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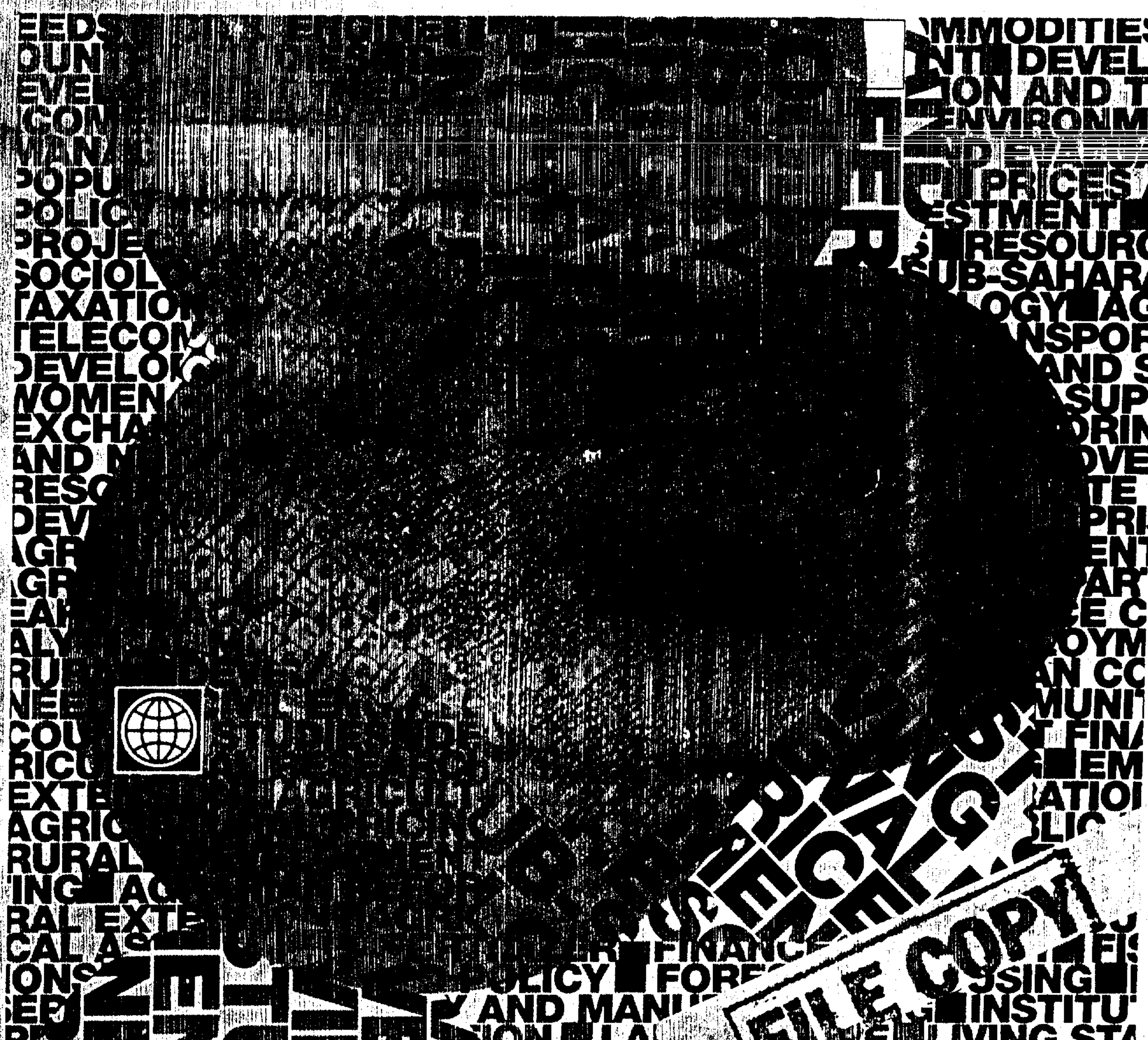
Balancing Water Demands with Supplies

The Role of Management in a World of Increasing Scarcity

Kenneth D. Frederick



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(List continues on the inside back cover)

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FOREWORD

One of the clearest indicators of Man's exploitation of the World's natural resources is the growing imbalance between the supply and demand of fresh water. The most disturbing aspect of the worldwide scarcity of fresh water is the speed with which it has come about. In a single generation the World's net renewable fresh water resources per capita have almost halved and, if the trend continues, will have reached dangerously low levels in many countries in another thirty years. In the Middle East and North Africa for example, water shortage is already severely constraining socio-economic development and indeed in many places available fresh water is insufficient to sustain human existence. Increasing water scarcity is also forcing water managers to reallocate supplies between traditional users such as irrigators, households and industries.

In the past, imbalances in the water equation have been mostly redressed by developing new water supplies. However, the limitations of this traditional supply-side approach are rapidly becoming apparent; the most accessible sources of water have now been developed and deeper drilling or longer transfers are becoming prohibitively expensive. The answer, therefore, must lie in reducing the demand side of the equation; by improving water use efficiency, introducing conservation measures, shifting water allocations between sectors and changing individual behavior towards water use.

Normally, restricting demand of resources can be achieved by encouraging markets and allowing prices to limit demand. The very nature of water, however, poses special problems for using markets and prices to respond to changing supply and demand conditions; farmers will pay high prices for water in a drought but would pay equally highly to get rid of water in a flood, events which are unpredictable and may be just weeks apart.

This paper deals with this increasingly important topic of how to balance water demands with supplies. It examines the experience of OECD countries in influencing the behavior of water users, and draws lessons from attempts to manage demand by imposing water use regulations and employing economic incentives. The paper points out that there can be no blueprint for applying demand management practices as most countries and communities differ in their response to regulations, encouragement and incentives. Nevertheless the guiding principles described should be of considerable value to those wishing to introduce demand management techniques into their nation's water equation.

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Because of the informal nature of this paper, and in order to present the results of research with the least possible delay, the typescript has not been prepared in accordance with the procedure appropriate to formal printed texts and the World Bank accepts no responsibility for errors.

TABLE OF CONTENTS

CONVERSION TABLE

From:	To:	Multiply by:
Volume		
cubic Meter (m^3)	US gallon	264.2
liter (l)	US gallon	0.264
acre-foot	US gallon	325,851
acre-foot	m^3	1,233.5
Area		
hectare (ha)	acre	2.471
Flow		
million gallons per day (mgd)	acre-feet per year (AF/yr)	1,121
mgd	$1000m^3$/day	3,785
Salinity		
milligrams per liter (mg/l)	parts per million (ppm)	1
Cost		
\$/m^3	\$/acre-foot	1,233
\$/m^3	\$/1000 gallons	3.785
\$/m^3/day	\$/gallon/day	0.004
\$/acre-foot	\$/$1000m^3$	0.8107

EXECUTIVE SUMMARY

The demands for water and the ability to control the location, timing, and quality of the resource for human purposes have increased rapidly during the last half century. The control over the timing and location of water gained through investments in dams, reservoirs, wells, pumps, and canals has been critical to converting a region's fugitive and uncertain natural water endowment into reliable freshwater supplies. But this growth also has highlighted the limitations of the traditional supply-side approach to water planning. The options for increasing reliable supplies quickly become limited and expensive once the best sites for water projects are developed. As water development expands and the resource becomes scarcer, the construction and management of water projects become less a means of adding to aggregate supplies and more a means of allocating supplies among alternative sectors such as irrigation, households, industry, and various instream uses. That is, a water project becomes a form of demand management.

In contrast to the constraints on supplies, demands for both instream and withdrawal uses of water tend to rise with economic and population growth. When demand grows faster than supply, demand management is required to bring water use into balance with supply. The OECD countries rely on prices and markets to prevent or resolve conflicts resulting from changes in the supply and demand for most resources. Water, however, is an exception. Its vital and often revered role has led many societies to restrict selling water and to price it well below its full cost and scarcity value. The nature of the resource also poses special problems for using markets and prices to respond to changing supply and demand conditions. Regulatory rather than economic instruments have been the primary tools used to allocate water, encourage conservation, and protect water quality. Recently, however, the inefficiencies and high costs of these regulatory approaches have led many OECD countries to introduce alternative approaches that rely on economic incentives to encourage voluntary measures for balancing the supply and demand for water.

