services. It is generally accepted that analysis using such full general equilibrium approaches is not currently feasible.

This “lowest resource cost to the nation” concept can be elaborated still further in the case of, say, a waterway improvement, by introducing the distinction between the cost savings on an existing volume of traffic which is to be moved in a region *and* the cost savings on incremental traffic which is generated by the lower effective transportation charges in the region due to the introduction of the improved facility.

With this distinction, the total efficiency benefit of a navigation improvement is equal to the sum of the reduction in costs of moving existing traffic and the net willingness to pay for the additional traffic attributable to the improvement (the
total willingness to pay for the incremental traffic less the incremental costs of accommodating that traffic, whether it is carried by water or an alternative mode) [see Haveman (1972)].

Current agency practice in the ex ante estimation of navigation benefits has been determined by direct congressional action in the Department of Transportation Act of 1966. This is the only project purpose for which Congress has explicitly dictated the definition of benefits and the concepts to be used by agencies in evaluation efforts. Largely because of this intervention, current navigation evaluation procedures deviate more from ideal procedures than in any other project purpose.

The early waterway benefit evaluation procedures utilized by the Corps of Engineers have been described by Eckstein (1958). The pre-1960 Corps practice was to evaluate the unit benefits of a navigation improvement by comparing the current rates that shippers would pay to transport commodities on the improved waterway with the rates they would pay for the next best alternative mode. Eckstein demonstrated that, because of the complex nature of the railroad rate-making process and the setting of railroad rates to cover full costs, it is the unit savings to shippers that are being estimated and not national resource cost savings per unit of traffic moved.

In estimating the volume of traffic that would utilize a proposed waterway, the Corps employed surveys of the commerce flowing into and out of the region. On the basis of the surveys, the reliability of which has often been challenged [see Nelson (1969)], an estimate was made of the volume of future traffic that would move by water. In practice, a sizable share of expected traffic growth in the region was often credited to the construction of the waterway traffic.

In this procedure, it was implicitly assumed that the difference between rail rates and barge rates would not change during the life of the project. Both potential technological change in the railroad or barge industries and competition from the waterway are ignored. Because post-waterway railroad rates are likely to decrease below their pre-project counterparts by more than barge rates for both of these reasons, there is sound a priori reason to expect that the traffic projected on the waterway by this technique is overstated. Prior to 1960, then, the procedures used to estimate both traffic on the waterway and unit savings on this traffic led to bloated estimates of the benefits from navigation improvements.

In 1960, a significant change in procedure was adopted by the Corps. The use of transportation rates was dropped, at least in concept, in favor of a comparison of the resource costs of shipping commodities by water with the costs of transporting them by an alternative mode in the absence of the project. However, even after the 1960 change, estimates of traffic expected to move on the waterway remained based on a comparison of current rail rates and barge rates expected to prevail when the waterway was completed. While the new cost-based procedures were superior in concept to pre-1960 procedures, in practice the reported estimates were similar under both methods.
In October 1964, however, a second revision in evaluation procedures was announced. This alteration—which took the form of an interim procedure to replace the post-1960 cost-basis-with-loopholes—was a substantial one in both form and practice. Proxies for long-run costs were used both in projecting traffic on the waterway and in measuring the benefits attributable to that traffic.

The effect of implementing this procedure was that estimates of traffic expected to move on the improved waterway were lower than estimates generated by earlier procedures. Because of the changes, fewer projects were able to demonstrate a benefit-cost ratio above unity. Congressmen and senators from states with strong waterway interests found this interim procedure to be a severe obstacle to project approval [see Haveman and Stephan (1968)]. Through Section 7 of the Transportation Act of 1966, Congress, led by the waterway interests, eliminated the interim procedure. The essence of this legislation was to force the Corps of Engineers to revert to the pre-1960 practice of estimating both waterway traffic and unit savings on the current rate basis.

As a result of this legislation, navigation benefits are based on an estimate of future waterway traffic, which, on a priori grounds, is seriously overstated, and on an estimate of unit benefits for this traffic, which represents savings to shippers rather than the appropriate (and smaller) savings in national resources devoted to transporting commodities.

As with other public water programs, cost-sharing has been an important issue in federal waterways policy in the past decade [Hanke and Davis (1974), U.S. National Water Commission (1973)]. The policy that the navigable waters of the United States should be free of tolls became explicit national policy a century ago. The conditions which may have justified a toll-free policy have changed, and in 1981 a tax on fuel used by shallow-draft inland waterway barge firms was initiated. Proponents of a tax cited familiar equity and efficiency arguments, while opponents were concerned that the competitive position of the barge industry would be weakened vis-a-vis the railroads, and that major waterways users such as agriculture, would be adversely affected. Shabman (1982) provides a discussion of these issues and the related literature.

4.3. Crop irrigation

Irrigation of agricultural crops represents the largest consumer of water diverted for human uses in the United States [Frederick and Hansen (1982)] and throughout the world. Particularly in desert climes, new water development can yield large increases in agricultural output, can stabilize agricultural returns, and promise to reduce unemployment and to stimulate economic development in rural regions. Economic analysis comes into play because both private and public development of irrigation water supplies can involve expenditures of large amounts of scarce resources, including capital, land and skilled labor. As the best sites become
converted, the net economic benefit per unit of monetary outlay tends to fall, and
many recent proposals do not stand up under careful economic scrutiny. Never­
theless, new irrigation projects remain high on the political agenda in arid zones
of developed as well as developing nations. [Carruthers and Clark (1981) broadly
treat irrigation economics.]

4.3.1. Productivity and demand for irrigation water

Numerous complexities are encountered in measuring the demand for irrigation
water. First, crop production, with or without irrigation, is a biological process
carried out in uncontrolled and highly variable environments. The process,
therefore, is subject to the vagaries of diseases and pests and variations in climate
(temperature, sunlight, wind, humidity, and rainfall), soil texture and fertility.
Second, yield response to irrigation water application is especially sensitive to the
rate at which water is combined with other inputs, such as soil nutrient levels and
investments in on-farm application systems. Third, crop response may be in­
hibited by dissolved salts (salinity) in the irrigation water which become con­
centrated in the crop root zone by the evapotranspiration process. Finally, a
realistic model will reflect the fact that the productivity of irrigation water varies
widely over the year, depending particularly upon soil moisture level and upon
stage of growth of the plant.