The experience of the OECD countries is examined to assess the relative advantages and disadvantages of voluntary and regulatory approaches for (1) transferring water among alternative uses, (2) encouraging conservation, and (3) protecting instream flows and water quality. Markets and price incentives provide opportunities for improving upon all three of these aspects of demand management. But even when voluntary measures are employed, the government retains an important role in defining and enforcing property rights, making allowance for the third-party effects of private water uses and transfers, providing for the public goods associated with instream flows, and regulating the prices of monopolistic suppliers. Institutional reforms to facilitate the reallocation of and to limit the demands on water supplies must take account of individual national priorities, cultural constraints, financial and technical capabilities as well as the current and likely future supply and demand for the resource. Although some general principles will apply to all countries, standard approaches to demand management may not be possible or desirable.

I. WATER RESOURCES AND ECONOMIC DEVELOPMENT

Since the first diversions of irrigation water, the economic development of arid and semiarid regions has been strongly influenced by the ability of a society to control its water resources and to use them effectively and sustainably. The development of irrigation and a centralized system of government to control and allocate water were important elements in the emergence of the earliest great civilizations in the Near East and Mediterranean areas. And the failure to understand and anticipate the long-term impacts of salinization and sedimentation on the productivity of their soils and irrigation systems likely contributed to the subsequent decline of some of these societies (Ackerman and Lof, 1959).

Water technology in 1900 had advanced little beyond the achievements of the Romans in transporting water over long distances and the water control techniques developed by the Dutch several hundred years earlier (Ackerman and Lof, 1959). The scientific and technological achievements of the twentieth century, however, produced major breakthroughs in understanding the natural systems underlying water supplies and in the capacity to control and use the resource for human purposes. Advances in earth moving, dam construction, pumping, and hydrology made it possible to transform and control the world's largest rivers and to tap deep aquifers. The development of hydroelectric power production and transmission provided a potential source of clean and inexpensive power. Improved irrigation and agricultural technologies greatly increased the potential scope and yields of irrigated agriculture. And new technologies for treating drinking water made it possible to curb the spread of water-borne disease.

These scientific and technological achievements encouraged major new investments in water projects. Large dams and water diversion projects were promoted as catalysts for regional economic development. For several decades ending in the 1960s, large multi-purpose dams were widely viewed as symbols of farseeing, humane management of natural resources. The number of reservoirs with at least 100 million cubic meters (m^3) of storage capacity increased rapidly during the first half of this century in North America and after 1950 in the world as a whole. Worldwide, the number of such reservoirs created from 1950 to 1985 was three times the number built in all previous years and their storage capacity was nine times as great (White, 1989).

Demands on the resource also increased sharply during this century. Global withdrawals increased nearly fivefold during the first eight decades, with three-fourths of this increase coming since 1950 (White, 1989). Irrigation -- which expanded from about 48 million hectares in 1900, to 94 million hectares in 1950, and to 250 million hectares currently -- accounts for about seven of every ten liters of water withdrawn from surface and groundwater sources. The increased development and use of water resources supported rapid agricultural, urban, and industrial growth in many areas of the globe.

It has become increasingly evident in recent decades that water costs are rising sharply and aquatic ecosystems are being jeopardized by current and planned use. In some areas, current water use patterns are unsustainable because they depend on non-renewable groundwater supplies, are resulting in high or rising salinity levels, or are otherwise contaminating freshwater supplies. In almost all areas, the impacts of water development and use on instream flows have been ignored. Although the demands on water resources continue to increase with a region's population and economic growth, the costs of adding to supplies rise as the level of water development expands.

Water development and use in the United States over the past century illustrate the transition from a period when water projects augmented effective supplies and were an important part of a strategy to settle and develop the nation's arid and semiarid West to the current situation in which new projects redistribute and only rarely add to supplies (Frederick, 1991a). During the nineteenth century, natural supplies shaped the exploration, settlement, and development of the nation. The capacity to control water flows was very limited, and highly variable streamflows and frequent flooding deterred development of about one-third of the original forty-eight states. Early in the twentieth century, technological advances in dam construction and in hydroelectric power production and transmission combined with federal policies encouraging settlement of the West by subsidizing irrigation set the stage for a prolonged period of development and rapidly growing use of western waters. This growth continued unabated for seven decades until most of the rivers had been tamed and were being used intensively for irrigation, municipalities, industry, and hydropower production. Although flooding was reduced, flood damage increased as a result of intensive development of the flood plains. These developments and a willingness to ignore their impacts on instream flows and the values they provide supported an illusion that water was not scarce. But the economic and environmental costs of this strategy increased sharply during the 1950s and 1960s. The quality as well as the quantity of the nation's surface waters suffered as a consequence of profligate water use and the increasing demands associated with rapid population and economic growth.

Gradually, the nation's policies shifted from those encouraging water control and diversion projects to those designed to protect and restore water quality and natural ecosystems. Billions of dollars have been spent over the past two decades to reduce the pollutants that reach the nation's waters, the wild and scenic nature of some streams has received legal protection, and instream water uses such as recreation and fish and wildlife habitat have received greater weight in the development, management, and allocation of water resources. Per capita water withdrawals peaked in the mid-1970s, and total withdrawals peaked (at least temporarily) five years later (Solley, Merk, and Pierce, 1988). The era of large-scale water projects has been replaced by an ongoing struggle over the allocation of supplies and the management of the enormous infrastructure that controls flows in river basins such as the Missouri, Columbia, Colorado, and Sacramento.

A transition is occurring globally from a period when a country had little control over its water resources and placed few demands on them to a time when water is highly controlled and is the object of competing demands. But a comparable transition in the policies and other institutions that influence the development, management, and allocation of the resource has yet to occur. Water is universally underpriced, and engineering solutions are promoted to water resource problems that stem largely from poor management and misallocation of the resource. This paper examines the difficulties of and alternative approaches to balancing water demands with supplies under conditions of scarcity.

II. ALTERNATIVES FOR AUGMENTING WATER SUPPLIES

Globally, water resources are abundant and completely renewable. Regionally, natural supplies are limited, highly variable, and uncertain. Average annual precipitation varies from virtually nothing in the driest deserts to as much as 10 meters in some areas. In addition, large annual and seasonal variations in precipitation and runoff often underlie the long-term averages. Streams may dry up or flood their banks depending on the season and climatic conditions. While groundwater resources are less susceptible, they are not immune to variations attributable to the hydrologic cycle and climate.[1]

While humans do not affect and are generally unconcerned about the volume of the global water resource, they do affect and are vitally interested in the quantity and the quality of freshwater available for specific uses.[2] The water available for a specific use can be purposefully altered by changing either a region's total freshwater supplies or the allocation of existing supplies.

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[1]In the United States, for example, groundwater is the source of about 30 percent of the average streamflow. Likewise, seepage from streams, lakes, and canals are important sources of groundwater recharge. Groundwater is important to streamflow continuity as most of the flow of many small streams comes from groundwater seepage during periods of low flow (U.S. Water Resources Council, 1978).

[2]"Freshwater" for the purposes of this discussion refers to water of sufficient quality to meet the needs for which it is intended. Water is rarely pure outside of a laboratory, and it does not need to be pure for most purposes. The U.S. Geological Survey's National Water-Use Information Program defines freshwater as water containing less than 1,000 milligrams per liter (mg/L) or the equivalent 1,000 parts per million (ppm) of dissolved solids. Yet, salinity levels of more than 500 mg/L are undesirable for drinking and many industrial uses (Solley, Merk, and Pierce, 1988). On the other hand, some salt tolerant crops can be grown successfully with salt levels in excess of 2,000 mg/L. The suitability of water for particular uses may also be affected by the presence of toxins, disease-causing organisms, nutrients, biochemical oxygen demand, and suspended solids.

Supply-side management involves activities and policies that increase the supply of freshwater available to the region. Demand-side management determines how this supply is used and abused. Thus, demand management involves both allocating scarce supplies among sectors such as irrigation, households, industry, and various instream uses and determining the conditions under which individual users within a sector use water.[3] Protecting the quality of the resource from abuse is an important part of managing the demand for water.

Water Development Projects

Water projects such as the construction of dams, reservoirs, wells, pumps, and canals are generally promoted as supply-side measures that add to a region's water supplies. To the extent that they control flooding and capture water that otherwise would be lost to human use as a result of evaporation or runoff to the oceans or other unusable sinks, these projects do indeed effectively increase freshwater supplies. The control that these projects provide over the timing and location of water is critical to converting a region's fugitive and uncertain natural water endowment into reliable freshwater

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[3]There is no generally accepted distinction between water-supply and water-demand management. A United Nations (1991) paper on water-demand management suggests that the distinction depends on the point in the water delivery system where 'supply' is defined. The U.N. paper defines supply "at the entry point to the distribution system: after source, bulk storage, transmission, and treatment works, but before distribution piping, distribution storage, and customer taps" (p. 2). Any actions that affect the quantity or quality of water arriving at the distribution system entry point are considered to be supply management. This definition is appropriate when investments in storage, transmission, and treatment works make it possible to increase water withdrawals for one use without adversely affecting other water users. But these conditions rarely exist today; new water diversion projects are likely to involve transferring water among alternative uses, a form of demand management. Moreover, the opportunity costs associated with these transfers are rising over time.

supplies. However, as water development expands and the resource becomes increasingly scarce (that is, when using water for one use adversely affects its availability for other uses), the construction and management of these facilities become less a means of adding to aggregate supplies and more a means of allocating supplies among alternative uses. And in basins where the flows are already highly controlled and intensively used, a new water project is likely to alter the allocation rather than the quantity of the resource. That is, the project is likely to be a form of demand management rather than supply management.

As the options for increasing aggregate freshwater supplies through the manipulation of surface flows diminish, the costs of water development projects rise dramatically. Rising water costs are inevitable for three reasons (Frederick, 1991a). First, as a river basin is developed, the best sites for storing water and generating hydropower are developed first. Subsequent increases in storage and generating capacity require larger investments in dams. A study of the 100 largest dams in the United States demonstrates the existence of sharply diminishing returns in the reservoir capacity produced per unit volume of dam constructed. In the 1920s, a cubic meter (m^3) of dam produced an average of 16,769 m^3 in reservoir capacity. The average declined in each succeeding decade, and by the 1960s only 468 m^3 of storage was produced per cubic meter of dam, a 35-fold decline in productivity over four decades (U.S. Geological Survey, 1984).

Second, there are also diminishing returns in the quantity of water controlled or the safe yield produced by successive increases in reservoir capacity. At some point, the increase in evaporation losses associated with additional surface storage can more than offset any gains in safe yield (U.S.

Geological Survey, 1984). A study of U.S. river basins suggests that safe yield reaches a maximum when storage is in the range of 160 to 460 percent of a region's average renewable supply (Hardison, 1972).

Third, the opportunity costs of storing and diverting water increase as the number of free flowing streams declines and as the value society attaches to instream water uses rises. When these opportunity costs are high, a water project is likely to be more an investment for managing demand rather than an investment in additional freshwater supplies.

Interbasin Transfers

Water resource problems and their solutions are local and regional in nature. There is no global market in water because transporting water long distances out of its natural channels is too expensive relative to its value in most uses. Interbasin transfers can increase water supplies in some areas. But, in most cases, they do so at the expense of other areas. Nevertheless, when a transfer moves water from low-value to high-value uses, it may be economically justified. Moreover, if it captures and transfers water that otherwise would flow unused to the sea, a transfer project might increase the combined effective supplies in the two basins. It is likely, however, that a transfer will impose opportunity costs on the basin of origin. As potential exporting areas become aware of the environmental and other opportunity costs associated with a loss of water, interbasin transfers become more difficult to arrange. Even when the exporting basin has no immediate use for the water, the water is apt to be viewed as important for future development. Consequently, where interbasin water transfers require agreement between separate entities representing the exporting and importing interests, some form of compensation is likely to be required.

Recycling

Quality is an important dimension of the availability of the resource for human use, and upgrading water through recycling and desalting to a quality suitable for human use can be an important means of increasing a region's freshwater supplies.

Recycling involves conveying treated wastewaters to a specific use before it reaches a natural waterway or aquifer. Thus, recycling differs from reuse of returnflows which is very common for irrigation and other uses where only part of the water withdrawn from a stream or aquifer is consumptively used. Acceptable uses for recycled water depend on the public's willingness to use such supplies as well as on the final quality of the treated water. In California, recycled water can be used for industrial cooling, groundwater recharge, barriers against salt-water intrusion, and irrigating freeway greenbelts, parks, golf courses, and certain types of crops. Although the technology exists to upgrade wastewater to meet standards for domestic use, public resistance and the high costs of advanced treatment are formidable barriers to the use of reclaimed water for drinking.

Recycling has become increasingly common in water-scarce areas during the last two decades but rarely accounts for more than a small fraction of a region's water supplies. California, which uses about 401 million m^3 (325,000 acre-feet) of recycled water annually, is the leading user of recycled water in the United States. Yet, recycling accounts for less than 1 percent of the state's developed water supplies. This quantity might have been even lower if it were not for federal regulations requiring effluent discharged into waterways to undergo at least secondary treatment and the past availability of federal subsidies for the construction of treatment plants. While recycled water is expensive relative to what utilities paid in the past for most of their water supplies, it may be a cost-effective source of new supply, especially when a community must treat its wastewater before disposal. In San Diego, reclamation with an estimated cost range of $292 to $474 per 1,000 m^3 ($360 to $584 per acre-foot) ranks just behind conservation as the most cost effective means of providing for future water demands (see table 1).

Desalination

Desalting is a means of augmenting freshwater supplies. Unlimited quantities of sea water are available to coastal areas, and brackish waters containing salt levels too high for most uses but well below the 35,000 ppm found in the oceans are available in many aquifers and inland seas. Three processes - distillation, reverse osmosis, and electrodialysis accounted for 98 percent of the 3,527 desalination plants in existence in 1986 and 99 percent of their combined capacity of about 11.4 million m^3 (3 billion gallons) per day (Office of Technology Assessment, 1988).

Distillation involves boiling saline water and condensing the steam into pure water. Distillation plants typically have high capital and energy costs, employ high-cost metals such as titanium and copper-nickel alloys to withstand high temperatures and corrosive brines, require highly skilled workers, continuous monitoring, and maintenance every few months. Their primary

Table 1: SAN DIEGO COUNTY WATER SUPPLY COST COMPARISON[a]

	$/1000m³	$/acre-foot
Desalted Sea Water	973 - 1,621	1,200 - 2,000
Imported Water	566 - 670	698 - 827
Desalted Well Water	365 - 649	450 - 800
Reclamation[b]	292 - 473	360 - 584
Conservation[c]	162 - 567	200 - 700

[a] Figures reflect 1990 costs.

[b] These costs are for water delivered to the end user.

[c] Conservation measures used in calculation include installation of high quality water-conserving shower heads and ultra-low flush toilets.

Source: San Diego County Water Authority, Economic and Financial Analyses, Clean Water Program for Greater San Diego, Phase 1 Water Reclamation Program, 1/16/91.

application is for desalting sea water. Multi-stage flash (MSF) distillation plants are found in 55 countries and account for about two-thirds of the world's desalination capacity. There are significant economies of scale in MSF distillation, and the volume of freshwater recovered from an average plant is between 25 to 50 percent of the volume of the feed water (Office of Technology Assessment, 1988).

Reverse osmosis (RO) involves forcing saline water through a semi-permeable membrane that screens out salts while allowing pure water to pass through. This technology is generally used for brackish water with salt concentrations of 10,000 ppm or less. However, recent developments in membrane technology have improved the economics of desalting seawater through this process. RO can remove organic and colloidal materials and some microorganisms as well as dissolved solids. Consequently, in addition to treating brackish and occasionally sea water for industrial and municipal use, the RO technology is used to treat wastewater prior to disposal or reuse. Reverse osmosis plants typically recover 50 to 80 percent of a brackish feedwater and 20 to 40 percent when sea water is used. In both cases 90 to 98 percent of the salts are removed by the membranes. RO accounts for nearly half of the desalination plants in the world but only about 23 percent of total desalting capacity (Office of Technology Assessment, 1988).