The conventional approach to measuring the productivity value of irrigation
water employs residual imputation on a crop-by-crop basis [surveyed by Young
et al. (1972)]. More sophisticated approaches recognize the multi-crop nature of
the typical farm and the sequential decision involved in scheduling the amount
and timing of irrigations throughout the growing season. Moore (1961) in the
United States, Flinn and Musgrave (1968) in Australia, and Yaron and his
associates [Yaron and Dinar (1982)] in Israel were among the pioneers in
formulating rigorous approaches to modeling aspects of the irrigation water
allocation problem. See Vaux and Pruitt (1983) for an extensive survey of this
literature.

The marginal value of irrigation water varies widely, due to the site-specific
characteristics of production described above (climate, soils, crops, technology).
They also may differ according to the conceptual framework employed in making
the estimate (short run versus long run; public versus private accounting stance).
Most surveys of the value of irrigation water have concluded that the long run
average value is lower in irrigation than in competing offstream uses [e.g. Howe
and Easter (1971), Young et al. (1972)].

Demand and price elasticity estimates cannot be derived by normal economet­
ric procedures, due to lack of market exchanges. Howitt et al. (1980) summarize
the parametric mathematical programming approach and argue for non-linear
objective functions. National inter-regional programming models have been de-
veloped to analyze a number of issues related to irrigation water demand and to pollution from agricultural sources [Christensen et al. (1981)].

4.3.2. Feasibility appraisals of irrigation investments

Numerous critics of federal appraisal practices have perceived a general pro-development bias in official evaluation procedures. These critiques begin with Teele (1927), and include Eckstein (1958), Freeman (1966) and Young (1978). In addition to the general sources of bias discussed earlier (including using too low a discount rate, recognizing secondary benefits, ignoring the opportunity costs of water and failing to consider potentially less-expensive, perhaps non-structural alternatives) several issues have been raised which are specific to the irrigation case. The federal procedures for shadow pricing inputs and products have been challenged. A major objection is that no charge for the opportunity cost of family labor and management has been included. Also, project revenue forecasts tend to overplay the scarcity of future food supplies. Forecasted crop shadow prices have generally ignored the historic tendency of falling real agricultural commodity prices even though persistent excess capacity in the U.S. agricultural production plant has led to expensive federal government supply control programs. Social benefit estimates should be net of subsidies to maintain crop prices [Martin (1979)]. Another bias has been the overweighting of the projected crop plan in the direction of high-margin specialty crops. At least a portion of the high margin in such crops should be charged against specialized management and risk-bearing, rather than credited to irrigation water. Since new production from irrigation development will, at the margin and from the national perspective, largely be registered in forage and feed grain crops, the high income specialty crops should have minimal weight in project appraisal. (Many of these criticisms have been addressed by the U.S. Water Resources Council's 1983 planning procedures but the Congressional practice of "grandfathering" projects appraised under earlier, less rigorous standards delays the effectiveness of such reforms.) Dudley et al. (1972) analyzed several important planning issues, including the optimal proportion of water to land. Martin (1979) and Sampath (1983) extended the typical partial equilibrium approach to benefit measurement, and appraised irrigation programs in a welfare framework which employs consumer as well as producer surpluses in measuring irrigation benefits.

External costs, such as the reduced productivity in downstream regions from saline irrigation return flows must be recognized [Moore (1981), Oyarzabal and Young (1978)]. In many cases, irrigation project plans must anticipate costs of drainage to alleviate downslope waterlogging and salinization from irrigation developments [Moore (1972), Johnson (1981), Carruthers and Clark (1981)].

Finally, insufficient attention may be given to assuring that the proposed public investment is the least-expensive means of achieving the same project outputs.
While lesser-cost alternative may be structural, such as reliance on private groundwater development in lieu of public surface-water projects, it might be non-structural, as when a quasi-market system is introduced to ration water supplies.

The equity and efficiency issues involved in federally-subsidized irrigation water supplies aroused debate in the 1970s [U.S. National Water Commission (1973)]. The “160 acre-limitation” in the 1902 Reclamation Act supposedly limited the subsidy to family farmers, but changing technologies and the possibility of significant economies of large size created a thrust to relax the limitation [Martin (1978)]. Seckler and Young (1978) challenged the notion that significant economies of size existed beyond 160 acres [see also Moore (1982)] and criticized the distributive impacts of the then-existing administrative procedures. They suggested that water, rather than land be the basis of the limitation and proposed a two-tier charge system in which subsidized water would be provided up to a specified limit and full cost charged to farms beyond that point. Legislation approved in 1982 raised the ownership limit to 960 acres, while providing for full cost water charges for farms larger than that cutoff.

5. Further topics relating to water supply

The previous sections dealt with theory and practice in evaluating large scale surface water impoundments by public sector agencies and related issues. Next, several aspects of water supply are taken up. Space constraints prevent coverage of such special topics as desalination and waste-water recycling.

5.1. Groundwater management

An aquifer is a geologic formation of permeable materials which is saturated with water. The earth’s groundwater resources are extensive – they constitute probably the largest source of fresh waters. Two hundred billion acre feet underlie the land surface in the coterminous United States [U.S. Water Resources Council (1980)].