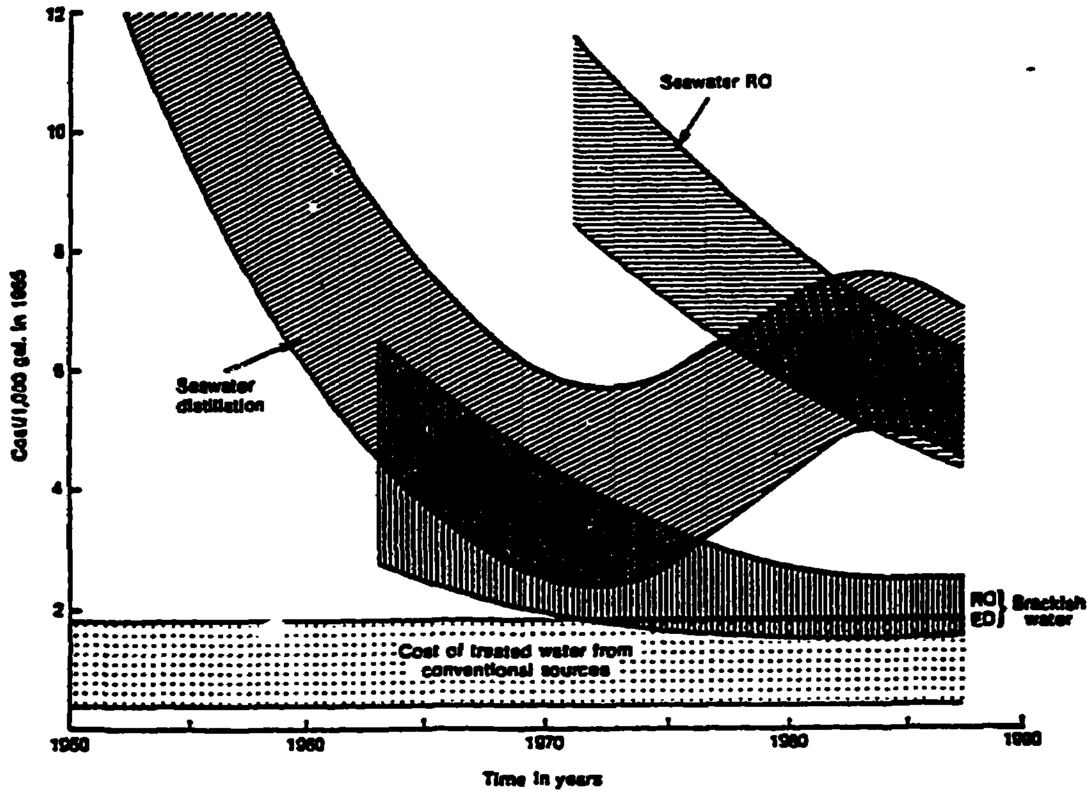
Electrodialysis (ED) uses a direct electrical current to remove salt, other inorganic constituents, and some organics from brackish water with salt concentrations up to 10,000 ppm. This process involves passing brackish water over a stack of several hundred ion-permeable membranes at relatively low pressure as an electrical current is passed across the stack. Half the membranes allow positively charged ions to pass through and the other half allow negatively charged ions to pass. One pass through a stack typically removes 40 to 50 percent of the salts. Partially desalted water is then passed through additional stages until the desired quality is achieved. Typical freshwater recovery rates now range from 80 to 90 percent of the volume of the feedwater. Energy use increases with the salinity of the feedwater. Electrodialysis accounts for 16 percent of the desalination plants worldwide but less than 5 percent of world capacity (Office of Technology Assessment, 1988).

Many factors including the costs of capital and energy, available expertise, and the quality of the feedwater influence the choice of desalination technology. Distillation and reverse osmosis are currently likely to be preferred for sea water, and reverse osmosis and electrodialysis are preferred for brackish water (United Nations, 1985). ED tends to be more economical than RO when the feedwater has less than 3,000 ppm of dissolved solids but less economical than RO with feedwater containing more than 5,000 ppm (Office of Technology Assessment, 1988). Costs depend in part on the quantity of salts removed. Consequently, desalting is less expensive if the water is not treated to meet drinking water standards and if the process starts with brackish rather than with sea water. Figure 1 indicates the trend in the approximate range of costs for desalinating water to a quality suitable for drinking.

Until recently, desalination has been undertaken largely in areas such as the Middle East and islands with meager indigenous water sources and few of the global desalination capacity in 1986 and the rest of the Middle East contributed an equivalent amount (Office of Technology Assessment, 1988). Desalination has been expensive relative to the prices most suppliers and users are accustomed to paying for water. Although it remains expensive, recent reductions in desalination costs (see figure 1) combined with sharp increases in alternative sources of supply. Saudi Arabia alone accounted for about 30 percent the costs of more conventional sources of supply have made desalination of brackish water a competitive source of drinking water in some water-scarce areas. Indeed, the combination of drought and the lack of attractive alternative sources of supply are leading a number of California communities to consider desalination

Figure 1: TRENDS IN COSTS OF DESALINATION

[Desalination costs (including capital and operating costs) for distillation and RO over the last 40 years for plants producing 1 mgd to 5 mgd of "polished" water ready to drink. Costs may be higher than the curves indicate when desalination equipment is not operated efficiently. The increasing distillation costs during the 1970s primarily reflect capital and energy costs]



RO Reverse Osmosis
ED Electrodialysis

Source: Office of Technology Assessment, 1988, Using Desalination Technologies for Water Treatment. OTA-BP-O-46 as a supplemental source of drinking water. Table 2 summarizes the costs and some other features of several existing and proposed desalination plants in California.

Weather Modification

Purposeful weather modification or cloud seeding is viewed by some as a promising, low-cost way to increase water supplies in arid and semiarid areas. Seeding of winter orographic clouds with silver iodide has been done for more than forty years in areas of the western United States. Proponents of this technology argue that cloud seeding can supplement water supplies for a few dollars per 1,000 cubic meters in areas with favorable conditions. The impact of cloud seeding on precipitation is difficult to measure, but a policy statement of the American Meteorological Society suggests that the seeding of cold orographic cloud systems increased seasonal precipitation in some areas by about 10 percent (Marchant and Dennis, 1991). Recent research suggests other materials such as liquid propane, special alcohols, and the bacteria used in snow making can condense precipitation from clouds at higher temperatures than silver iodide (Hof and Schine, 1991). If true, this would expand the conditions under which cloud seeding might increase precipitation and runoff. But even if the technology is perfected and the economics are favorable, cloud seeding might face legal obstacles. Towns receiving more snow might object to higher snow-removal costs, downstream residents might suffer increased spring flooding, and downwind communities might feel that they are being deprived of precipitation that

Table 2: DESALINATION PROJECTS IN CALIFORNIA

Name of Plant	Type of Plant	Capacity ($1000m^3$/year)	Salinity (ppm tds) intake/product	Cost ($/$1000m^3$)
Proposed Projects:				
Santa Catalina Island	reverse osmosis	183	BW / potable	$1,317
City of Santa Barbara (temporary, 5 year plant)	reverse osmosis	12,335	33,200-33,500/284-400	$1,513
Marin Municipal Water District *	reverse osmosis	6,168	SW / 10-20	$1,865
Monterey Bay Aquarium *	reverse osmosis	30-59	SW / 400	$1,459
Existing Coastal Desalination Projects:				
Chevron Gaviota Oil and Gas Processing Plant (25 year design, operation begun 1987)	reverse osmosis	120	SW / 50-500	$3,243
Diablo Canion Power Plant (PG&E) *	MSF distillation	802	SW / under 200	$1,216
San Nicolas Island, U.S. Navy *	reverse osmosis	20	SW / potable	$1,317

NOTE: * These projects have not been presented to the Coastal commission for review.
SW = seawater of varying levels of salinity depending on whether intake is from beach wells (lower salinity) or directly from the ocean.
BW = intake from beach wells, estimated salinity levels around 25,000 ppm.
The data represent 1990 costs and were converted from acre-feet to cubic meters at the rate of 1 acre-foot = 1,233.5 cubic meters.

Source: California Coastal Commission, Seawater Desalination in California, Preliminary Draft Report, 3/29/91.

otherwise would have fallen on them. If the technical and legal hurdles are overcome, areas with favorable conditions might be able to augment their annual water supplies by a few percent through cloud seeding.

Icebergs

Enormous quantities of freshwater are stored in polar ice, and towing icebergs from Antarctica has been proposed for increasing freshwater supplies of coastal communities. Results of some preliminary analysis by Hult and Ostrander (1973) were optimistic about the possibilities of using icebergs as a supplemental source of water for desert coastal areas such as southern California or in the Persian Gulf area. This optimism, however, has been shattered by more recent assessments focusing on technical, economic, legal, and environmental obstacles (Frederick with Hanson, 1982).

Vegetation Management and Water Harvesting

Less exotic technologies for increasing water supplies are managing vegetation to increase runoff and water harvesting. Streamflows can be increased by removing high water-using plants that thrive along streams and have little direct value to humans. Removing these phreatophytes, however, is likely to have adverse effects on wildlife habitat. Forests can be managed for increased water yields, but this may create conflicts with a forest's timber production and recreational opportunities. Water harvesting, the diversion of runoff to fields and cisterns, is an ancient technology to make better use of rainfall to supplement water supplies. Although the use of vegetation management and water harvesting might be extended, the potential impacts on an area's water supplies are likely to be minor.

III. IMPROVED MANAGEMENT OF EXISTING SUPPLIES

The division of natural hydrologic regions into multiple political units and separate ownership of water-supply facilities are two factors that might impede the efficient operation of a region's water-supply system. Eliminating such inefficiencies might provide a cost-effective means of increasing freshwater supplies.

Joint operation of the storage and distribution facilities of the three principal water agencies supplying the Washington, D.C. metropolitan area illustrates the potential benefits of coordinating the management of a region's water-supply facilities (Sheer, 1986). With relatively little new infrastructure investment, the water-supply coordination agreement that went into effect in 1982 increased drought-condition supplies by nearly one-third. In the absence of such an agreement, facilities costing an additional $200 to $1,000 million would have been required to achieve a comparable increase in yield. The increases in water supplies were achieved largely by using Potomac River water during periods of high flows and saving the available reservoir storage for low-flow periods. Although the operating changes produced sizable net benefits, they did sacrifice some of the system's capacity to protect against floods.

Sheer (1986) also examined two other situations where integrated management of a region's reservoirs and water supply system could provide a low-cost, environmentally benign means of increasing safe water yields. His analysis suggests that joint management of the reservoirs on the North Platte River could reduce the basin's water shortages by about 30 percent. And coordinated management of ground and surface water could lead to a 20 percent increase in the water-supply system of Houston, Texas. These studies led Sheer to conclude that "expenditures on improved management probably will be the most cost-effective water-supply investment possible over the next decade" in the United States (Sheer, 1986, p. 112).

Ground and surface water resources are seldom managed as a unitary resource although they are usually hydrologically interconnected and substitutable for many purposes. The potential advantages of coordinated management of ground and surface waters that Sheer demonstrated for Houston, Texas may apply in many situations although the nature of the existing inefficiencies and the types of changes needed to achieve sound conjunctive management may differ widely. Houston's historical reliance on groundwater resulted in mining, subsidence, loss of aquifer storage, and eventually necessitated a sharp reduction in groundwater use. Conjunctive management could have avoided the past depreciation of the city's groundwater resources, and as Sheer demonstrates, it can now significantly increase the reliable supplies provided by the city's existing water-supply facilities.

Water development in many areas has focused on surface waters to the neglect of groundwater resources. Using groundwater storage to augment safe supplies may have significant advantages over constructing surface reservoirs. Evaporation losses are eliminated by underground storage, and the environmental and financial costs of using an aquifer for storage may be significantly less than the costs of another surface reservoir.

In the absence of conjunctive management, perverse water-use incentives may result from water marketing. For example, 247 million m^3 (200,000 acre-feet) of the 863 million m^3 (700,000 acre-feet) of water accumulated by California's State Water Bank in 1991 represented a substitution of groundwater for surface water. That is, farmers in northern California sold their surface water rights and replaced this water by pumping from an unmanaged, common property groundwater resource (Brickson, 1991).

Multi-state water laws and water management systems as well as institutional inertia impede the introduction of more efficient management systems in the United States. The obstacles to integrated regional water management are even greater when different countries and cultures and perhaps even historical animosities are involved. The Middle East is perhaps the prime example of a situation where, although water scarcity seriously constrains human development prospects, political borders and historical animosities constrain the rational development and management of the region's water resources.

IV. THE GROWING IMPORTANCE OF DEMAND MANAGEMENT

Water-supply projects have been the traditional response to hydrologic uncertainty and anticipated increases in the demand for water. Most industrial and municipal water suppliers in the developed nations have attempted to build capacity sufficient to provide full and uninterrupted supplies under all but the most extreme droughts. Streamflows, reservoir levels, and groundwater stocks rather than offstream water use fluctuated in response to changes in natural water supplies. Only on very rare occasions were withdrawal users in the developed countries expected to adjust to changing supply and demand conditions. The preceding section, however, suggests that the options for increasing reliable supplies quickly become limited and increasingly expensive once the easy water projects are developed. Where low-cost alternatives are still available, they are likely to have only minor impacts on total effective supplies. Improved and integrated management of existing supplies and facilities have the potential to provide low-cost additions to safe water yields in some areas. But the institutional obstacles to doing so are likely to be formidable. Consequently, additions to freshwater supplies will be slow at best in most areas. And in some cases, freshwater supplies may decline as the additions attributable to purposeful human activities are overwhelmed by the negative impacts of contamination and groundwater mining.

In contrast to the constraints on supplies, demands for both instream and withdrawal uses of water tend to rise with economic and population levels. Technological changes can decrease the demand for a particular water use. When users have incentives to adopt them, technologies such as more water-efficient irrigation practices, toilets, showerheads, and appliances can reduce the demand for water and improved sewage treatment can reduce the demands municipal and industrial wastes place on the resource. But technological developments also can generate new demands on water resources. For example, the development of electricity and hydroelectric power created a demand for water and water storage that did not exist before.

When demand grows faster than supply, eventually demand management is required to bring use in balance with supply. Actual water use cannot exceed the available supply in any period. Shortages, which imply some form of forced rationing, are a common result of large drought-induced reductions in supply. But this crude and potentially costly form of demand management should be acceptable only during emergencies such as major droughts and breakdowns of a supply system. It does not represent a desirable method for bringing long-term demand into line with supplies. Yet, conflicts over water are becoming increasingly common even during periods of normal precipitation and runoff. And in the absence of alternative methods of managing water demands, these conflicts are resolved by forced rationing.

For most resources, the OECD countries rely on prices and markets to resolve and prevent conflicts resulting from changes in supply and demand. The advantages of prices and markets for allocating most scarce goods and resources are now almost universally recognized. Prices provide incentives to conserve when a good is scarce; they signal producers how and how much of a good to produce and consumers how to spend limited incomes to maximize their welfare. Under some circumstances markets result in socially- efficient levels of production and resource allocations. Under almost all circumstances, economies relying largely on markets and prices to allocate scarce resources and guide investment decisions have performed better than centrally-planned economies.

In spite of these apparent advantages, markets and prices have rarely been the principal or even important mechanisms for allocating water resources. Water's vital and often revered role has led many societies to restrict selling water and pricing it to reflect its full cost and scarcity. But even in the absence of societal reservations about treating water like other goods, the nature of the resource makes it difficult and in many cases impossible to establish efficient markets.

V. NATURE OF THE RESOURCE AND DEMAND MANAGEMENT

Efficient markets must satisfy two conditions. First, there must be well-defined and transferable property rights in the resource or commodity being traded. Second, a market transfer is efficient only if the full benefits and costs are borne by the buyers and sellers. Both conditions are likely to be violated for water resources. For marketing to even exist, transaction costs must be low enough to enable mutually beneficial trading. Absence of the necessary natural or artificial plumbing limits the feasible scope of water marketing.