The groundwater resource presents problems of quantity and quality similar to surface water as well as a number of special issues. The major characteristics of aquifers that affect the costs of water supply are (a) depth to water table, (b) thickness of saturated zone, (c) transmissivity (the rate at which water is transmitted through the aquifer), and (d) characteristics of the formations through which the well must be drilled [Carruthers and Clark (1981)]. Much of the economic literature can be interpreted as incorporating notions of diminishing returns, time discount and external costs into a field still dominated by simplistic “safe yield” concepts.
Groundwater basins are typically exploited by a large number of independent pumpers withdrawing from the common groundwater supply. The economies of large size so evident in surface water developments are not present in groundwater extraction. Groundwater systems vary greatly in their physical characteristics, and obtaining information on the depth, porosity, and water quality in an aquifer can be a costly undertaking. As a result, accurate representation of the physical system in order to predict impacts of alternative extraction policies may be difficult to achieve. [See Gorelick (1983) for a survey of physical aquifer models.] As groundwater ordinarily can move (slowly) in response to withdrawals, the action of any one pumper affects the conditions experienced by other users; thus they are interdependent and external costs (or benefits) are imposed.

Under unregulated management, where non-renewing groundwater is held in common ownership and utilized by otherwise independent agents, the resource is “fugitive” and must be captured in order that the user can claim property rights to it. The individual user’s property rights to future use of the pool are indefinite, as other pumpers may utilize the water in the meantime. In such instances, the self-interest of the individual user may lead to socially non-optimal pumping regimes. This “common pool” problem is conceptually similar to that of the open access oil pool or fishery, which has been extensively analyzed [Haveman (1973), Ciriacy-Wantrup and Bishop (1976), Randall (1983)].

O.R. Burt, in a series of influential papers, contributed fundamentally to the understanding of optimal groundwater management. He incorporates both direct and external costs of pumping and the tradeoffs between diminishing returns to usage now and the present value of future uses into a dynamic optimization framework [see Burt (1964, 1975)]. Brown and McGuire (1967) also employed a single-celled aquifer model, developing an optimal policy for allocating publicly-supplied surface water conjunctively with groundwater. Bredehoeft and Young (1970) treated a multicell aquifer case, and as did Mapp and Eidman, (1975) developed more realistic representations of crop response to reduced irrigation water supplies. Daubert et al. (1984) treat a somewhat different issue, that in which heavy groundwater withdrawal from a renewable tributary aquifer reduces stream flow, and adversely affect supplies available to senior surface water rights holders.

Finally, withdrawals of groundwater often impose spillover costs, i.e. encouraging flow of poor-quality water into parts of the aquifer [Cummings (1971)] or subsidence of overlying land surface [Warren et al. (1975)].

5.2. Interbasin water transfers

When the origin of transferred water is in a different hydrologic region or basin (and often a different political jurisdiction) than the destination of that water, a
major conveyance system is typically required. The change of ownership rights can involve interstate (or province) or even international institutional considerations and conflicts. Inter-basin Water Transfer (IBWT) proposals typically require funding and political sanction from the national government. They raise serious economic problems, particularly those involving the perceived demands of the importing basin versus the possible future needs of the basin of origin. Income distribution and environmental impacts and the effects on communities and associated sociopolitical institutions are other concerns.

The most general treatment of the economic considerations for evaluating an IBWT is provided by Howe and Easter (1971), who advocate the need for rigorous economic analysis of primary and secondary benefits and costs from both a regional and national viewpoint. Adapting E.N. Castle's suggestions, Howe and Easter set out two principal conditions for economically efficient transfer of water which can be expressed as follows:

(a) The increments to net incomes in the importing region or regions must exceed the sum of (i) the loss of net incomes in the exporting region, (ii) net income losses in regions whose outputs are competitive with those in the importing region, and (iii) the costs of the physical conveyance systems.

(b) The cost of the physical transfer system must be less than the cost of the best alternative for supplying the same amount of water to the importing region.

Net incomes and costs are assumed to be correctly expressed in present value terms on the basis of a consistent time period and discount rate. The calculation of net incomes should include direct impacts, real external costs (water quality degradation, forgone power or recreational benefits) and real secondary benefits which may arise from a departure from the competitive conditions including unemployed resources, immobility of resources and the existence of economies of large scale in production. Bain et al. (1966), Hirshleifer et al. (1960), Hartman and Seastone (1970), Kelso (1973), Cummings (1974), and Supalla et al. (1982) have studied particular cases.

5.3. Conservation

Water “conservation” has been suggested as a policy tool for managing increasing water scarcity, so much so that the concept became a key element in the Carter Administration water program. A difficulty is that, as Mann (1982) notes, several different meanings can be attached to the term. Therefore, while “everyone is in favor of ‘conservation’, no matter what it means” the idea has some practical limitations.

Generally, conservation means an avoidance of wasteful usage, but one person’s waste often is another’s benefit. Those who perceive the value primarily in developing and withdrawing water for human consumption and production
activities tend to regard water which is not "used" in this sense as wasted. This view, in the extreme, holds that water is wasted if it flows by a potential dam site or to the sea.

A much different position emphasizes the aesthetic value of water in its natural, free-flowing state. Some of the more utilitarian off-stream uses of water are wasteful from this perspective, while conservation is understood as protection from such "less valuable" uses.

Yet another concept of conservation is improving the technical efficiency of water use. Losses, due to leakage, evaporation or avoidable wastage in production and utilization of water should be reduced where technically feasible [see, for example, Flack (1981)]. This view, however, may not carefully consider the economic costs of reducing wastes relative to the gains. The "conserving" of one resource will usually imply use or depletion of one or more other resources. Also, in many instances, losses to an upstream user are the downstream user’s supplies, and technically efficient solutions may have unexpected basin-wide implications.

The economic approach to conservation [Ciriacy-Wantrup (1952)] views conservation as an economically efficient allocation of resources encompassing the dimensions of time and space. This perspective emphasizes that the opportunity costs of other resources, in addition to that of water, must be considered in assessing waste. Pricing water at its marginal supply cost (incorporating the opportunity cost of water itself) will assure that water is not wasted, since the rational user (private or public) will not over- or under-invest in water supply capacity when faced by the appropriate incentives [Griffin and Stoll (1983)]. Where markets and pricing are not feasible, benefit cost analysis, employing shadow prices for non-marketed impacts, will aid in preventing wasteful use of water as well as of related resources. Saving water is truly "conservation" in the economic sense only if the benefits of the water-saving technology exceed the costs.

5.4. Water supply from reallocation

A regional water economy can be characterized as being either in an "expansionary" or a "mature" phase [Randall (1981)]. In the expansionary phase, the incremental cost of new water supplies remains relatively constant (in real terms) over time, and water development project sites are available to meet growing demands. The mature phase is characterized by rapidly rising incremental costs of water and increased interdependencies among water uses and users.

The rising cost of water supply in a maturing water economy brings about a search for sources of water among existing uses whose incremental value productivity is less than either the cost of new supplies and the benefits of new uses. Since crop irrigation typically accounts for 80–90 percent of water consumption
in arid regions, reallocation of water from agriculture to sectors with rapidly growing water demands is receiving increasing attention.

Most surveys of the value productivity of irrigation water [e.g. Howe and Easter (1971), Young et al. (1972)] have concluded that the long run marginal value is lower in irrigation than in competing offstream uses or than in some instream uses. Put another way, the maximum willingness to pay in agriculture tends to be much less than the willingness to pay for water by households and industries. Hence, where municipal and industrial demands are rapidly growing in water-scarce regions, forgone net benefits from reducing agricultural use may be less than the costs of a new supply. Substantial economic savings can be achieved from reallocation to the higher uses as compared to constructing new water supplies [Kelso, Martin and Mack (1973)].

The above hypothesis has proven controversial in some quarters. Arid-region governments have exhibited special concern for both the farm water users and the forward- and backward-linked economic sectors supplying inputs, processing and marketing services. The conventional wisdom has held that the indirect effects of reallocation on employment and income would be large, such that the full costs of removing water from crop production would be unacceptable.

The empirical evidence seems to suggest otherwise; that the economic impacts would be relatively limited [Young (1984)]. Water removed from irrigation would be the least valuable, drawn largely from the food and feed grain and forage sectors. Since foreseeable urban growth would account for only a small percentage reduction in irrigation water supplies, the sacrifices in net productivity would be minor relative to the gains in the growing sectors. These sectors also account for relatively small indirect incomes per unit of water consumed as compared with those from the emerging urban sectors. Also, inexpensive water may be obtained by reducing seepage in irrigation canals [Stavins (1983)].

State water and property laws generally protect the interests of farmers whose water is demanded by urban sectors; indeed, they often reap large capital gains in the transfer. The rate of loss of irrigation water, even in highly urbanized areas, will be slow, on the order of one to two percent per year. In such cases, the indirectly affected workers and businesses have time to anticipate and adjust.

6. Institutional arrangements for allocating and pricing water

This section treats the issues of allocating water among users and of pricing as largely separate problems. Note, however, that the literature outlining an ideal water market system and that dealing with water pricing appear to converge with the notion of a pricing system which reflects the opportunity costs of water with the mechanism of transferable water rights or entitlements.
6.1. Water allocation institutions

The institutions that affect the allocation of water among competing uses are crucial in determining the efficiency and equity effects of water use. These institutions concern "...sets of ordered relationships among people which define their rights, exposure to the rights of others, privileges, and responsibilities" [Schmid (1972, p. 893)]. These rights—basically, property rights—structure the incentives and disincentives between and among individuals in their decisions regarding water use [Ciriacy-Wantrup (1969)]. In the United States, these institutions are largely established by the individual states.

The research and writing concerning the structure of water allocation institutions is a part of what has become known as "analytical institutional economics". These writings are both positive and normative, and consist of the application of the neoclassical micro-economic research program to the laws, rules, and other institutions affecting water allocation. Ciriacy-Wantrup contributed prominently and his (1967) essay summarizes much of his thinking. The exhaustive studies of water rights law [e.g. Clark (1967)] are indicative of the complexities involved.

6.1.1. Goals of water rights systems

The selection of a system of water rights involves a compromise among several, often conflicting, social goals. Not surprisingly, therefore, different cultures have chosen different forms of water institutions, reflecting the relative importance of the various objectives. In the United States, the principal objectives which a water rights system is expected to attain are often stated as economic efficiency and fairness (i.e. equal treatment of equals). In other cultures, however, the desire for orderly conflict resolution and for popular participation and local control are of at least as much importance in understanding the evolution of water rights systems [Maass and Anderson (1978)].

An important factor influencing the form of water institutions in a society is the relative scarcity of water. A second factor is the transactions costs required to establish and enforce a water rights system. Where water is plentiful relative to demand, laws governing water use and allocation tend to be simple and enforced only casually. When water is scarce, however, more elaborate systems of rights have evolved. In many regions, water supplies are only now becoming sufficiently scarce to require more formal allocation mechanisms. The resulting conflicts could be mitigated if a well-defined market system for transferring rights was available in which compensation could be easily provided for the reallocation of rights. Institutional innovations to create such mechanisms tend to emerge in response to increasing water scarcity and reduced cost of enforcement [Ruttan (1978)].
6.1.2. Desirable attributes of a water allocation system

The attributes of a water rights system are closely linked to the objectives which the system is expected to attain. Nearly all of the literature concerned with designing water allocation systems have focused on those attributes required for achieving allocative efficiency. Two attributes associated with this objective are "security" and "flexibility" [Ciriacy-Wantrup (1967), Trelease (1965)]. A system is secure if it affords protection against legal, physical and tenure uncertainties. Only when rights are reasonably secure, will users undertake profitable long-term investments to capture and use water. Flexibility refers to the ability to change at low cost the allocation of water between regions, uses, and users over time—in short, the ability to accommodate changes in demand, reallocating water to higher-valued uses as they emerge. While security is desirable, it can cause a reduction of flexibility.

A third attribute is certainty—the rules of water use must be easy to discover and to understand. However, even if the rules are certain, basing them on the concept of water as a "free good" results in a rule of capture and the associated overuse and misuse of the resource. A final consideration, emphasized by Trelease, is that a desirable system should minimize the possibility that water users would impose uncompensated costs on third parties.

To sum up, a system of rights must be well-defined, enforced, transferable, and confront users with the full costs of their actions. An institutional arrangement with these attributes will permit the establishment of a market for rights which will readily reflect changing demands.