The nature of the resource makes it unlikely that the full benefits and costs of a water transfer are borne by the buyer and seller. Externalities, or third-party effects, are likely to result when water is transferred from one use to another. Altering the diversion and return flow points on a stream may affect the timing, location, quality, and quantity of water available to other users of the stream. In addition, water resources may produce public goods that are affected either positively or negatively by a water transfer. Non-paying individuals cannot be excluded from enjoying the benefits of public goods. Consequently, users of such goods have an incentive to free-ride and producers have an incentive to underinvest in these goods from a social perspective because they are unable to recover their costs in the market place. For example, if the vista or recreational opportunities provided by a free-flowing stream are not marketable, the private sector will underinvest in instream flows and ignore the impacts of water transfers on the public goods produced by these flows. Moreover, polluters will underinvest in waste reduction and treatment when the costs of using water bodies for the disposal of untreated wastes are borne by society rather than by the polluters.

The variability and fugitive nature of many water supplies pose problems for creating well-defined water rights. Storage facilities combined with wise management can help even out fluctuations in supply and, thereby, reduce the uncertainties associated with a water right. But when runoff in a basin can vary by a factor of 20 or more from one year to the next and managers do not know in advance whether they might have to deal with drought or flood conditions, large supply uncertainties are inevitable. A society's water laws and administration can determine how the resulting risks are distributed, but they do not eliminate the uncertainties.

Competitive markets and prices require the presence of many buyers and sellers. But it is rarely practical to have multiple water suppliers to a household, business, or farm. Large economies of scale make the water supply industry a natural monopoly. Consequently, water prices are usually set by utility managers or regulatory agencies rather than by the interaction of supply and demand. Nevertheless, a public utility or regulated monopoly, at least in theory, can supply water efficiently and can set prices at levels that would equate the individual's cost of using water with the social cost of that use.

In summary, the nature of the resource poses special policy problems for using markets and prices to respond to changing supply and demand conditions. Consequently, regulatory rather than economic instruments have been used to allocate water, encourage conservation, and protect water quality in most situations. In recent years, however, OECD countries with a strong predilection toward market solutions to economic problems have begun to rely increasingly on controlled economic incentives to influence water use.

Property rights are critical to establishing conditions under which markets and prices provide individuals with opportunities and incentives to develop, transfer, and use the resource. In a lawless society, the strongest, most clever, and determined members control the most valuable resources. To avoid the chaos, uncertainty, and inequities of such an outcome, governments establish and enforce rules defining the rights to use and transfer resources. And to offset the inefficiencies that would result from the externalities associated with transfers, the public goods produced by the resource, the variable and fugitive nature of natural supplies, and the monopolistic nature of the water industry, the government's role would have to extend beyond just the creation and enforcement of transferable property rights.

The following section describes the various approaches that have been developed for establishing water rights and examines how the laws affect the transferability of the resource. Subsequent sections examine the relative advantages of market-oriented and command-and-control approaches to demand management.

VI. WATER RIGHTS

Three basic approaches have developed for establishing water rights. The common law system of riparian rights gives owners of the lands bordering a water body rights to use the water in ways that do not unduly inconvenience other riparian owners. Prior appropriation awards water rights according to the principal of "first in time, first in right." And a permit system considers water to be a public resource that only can be used with permission of the government.

Riparian rights probably have their origins in the earliest legal systems establishing private ownership of land, and elements of riparian rights are found in early Roman and Moslem laws. Riparian rights have been adopted in many areas ranging from some arid Moslem countries to some humid parts of Europe and the eastern United States. The principal features of the riparian doctrine are: (1) water use is limited to riparian lands; (2) a riparian land owner can use water at any time as long as the use is reasonable; and (3) water shortages are shared by all riparian owners.

Riparian rights flourished where water was relatively abundant; they have important limitations for dealing with scarcity and changing supply and demand conditions. Riparian rights are apt to be poorly defined because they are subject to regulatory or judicial determinations as to what constitutes a reasonable use or what might unduly inconvenience other riparian owners. And the quantity of water associated with a riparian right varies with the climate. Uncertainties about the availability of water may discourage investments that require a secure water supply. Furthermore, riparian rights are incompatible with water marketing because they are attached to the land and use of the water is restricted to those lands.[4] Where water has become scarce, there has been a tendency to replace riparian rights with permits. This trend is likely to continue.

Prior appropriation water rights, which have their origins in mining law, emerged in the western United States when government organization was weak and underdeveloped. The riparian water laws imported from England by the eastern states were poorly suited to the arid and semiarid West where streams were less numerous, flows were smaller and less reliable, and development opportunities often required transporting water beyond riparian lands. Miners (and subsequently irrigators) seeking to establish secure rights to use water in locations removed from any surface source claimed prior appropriation rights to the water they used as well as to the minerals they mined. Appropriative water rights were eventually recognized in all western states and sanctioned by federal and state statutes.

The principal features of prior appropriation rights are: (1) water rights are established by withdrawing water from its natural source and putting it to a "beneficial" use; (2) during periods of shortage, junior rights receive no water until senior appropriators have received their full allotment; and (3) failure to use water for some period of time results in loss of the right, creating a "use it or lose it" incentive.

The "first in time, first in right" principle of the prior appropriation doctrine supposedly assures a full supply to the owners of the most senior rights under virtually all conditions and places all the risk on the junior rights holders. In

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[4]Groundwater rights in Arizona are attached to the overlying land, but landowners may transport water to other areas. Consequently, "water- ranching," a practice in which urban areas buy rural land for their groundwater rights, has become common in that state. The selling price of the land largely reflects the value of the water because rural land without water has little value in such an arid climate.

practice, the allocation of drought- reduced water supplies is not likely to be so straight forward. Preferential use provisions in twelve of the prior-appropriation states set priorities of use independent of the seniority of the appropriative right. Moreover, it is inconceivable that households in any state would be left without water while irrigators holding more senior rights receive their full allotment.

Appropriative rights can be transferable. In practice, however, they are commonly attenuated in ways that limit where and how water can be used. In some cases, transferring a water right is prohibited outright. But even when there is no such prohibition, other restrictions may reduce the opportunities for and the profitability of water marketing. For instance, most water rights are contingent on the water being put to a "beneficial use," a qualification that creates uncertainty as to the nature of the right and its transferability. Indeed, some state courts in the United States have ruled that sale of a water right is evidence that the initial owner was no longer putting the water to a beneficial use and, therefore, was grounds for forfeiture of the right.

In their earliest forms, riparian and prior appropriation rights to water could be acquired without any interference of the state. As the resource became increasingly scarce, governments in countries employing these systems of water rights assumed a more active role in allocating available supplies. Riparian rights often have been replaced by or supplemented with some form of a permit system involving an administered disposition of water. Most of the states that adopted the prior appropriation doctrine subsequently decreed that the waters within their borders are public. Although rights acquired earlier through the appropriation (and in some states the riparian) system are still recognized, permits are now required for new surface water diversions. Some form of a permit system now governs the use of at least some of the water in virtually every country (Teclaff, 1972).

The view that water is a public resource to be managed and allocated by government authority has its roots in some of the earliest fluvial civilizations where water management was a principal function of government. Roman law, while allowing riparian land owners to use public streams, recognized the right of the government to require permits for the use of navigable waters. In the thirteenth century, Spain declared all streams, regardless of their navigability, to be public property. French law and the Napoleonic Code held that at least the most important perennial streams are public property and subject to government control (Teclaff, 1972).

Islamic water law is a system of religious and traditional doctrines and principles that pervade local customs and water uses in Moslem countries. It sets forth the concept of common water ownership and equitable proportionment of the resource. But Islamic law does not comprise a national system of water law, and it offers little guidance for centralized water management (Radosevich and coauthors, 1976).

When water belongs to the public or state, government authorization is required to put it to private use. Authorizations vary as to their permanence as well as to limitations on use of the water. One classification differentiates between permits which are less permanent and easily revoked and concessions which are for a fixed period or are permanent. A concession establishes reciprocal rights and obligations between the grantor and grantee (Teclaff, 1972). In principle, both short-term permits and long-term concessions might be transferable. In practice, transfers of water to other uses and locations may be limited by the nature of the right as well as by the infrastructure to store and transport the resource.