6.1.3. Empirical studies of water allocation institutions

Numerous studies have analyzed the nature of various water allocation systems, and the relationship between the characteristics of systems and the efficiency and equity impacts of water use. The issue of water transfers is a primary focus of these analyses, in particular, (1) the pecuniary and technological externalities associated with private water transactions and the importance of these in generating political opposition to large scale transfers [Hartman and Seastone (1970)]; (2) the forbidding of transfers in the presence of any such external effects (which implicitly presume that these spillovers are infinitely costly) which are present in water laws of most western states [Ditwiler (1975)]; (3) the consumptive use basis for the measurement of the benefits and costs of water transfers [Johnson et al. (1981)]; (4) the integration of the pricing and water allocation literatures and the potential of "transferable water entitlements" to facilitate water reallocations in water scarce economies with high incremental costs of new supplies [Randall (1981), Howe et al. (1984)]; and (5) the evaluation of potential gains from
replacing the public sector constraints with allocation institutions having the characteristics of a market [Gardner and Fullerton (1968), Angelides and Bardach (1978), Brown et al. (1982), Howitt et al. (1982), T.L. Anderson (1983), Wong and Eheart (1983)].

6.1.4. Institutions for allocating irrigation water

Since irrigation is the largest consumer of water worldwide, and receives a major share of public investment funds devoted to water supply and management, institutions for its allocation deserve special mention.

The complexity of the institutional arrangements necessary to efficiently and equitably operate irrigation delivery systems is not generally recognized, even among social scientists. This complexity arises mainly from four sources: (1) the large number of individuals whose disparate water needs must be met; (2) the tendency to large seepage losses of water along pervious watercourses; (3) the physical interdependence among water users, such that one's water supply depends on the actions of others up-canal; and (4) the variability of water supplies due to natural climatic swings. These conditions require "institutional arrangements" in the sense used by Fox (1976), denoting an interrelated set of entities (organizations) and rules which serve to organize activities to achieve social goals. Organizations to represent the interests of the numerous water users, to establish and enforce rules and to maintain the ditches are an important institutional need in public irrigation systems [Easter and Welsch (1983)]. Many countries tend to provide the physical delivery system and assume that the local water management institutions will automatically follow.

Numerous forms of rules which allocate water among users are observed, ranging from informal systems where all farmers can take water whenever it is available to the elaborate volumetric pricing system found in Israel [Yaron (1979)]. The main limitations of existing systems are in apportioning seepage losses equitably from head to tail along the ditch and protecting downstream users from unauthorized withdrawals above them [Bromley (1982)]. Wade (1982) describes the tendency for lack of enforcement of established distribution rules, such that the wealthy and the powerful are favored. Seckler and Nobe (1983) emphasize the role of management controls in alleviating such problems. Maass and Anderson (1978) combine careful institutional descriptions of case studies in Spain and the United States with a series of simulation model analyses of the economic impacts of alternative sets of allocation rules. Bromley et al. (1980) recognized the parallels between the issues involved in the initial organization of a group of irrigation water users and the problem of the "Just Society" studied by the philosopher John Rawls. They set out a sophisticated set of rules and procedures for establishing water users' organizations.
6.2. Beneficiary charges for water use

This section focuses on the problems of beneficiary charges when water with private good characteristics is publicly supplied. Thus, the cases where water is supplied privately or through a market are not dealt with, nor are the problems of financing programs with non-rival, collective good attributes, such as those for water quality improvement or flood control. In the cases analyzed, the rates or prices set have both resource allocation and equity impacts, and influence the level of agency revenues. The principles of pricing or rate setting are taken up first, followed by the related issues of cost-sharing and cost allocation.

Empirical evidence on the effect of pricing on water consumption suggests that imposition of a measuring/metering system together with volumetric charges results in significant impacts on consumption. Schramm and Gonzales (1976) present a case study on irrigation in Mexico, while Hanke (1970) and Gysi (1980) report on the effects of water meters on urban consumption. Once a metered system is installed the demand has been found to be relatively price inelastic. [See Howe (1982) and C.E. Young et al. (1983) for cross-sectional estimates of price elasticity of household water demand.]

6.2.1. Rate-setting

Rate-setting represents a choice of policies within a multiple objective framework, in which (a) allocative (Pareto) efficiency, (b) equity of income distribution, and (c) “fairness” of apportioning costs are all major social objectives. Subsidiary criteria include simplicity, administrative feasibility, and stability [Bonbright (1961, pp. 290–292)]. A general principle or rule for setting rates can be associated with each major criterion. The principles each convert one of the major social goals into a broad practical guide or formula for setting rates.

The marginal cost pricing principle is the rate-setting rule applied where allocative efficiency (maximizing net social product) is the primary objective. When rates are set according to the schedule of marginal cost of supplying water, then the user will demand the commodity so long as marginal willingness to pay exceeds incremental cost, and the optimal level of usage will result. A corollary of this principle is that the common practice of “flat rate” pricing of water, in which no marginal charge is imposed, is likely to encourage consumption beyond the optimal level.

While economists have generally endorsed the marginal cost principle, application of it is difficult because of the variety of definitions of the appropriate marginal cost concept for pricing policy [Saunders, Warford and Mann (1977)]. An example concerns the transactions costs associated with measuring, allocating and monitoring a water pricing system. In an irrigation system with plentiful
water supplies and numerous small field units, the transactions costs of a volumetric pricing system may exceed the value of water saved [Bowen and Young (1983)]. A second example is the long debate over the “Short Run Marginal Cost Principle” stemming from the work of Lerner and Hotelling in the 1930s. Strong objections to setting public utility prices equal to marginal costs, especially where marginal cost is below average cost (hence, requiring public subsidy) emphasized the absence of a market test to determine whether users were willing to pay the total cost of supplying the commodity, the potential misallocation of resources stemming from the additional taxation, the redistribution of income in favor of users of products of decreasing cost industries, and the impetus toward centralization of the economy [Coase (1971)].