Government controls over groundwater came much later than they did for surface water. Commonly, groundwater was treated either as part of the land or as a resource that the landowner could capture at will. Moslem countries, because of their aridity and dependence on groundwater, were the first to develop detailed rules regarding groundwater use. Under customary Moslem law a well and the water in it are the private property of the person who dug the well. While the owner might be required to share water for domestic use, there is no obligation to share water for irrigation. As the links between ground and surface waters have become better understood and overall supplies have become scarcer, there has been a general trend to incorporate groundwater into the legal code governing a country's surface waters (Teclaff, 1972). Most states in the western United States have adopted some form of a permit system for groundwater use. Only Texas grants landowners unrestricted rights to pump groundwater in any amount without liability for damages inflicted on other parties. While California's landowners also may pump water underlying their land without a permit, court rulings have held that landowners' rights are coequal and groundwater should be allocated in proportion to ownership of the overlying land (Weatherford, 1982). Rapid depletion of groundwater stocks during the current extended drought increases the likelihood that California's legislature will restrict groundwater use.

Environmental concerns underlie some of the more recent restrictions on water rights. One of the oldest uses of streams and lakes has been for disposing of a society's wastes. As long as the assimilative capacity of a water body is not exceeded, waste disposal is not competitive with other water uses. When the capacity is exceeded, both instream and withdrawal uses of the water are likely to be affected adversely by waste disposal. The capacity to dilute and assimilate pollutants resulting from natural or anthropogenic sources declines as the volume of water withdrawn increases. The combination of streamflow depletion and waste disposal can undermine the utility of a water body. In extreme but not uncommon cases, streams and lakes that once provided habitat for fish and wildlife, recreation and esthetic values for communities and visitors, and water supplies for a variety of offstream uses have been converted into contaminated and malodorous liabilities. Consequently, protecting the integrity of the resource and the value of rights to use it for other purposes requires limiting the pollutants that can be introduced into water bodies.

VII. DEMAND MANAGEMENT

When a resource is scarce, the issue is not whether to engage in demand management, but how to do it most effectively. As noted above, both cultural factors and the nature of the resource have inhibited the use of water markets and market-determined prices. Traditionally, all countries have relied largely on a regulatory or command-and-control approach to allocate scarce water resources. And lacking effective markets and market- determined prices to resolve the growing water conflicts, government regulations over water have increased in recent decades. This trend is evident in the laws declaring water to be a public resource and in the proliferation of environmental laws and regulations to protect it from abuse. A counter trend has emerged in several OECD countries. In an effort to achieve greater efficiency and cost-effectiveness, opportunities for voluntary water transfers are being expanded and economic incentives to conserve and protect supplies are being introduced.

A more efficient policy implies that the beneficiaries of any resulting change would be able to fully compensate any losers and still come out ahead. Under the Hicks-Kaldor definition of optimality, it is not required that compensation actually take place. Efficiency has been criticized as a policy measure because it depends on the initial distribution of the property rights; the distribution of the nation's wealth influences the nature and value of the benefits and costs that are included in an economic assessment of policy. And while economic efficiency is important, it is not the only criteria for policy evaluation. Equity, human health, food security, and political stability are just some of the other objectives that may underlie a nation's water policies. Some of these goals are likely to imply conflicting water uses. Consequently, in the absence of information as to the relative importance of a nation's objectives, it is impossible to know what set of policies might be optimal or even to know that one policy is unambiguously better than another. On the other hand, it is likely that institutional changes promoting economic efficiency in the use of water would, or at least could, help promote other social goals such as equity, health, security, and stability. And where changes designed to increase water use efficiency do adversely affect other social objectives, alternative policy instruments may be available to compensate for these impacts. Thus, efficiency and cost effectiveness are the principal criteria for assessing the relative advantages of voluntary and regulatory approaches to demand management in the following discussion.

This discussion divides demand management into three components: (1) transferring water among alternative uses, (2) encouraging conservation, and (3) protecting instream flows and water quality. This third component might be considered as a part of the first two. Allocating or transferring water for instream use protects instream flows, and conserving on the use of water bodies for the disposal of wastes protects water quality. The environmental issues are discussed separately because of their growing importance and the special institutional issues they present.

Transferring Water among Alternative Uses

The institutions controlling water use are often rooted in an era when the resource was not considered to be scarce and transfers were viewed as unnecessary or unimportant. But as water becomes increasingly scarce, the benefits of being able to transfer supplies effectively in response to changing conditions grow. Howe and coauthors (1986a) suggest six criteria for comparing alternative institutional arrangements to allocate water: (1) flexibility in allocating supplies in response to both short-term and long-term changes; (2) security of tenure to encourage investment in and maintenance of water-using systems while allowing for users to respond voluntarily to incentives to reallocate supplies; (3) whether the user is confronted with the real opportunity cost of the resource; (4) predictability of the outcome of the transfer; (5) equity impacts; and (6) whether public values are adequately reflected in the process. Low transaction costs of moving water from one use to another might be added to this list. All these criteria relate closely to the Hicks-Kaldor definition of economic efficiency.

Both market and regulatory approaches to allocating water are likely to fall short of satisfying all of these criteria. If an administered system is flexible, the tenure of water rights is likely to be insecure, and vice versa. Water users do not bear the opportunity costs unless they are able to sell and transfer water to other uses. The central water authority would have to be endowed with uncommon wisdom and foresight if their allocations of water are to result in predictable outcomes that incorporate society's equity concerns and public values. The transactions costs of such a centralized system would depend on the efficiency of the water authority and whether or not their decisions can be challenged in the courts.

Powers of eminent domain that enable public agencies and utilities to condemn and assume ownership of water rights can be an effective means of reallocating water in situations where the public has a strong interest in change and when funds are available to compensate the former rights holders. Such powers are best used sparingly and for clearly identified purposes; they are not an efficient means of transferring water in response to short- or long-term changes in supply and demand conditions.

The courts have been used to challenge the rights of long-standing water users in the United States. Judicial decrees have established the existence of high-priority water rights for Indian and federal reserved lands. But often these rights are unquantified and only can be satisfied by voiding the rights of existing water users. The resulting uncertainty over water rights discourages investment and voluntary transfers. The public trust doctrine, which holds that the state as trustee has an obligation to protect instream values, has been used to limit the rights of the city of Los Angeles to divert water from the streams feeding Mono Lake. This case provides a potentially important precedent for challenging long- standing water withdrawal rights. However, high transactions costs and the uncertainty as to property rights that exists during a prolonged judicial process can be major disadvantages of using the courts to reallocate water.

The enormous geographic and temporal diversity in water supply and demand situations suggests that no single institutional arrangement is likely to be preferred in all instances. Howe and coauthors (1986a) argue that markets meet their six criteria better than any likely alternatives in many situations. Well-functioning markets provide flexibility, and well- defined property rights, that are essential to such markets, provide security of tenure. Competitive markets also provide water users with opportunity costs. Objections to water marketing center around criteria four through six listed above.

The potential importance of externalities associated with water transfers is an obstacle to institutional change designed to encourage voluntary water transfers. Externalities raise doubts that a transfer would be in the public interest. And even when a transfer would be efficient in the Hicks-Kaldor sense, the potential for uncompensated impacts on third parties and public goods may be a source of opposition to water marketing. When a transfer alters the point of diversion or return flow on a stream, individuals other than the buyer and seller are affected. Or when irrigation water is sold for municipal use, rural communities are affected. Rural areas in the western United States may oppose water marketing because of a fear that the inevitable transfers of irrigation water to the cities will reduce the ability of rural areas to control their future and will result in less economic opportunity; a diminished tax base; and losses to wildlife, natural areas, and recreation in the water exporting region (Oggins and Ingram, 1990). The buyer and seller do not voluntarily take such effects into account when negotiating a trade.

Water transfers are permitted in the western United States if third-party interests are protected. The states have developed a variety of institutional arrangements to consider these interests prior to approving or rejecting a proposed transfer. Nunn and Ingram (1988) concluded that the courts, legislature, special purpose districts, and administrative agencies all have limitations as to their ability to generate and consider information relevant to a water transfer. In their view, legislative bodies are sensitive to information about direct and nonuser impacts but distort information on direct benefits and costs; the courts and water agencies are not likely to consider community and other social impacts; and while a special district could consider both the direct and indirect impacts, the leadership of the district is likely to be captured by an elite that pursues narrow goals. Some form of mediation or negotiation in which special districts, counties, cities, and state agencies all participate in and influence transfer decisions is proposed as an alternative to the traditional arrangements for considering third-party impacts.