While most of these objections can be dealt with by a multipart pricing system (involving price set equal to marginal cost, plus an assessment levied on users to reflect the costs which do not vary with output), establishment of such multipart systems which accurately reflect costs is difficult. Multipart rate structures are now frequently found in municipal and industrial, irrigation and hydroelectric power systems. Water pricing in Israel, in which all users are metered and face a rate structure with increasing blocks is an example [Yaron (1979)]. However, as they have been applied, multipart pricing systems often fail to account for an economically correct concept of opportunity costs, focusing rather on historical or embedded costs. The opportunity costs which are relevant include both the value of water in alternative uses or at a future time, which is called “user cost” [Howe (1979)]. Also relevant are the costs of securing incremental supplies in the presence of demand growth [Munasinghe and Warford (1982), Milliman (1971), Davis and Hanke (1971), Seagraves and Easter (1983)]. In this view, historical costs are sunk, and therefore irrelevant to establishing an efficient rate structure. Moreover, the opportunity costs of water should be determined by a market mechanism rather than by administrative procedures [Randall (1981), Howe et al. (1984)].

We turn next to a brief discussion of some alternative rate-setting principles which have been proposed or utilized.

The “ability to pay” principle is an alternative principle for rate setting, and rests heavily on the equity criterion. The rule provides the most common basis for setting rates for irrigation in the United States (and elsewhere), and is also regularly applied to village water supplies in developing countries. A common practice is to require only operating costs to be recovered fully plus a small fraction of the initial investment.

The U.S. experience with federal irrigation projects is illustrative. Originally planned early in this century according to a full cost recovery concept, three decades of unsuccessful attempts to fully recover costs ensued. In implicit recognition that costs overshadowed benefits (thus yielding zero demand at full costs) an ability to pay procedure was authorized in 1939 [Huffman (1953)]. A
complex formula has been developed which limits the farmer repayment requirement to about 10–20 percent of estimated federal costs [North and Neely (1977)].

The ability to pay approach has little to commend it except in instances where low income groups are to be explicitly subsidized. The concept is relatively subjective, and political pressures arise to set the formula in ways which redistribute income from taxpayers to water users. Since charges bear little relation to costs, whether consumers would be willing to pay the total costs of supply is not tested.

The "net benefit" principle, sometimes termed the "rent" principle, seeks through charges to capture most or all of the economic surplus accruing to the user. Net productivity of the user would govern the calculation, but neither past or opportunity cost would enter in. The approach has been proposed for pricing public irrigation water, and is often embraced in more centralized political systems [Ansari (1968)]. The benefit principle is consistent with the view that water and its fruits are the property of the state. Setting rates strictly on the basis of net benefits appears to reflect a relatively deterministic view of the resource allocation process, one which ignores the incentive effects of pricing structures and appears to violate accepted equity principles.

The average cost principle calls for recovery of all costs by charging for each unit received according to the average cost. It is simple and easy to understand. It is fair and equitable in that beneficiaries pay just the resource costs incurred in their behalf. The desired signals to resource users are provided, although not in so precise a way as could be achieved by multipart pricing. As the approach is usually applied, however, historical or "embedded" costs serve as the basis of the calculation rather than opportunity costs.

In sum, in some places water is not yet sufficiently scarce to justify the tangible and intangible costs of establishing formal pricing systems. In such cases, flat rates will satisfy repayment requirements. However, when signals of scarcity of water (and of the costs of related construction capital and labor) are absent, pressures arise for structural solutions to satisfy incorrectly perceived water "needs". The expectation of increasingly scarce water supplies suggests adoption of entitlement and rate systems which reflect supply costs and the changing opportunity costs of water [Randall (1981)]. Such systems can be both efficient and fair, and have been observed to be operable in practice [Howe et al. (1984), Brown et al. (1982)].

6.2.2. Cost-sharing and repayment

The terms "cost-sharing" and "repayment" refer to the rules and procedures for apportioning the costs of federal projects in the United States among the federal government and local beneficiary groups such as irrigation or flood control districts, state fish and game or recreation agencies, or water quality control
organizations. Since cost-sharing rules determine how and by whom costs will be borne, they represent the government's *de facto* pricing policy when the outputs of projects are not explicitly priced. The trade-offs among allocative efficiency, equity and fairness have come to a focus in the cost sharing rules actually adopted by the government.

North and Neely (1977) have shown that federal cost-sharing rules vary widely according to the agency constructing the project, the technology adopted to serve the various project purposes, the type of project output, and whether the costs in question are initial capital costs or operating and maintenance costs. Critics of federal policies have identified biases in existing rules such that the benefit-cost ratio calculated from a local perspective is substantially larger than that calculated from a national point of view, leading to inappropriate incentives [Allee (1982)].

Consistency in sharing costs between agencies, between structural versus non-structural solutions, between capital and operating costs has yet to be achieved. Davis (1968) examined the effect of repayment rules on the choice of water quality control techniques. Marshall (1970) and Marshall and Broussalian (1972) have extensively discussed conceptual issues. Marshall proposes adoption of the "Association Rule", which would require the local share of project cost be in proportion to the local share of benefits. Other rules which would tend to provide appropriate incentives include: uniform costs shares for all techniques (including non-structural); uniform cost shares for all cost categories; and uniform cost shares for all agencies for a given project purpose.

The issue only arises, of course, in the absence of a systematic long run marginal cost pricing system. However, it must be recognized that the traditions of pricing some water project services (i.e. irrigation water) on an ability to pay basis, and the difficulties in identifying beneficiaries of non-exclusive services (water quality improvement, flood abatement), create complex practical problems. Both the Carter and Reagan administrations have promised major revisions in cost-sharing policies, moving toward larger local shares and "up-front" contributions by states or beneficiary groups. As of this writing, no formal agreement among the executive branch, the Congress and the states on this issue has been announced.

6.2.3. Cost allocation

"Cost allocation" is the process of assigning an appropriate share of joint multiple purpose project costs to each project purpose or user class, and is a basic measurement issue in designing appropriate pricing or cost-sharing policies. User classes may be grouped according to economic sector, political sub-division or both, and joint cost allocations among them have both allocative and distributive implications.
Given the nature of the problem there is no ideal allocation procedure, and some degree of arbitrariness afflicts all of the suggested alternatives. Gittinger (1982, p. 233) and James and Lee (1971, p. 259) each list several guidelines for selecting allocation rules, of which three stand out. First, the method should be fair in that the user class be charged at least the incremental cost of receiving project benefits. Second, the joint cost allocation procedure should not make infeasible any service class for which incremental benefits exceed separable costs. Third, no class of service should be assessed charges in excess of the benefits to be received.

Numerous cost allocation formulas can be identified, the most common of which are the "Proportionate Use of Capacity" and "Separable Costs–Remaining Benefits" (SCRB) methods [James and Lee (1971, p. 533)]. Because the first method assigns joint costs in proportion to the quantity utilized, expressed in terms of volumes or flow rates, it may be difficult to apply in cases where project outputs cannot be measured in volume terms, as with non-consumptive uses, water quality, or flood control. A more significant objection to this procedure is that it can fail the second or third guidelines above [Herfindahl and Kneese (1974, pp. 291–292)].

The SCRB method allocates to each user class the identifiable (or separable) costs of including that purpose or service in the project, plus a share of the joint or common costs. The joint cost share is allocated as a proportion of the benefits net of separable costs ("remaining benefits"). The SCRB method satisfies the guidelines listed above, and is relatively simple to apply. Accordingly, it has been selected by federal agencies in the United States as the most acceptable approach. Loughlin (1977) proposes a refinement to deal with a possible inequity in the sharing of the savings resulting from multipurpose developments as compared with single purpose projects.

Some recent cost allocation proposals are based on a game theoretic framework. The theory of cooperative games provides approaches to joint cost allocation which take strategic possibilities into account. Heaney and Dickinson (1982) provide an integration of this literature with the more traditional analyses. See also H.P. Young et al. (1982) and Loehman et al. (1979) for applications. These highly formal approaches identify limitations of the traditional (i.e. SCRB) methods, but their complexity has inhibited the adoption of alternative solutions at the applied policy level.

7. Federal water management strategies

In large part because of the economic characteristics of water, a wide variety of institutions have grown up around the productive and consumptive uses of this
A simple listing of these arrangements will indicate their diversity and pervasiveness:

- to improve water quality a complex subsidy-rule enforcement strategy has been adopted by federal and state governments; construction of municipal waste treatment plants is highly subsidized by the federal government;
- massive public works expenditures have been undertaken to reduce flood damage, reduce transportation costs, reduce municipal and industrial water supply costs, provide irrigation water, and to expand recreation opportunities;
- publicly-imposed charges have been established for irrigation water, hydroelectric power, use of inland waterways, and recreation;
- administrative regulations for evaluating proposed public water resources investments have been established;
- regulations for using water resources for navigation, irrigation, and recreation purposes have been imposed;
- mandatory flood insurance legislation interacts with flood control investments, as do local floodplain zoning restrictions;
- provision for privately initiated litigation to prohibit public agency construction for rule enforcement, or to modify construction or regulatory plans, exists and has been widely used.

All of these institutional arrangements have evolved to deal with problems in the use of water resources, and most have been designed to deal with inefficiencies in water use which would occur because of the physical and economic character of water resources. Yet, in many cases the institutions which have been developed have serious problems of their own, and may generate their own inefficiencies. Indeed, in some instances it is not clear that the institutional arrangements in existence are superior to no public or collective intervention.

In the following paragraphs, we will indicate the nature of the inefficiency problems created by a few of these institutional arrangements, and in so doing indicate a variety of the reforms in water resource management which have been proposed [see also Lord (1979)].

7.1. Water pollution control strategies

The record of policy effectiveness in this area is mixed, at best. Subsidies to only conventional "end of pipe" treatment leads to a concentration of resources on this approach when a wide range of other, less costly, waste reduction techniques are available. The drive for technology-based standards and individual source permits fails to recognize differential watercourse capacities, different discharge levels in a region, and different levels of potential recreational use in a region, and tends to lead to excessive control costs. The subsidy funds have been dissipated
by failing to concentrate them on municipalities with the most harmful waste loads and by restricting their use to only the construction of waste treatment facilities and not their operation. By subsidizing the capital costs of treatment facilities, sewer charges on industrial, commercial, and domestic dischargers are decreased, providing a windfall to polluters and decreasing their incentive to reduce discharge flows.

It is also generally agreed that the rule enforcement aspect of the strategy has been less than fully effective. Political bargaining is the very nature of the rule-making/enforcement approach and in this and other cases the bargaining is between parties of unequal power. While the regulatory process is often viewed as an instrument for public control over the behavior of the regulated, the opposite result has often occurred. At every stage in the bargaining process, those being regulated have much at stake while the public interest is diffuse, poorly organized, and represented. Predictably, the bargains struck favor the regulated. In the case of water pollution, the enforcement process has been long and drawn out and costly in terms of legal and administrative resources. Industrial polluters confront higher marginal returns from employing legal counsel to oppose and negotiate enforcement efforts than in undertaking pollution control efforts.

Policy measures without these adverse efficiency and equity consequences have been studied and proposed in the water pollution area. In particular, the case for the application of an effluent charge [Kneese and Schultze (1975)] or marketable effluent permits [Joeres and David (1983)] to water pollution control policy seems especially strong. Incentives for waste reduction would be provided, the windfall gains implicit in the current policy would be avoided, and the allocative inefficiencies generated by regulatory uniformity would be corrected. Perhaps most importantly, the system of bargaining between regulator and regulatee would be replaced by a system which rewards reductions in residuals discharges.

7.2. Public water resources investment policy

Several aspects of public investment policy in the water resource area have led to resource misallocation, inequity, and incentives for inefficient private sector behavior. The efficiency implications of a few of these have been discussed above; others have been well-documented in the literature.

The contention that project evaluation procedures have generally overstated some categories of benefits and understated costs was argued in Section 4 above. These biases are not likely to be fully corrected until the measurement and evaluation function is removed from the operating agencies and placed in the domain of an agency with independent evaluation capabilities. The agency chosen should not only be responsible for evaluating the efficiency and equity impact of
proposed projects, but should also be responsible for defining the alternative activities available for meeting the objectives at stake. It is the definition of the options which gives the operating agencies the ability to define the "need" which the standard functions of the agency can meet. It is this ability which has caused the water resources agencies to single-mindedly pursue structural alternatives to the exclusion of a wide range of other non-structural options—for example, congestion charges, flood insurance or floodplain zoning, reduction of water sale restrictions—which could attain the objectives at a lower social cost.

The inequities generated, while less understood, may be fully as serious as the inefficiencies caused by inadequate project evaluations. Because most of the benefits from these projects are tied to the ownership of fixed assets, primarily land, their value becomes incorporated into property and land values and is reflected in the wealth account of the owners of these assets. Because the owners of irrigated and flood plain lands, barge lines, and enterprises benefiting from subsidized transportation costs are not typically poor or even middle income people, the effect of these subsidies is to increase the inequality in the national distribution of wealth holdings.

The incentives for inefficient private behavior is perhaps the most serious characteristic of federal water resource development policy. As is well recognized, floodplain protection through the erection of structures has not been accompanied by a reduction in flood damages. Indeed, even though many billions of dollars have been spent on flood protection projects since 1936, estimates of national flood damages have increased steadily. The current strategy is to confront potential flood damages with the construction of flood protection works which display a favorable damage averted/cost ratio, financed by the general fund of the Treasury. With the floodplain protected, private development which previously appeared inefficient becomes profitable. With the higher level of development, even the reduced stream flows cause damages in excess of what they would have been without flood protection. In effect, because the services of the improved floodplain are made freely available to any development activity, an elaborate series of inefficient activities are stimulated: uneconomic invasion of the floodplain occurs; land values in the plain rise rapidly; alternative measures of damage aversion are not undertaken even though more effective; political pressure for most subsidized control projects is generated; and in the long run, no real flood damages are averted.

The dimensions of this perverse incentive problem have been recognized for nearly a decade now, and a program of mandatory flood insurance with appropriate incentives for efficient behavior has been studied and proposed. Nevertheless, little corrective action has been undertaken. Although flood insurance has been offered to residents in floodplains at a subsidized rate through the 1968 National Flood Insurance Act, few takers have been found. To residents in
floodplains, additional protection works financed by taxpayers appear more profitable than the flood insurance subsidy! Examples of other water resources policies with such perverse incentives are numerous.

7.3. The use of litigation in resolving water resource policy disputes

As indicated above, standards and criteria for the evaluation of proposed water resource investments have been established by legislative and by executive action. Increasingly, the application of these rules by the agencies has been challenged in the courts by private groups opposing the construction of individual proposed projects.

Since individual agencies in the U.S. system are left to decide how standards and criteria are to be applied, when third parties believe a rule has been violated, an independent institution—the judiciary—determines procedural rules. These proceedings involve full revelation of factual claims by both parties (including factual claims adverse to one’s position) and the resolution of the dispute by the court based upon its understanding of the factual claims and the validity of the data and logic on which the claims rest.

In the water resources area, litigation regarding public investment appraisals has increasingly concerned the extent to which the analysis accompanying a proposed project fulfills the study requirements of the National Environmental Policy Act (NEPA). Much litigation focuses on the benefit–cost evaluation which accompanies every proposed federal project and on the environmental impact study (EIS). This dual focus exists because NEPA, which mandates the EIS, dictates that an evaluation of economic impacts be a part of the EIS.

Although an analysis of the beneficial and detrimental impacts of disputed projects would be expected to help the court to assess the factual conclusions and the accuracy of assertions regarding the effects of these projects, in fact, these government studies appear to have hindered the judicial process. The use of statistics, computer models, probabilities, and mathematics in these government-sponsored studies has appeared sufficiently forbidding to the courts that extreme and undue deference has tended to be given to the government’s position. An accepted presumption is that the conclusions of the government-sponsored report rest soundly on the analysis that underlies it, and that this analysis, in turn, is accurate, pertinent, and appropriate. When this presumption is challenged, however, the government representative often obscures facts and relationships which could be expressed in layman’s terms by using scientific jargon, computer modeling, and seemingly complete statistical analysis. This tendency to overwhelm the court with volume and technical detail plays on the inability of the courts to determine if the facts in a situation do or do not comply with a general rule if it is unable to understand the factual evidence presented. The result is the
loss of the probing skepticism so critical to a rational decision process, and with it the loss of an important mechanism for insuring public decisions which meet efficiency goals [see Carroll et al. (1983)].

7.4. Concluding remarks on public water policy

Pervading our description of water resource policy has been the problem of the separation of the beneficiaries of resource use from those who bear the cost of such use. Because of this separation, distinguishable groups of people are subsidized at the expense of other (typically larger) groups. Moreover, the subsidized are provided both the incentive and the wherewithal to manipulate the political system to maintain the flow of subsidy—whether or not an economic or social function is served and without regard to cost [Gardner (1983)]. As our discussion has revealed, these groups are readily identifiable—landowners along flood protected watercourses, the owners of industrial and commercial firms contributing to waterborne wasteloads, irrigators using publicly developed water supplies, and the owners of barge lines using public waterways.

Improvements in the efficiency and equity of water resources policy are likely to be achievable by a reduction of the large volume of subsidies conferred by existing policy. Elimination of the existing separation of beneficiaries and cost-bearers of policy measures through a comprehensive beneficiary charge policy could yield this improvement. The major components of such a policy would move toward:

- Effluent charges or marketable effluent permits to discourage waste discharges to public watercourses, coordinated with programs governing solid waste and airborne disposals.
- An increase in the price of publicly-produced irrigation water to reflect its supply cost and opportunity cost in alternative uses.
- A national system of mandatory flood control insurance with premiums set equal to expected loss.
- Imposition of long-run marginal cost-based user charges on barge lines using public waterways.
- Supply cost and congestion-related user charges for waterbased recreation areas.

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