Another concern is that the legal and administrative hurdles imposed to protect these third-party interests may block socially-desirable transfers by unduly increasing the time, cost, and risk associated with a proposed water transfer. The potential benefits of a trade may have to be large to justify the costs and risks associated with overcoming these hurdles. The appropriateness of market transfers and the types of institutional arrangements for incorporating third-party impacts depend on the values that are at stake. The challenge is to develop institutions that take account of impacts on third parties and public goods without imposing high transactions costs.

Voluntary transfers and their impacts on third parties generally occur within river basins. All water resources within a basin are apt to be interrelated, and efficient water use would take into account impacts on the overall hydrologic system and the ecological system of which it is an integral part. Thus, the merits of a proposed transfer or water development project depend on implications for the entire basin. In practice, an assessment of third-party impacts is likely to be limited by political boundaries. Basinwide management is particularly difficult to achieve when waters cross national borders; in the United States, third- party considerations often end at state borders.

Another challenge is to develop procedures for transferring water to or from non-marketed uses in ways that best serve the public interest. Market transfers will not make adequate provision for the environmental benefits provided by instream flows. A subsequent section discusses protecting instream flows and water quality through regulations and markets. The following discussion considers several means of facilitating short-term and permanent water transfers for offstream or instream use.

The Colorado-Big Thompson Project, which brings an average of 284 million m^3 (230,000 acre-feet) of Colorado River water annually from the western slope of the Rocky Mountains to northeastern Colorado, represents one of the more innovative institutional arrangements for transferring water. Rights to proportional shares of this water are traded actively without having to worry about third-party effects. Neglecting third-party impacts represents an exception to water law in the western United States where return flows are treated as part of the stream and subject to appropriation. The exception is possible because the water is transferred from another basin and the federal government retains ownership of all return flows. While this arrangement does not eliminate the third-party effects of water transfers, it does eliminate the buyer's and seller's responsibility for them. An analysis of this project and the water market it produced concludes that the advantages of being able to transfer water readily among agricultural, municipal, and industrial users in northeastern Colorado more than offset any disadvantages associated with ignoring the impacts on return flows (Howe, Schurmeier, and Shaw, 1986b). The experience of the Colorado-Big Thompson project raises the broader question as to when third-party impacts can and cannot be advantageously ignored.

Third-party objections to water transfers might be reduced by allowing a user to transfer only that portion of the water right that has been consumptively used. For instance, an irrigator consuming only half of a 100 unit withdrawal would be allowed to sell only 50 units. The efficiency implications of such a policy would depend on the type of transfer involved and the interpretation of the restriction. For instance, the efficiency impacts would differ depending on whether the buyer in this example is restricted to withdrawing only 50 units or whether any quantity could be withdrawn as long as the consumptive use did not exceed 50 units. The first interpretation would represent an inefficient constraint to transfers among agricultural users with roughly the same points of diversion and return flow. The latter interpretation provides no incentive for the new user to limit withdrawals through more efficient irrigation practices. The interpretation is less important for transfers from agricultural to municipal use that will have little, if any, return flow. On the other hand, a transfer that alters the diversion and return flow points on a stream might have important third-party impacts even if it does not alter aggregate streamflow. For example, a transfer that moves the diversion from a point above a hydroelectric power plant or valued fishing and rafting area to one further downstream would benefit the power producer or recreation interests.

Maass and Anderson (1978) evaluated the institutions and water allocation procedures of six irrigated areas in Spain and the western United States. In some communities, farmers feared that water marketing would lead to instability and a loss of local control. Their concerns about having irrigation water transferred to the cities over time were projected to a dislike of using markets to allocate supplies seasonally among growers within the same irrigation district. In contrast, the district of Alicante in Spain had discovered that marketing, including an auction, provided the best means of distributing limited and erratic water supplies. Maass and Anderson demonstrate that using markets rather than turns to distribute water to farmers in these districts during periods of shortages would provide significant gains in net agricultural income. Moreover, the market procedure tended to result in the most equal distribution of losses associated with drought.

Victoria, Australia has defined some water rights as explicit shares of stored water (capacity sharing) rather than in terms of delivered water with a given volume and reliability. Instead of leaving decisions as to reservoir releases up to a central authority, capacity sharing leaves these decisions up to the individual owners of the rights. The reservoir operator serves as a kind of banker making releases on request and keeping track of the balance of each customer. Balances are calculated continuously by deducting the amount of releases from storage shares, adding shares of inflows, and deducting estimated evaporation and seepage losses. Water transfers simply require the operator to make the appropriate debits and credits (Patterson, 1989). Where flows can be controlled by storage, the simplicity of transfers under the capacity sharing system and the control it provides individuals over the timing of their water receipts have great appeal. However, this system does not eliminate third-party problems. Indeed, it could contribute to these problems, especially if it resulted in much greater variability in reservoir releases.

Auctions have been used to allocate new irrigation water in the state of Victoria in recent years (Simon and Anderson, undated). Under an auction, where the bidding process is open to all potential users, the successful bidders are likely to be the higher-value water users. Some potential efficiency gains were sacrificed to protect equity objectives in Victoria's auction. Speculators and producers in irrigation districts and urban areas were not eligible and individuals were limited as to the quantity of water that they could purchase. Fifteen-year diversion rights were auctioned, providing some security of tenure. Flexibility to respond to changing conditions during this period might be achieved by allowing subsequent transfers cf the auctioned rights.

Water banking implies some form of organized water trading with a clearinghouse to facilitate transactions (Wahl and Osterhoudt, 1985). A variety of rules have been used to govern water-banking operations in the western United States. Idaho's Water Supply Bank established in 1980 to facilitate short-term leasing or renting of water sets a uniform price for selling water each year. Early commitments of water to the bank are encouraged by selling water made available before July 1 first and sharing the proceeds of the sales proportionally among these sellers. Subsequent water commitments are sold on a first-come, first-served basis and the sellers are reimbursed accordingly. Transfers are facilitated because the bank deals only with stored water and rights cannot be acquired to the return flows from stored water.

Temporary water banking has been instituted in California on two occasions to allocate water during severe drought. A federal water bank was established during the 1976-77 drought to facilitate transfers within the agricultural sector. The bank was endowed with funds to purchase water from willing sellers for resale to irrigators needing additional supplies to protect long-term investments in perennial crops (Wahl and Osterhoudt, 1985). California established a State Water Bank in February 1991 to assist in the transfer of supplies diminished by four years of drought. The bank acquired water for $101 per 1,000 m^3 ($125 per acre-foot) and sold it for $142 per 1,000 m^3 ($175 per acre-foot) plus the costs of transporting it from the Sacramento/San Joaquin Delta to the point of use. Water for the bank was acquired by idling farmland, pumping additional groundwater, and using surplus water in reservoirs. During the first five months of operation all the purchases went either to provide critical water needs for permanent crops or to urban areas with a greater than 25 percent deficiency in supply (Gleick and Nash, 1991). Some of the water purchased by the bank could not be delivered because of losses in the system. These losses may have provided minor relief for fish and wildlife habitat in the Delta.

The Metropolitan Water District of Southern California (MWD) has entered into or is exploring a number of innovative means for acquiring additional supplies during drought and for long-term growth. Dry-year fallowing contracts with farmers give MWD the option of using some of the farmers' water during drought periods. The district is funding research to determine the dollar value lost when some portion of the water normally applied to alfalfa is withheld. With that information in hand, they might pay irrigators to use less water. MWD is funding conservation investments such as lining of canals in the Imperial Irrigation District (IID) in return for rights to the water that is conserved. These investments reduce the recharge of the groundwater used by Mexicans just across the border. But these third-party impacts were ignored in the agreement with MWD and IID because the Mexicans have no legal claim to the water. The district is contemplating installing drip irrigation in other agricultural areas in return for the water saved (Metropolitan Water District of Southern California, 1991).

Encouraging Conservation

As water becomes scarce and demand grows faster than supply, conservation becomes essential. The issue is how to conserve most effectively in view of a society's objectives such as efficiency, equity, and political acceptability. Conservation might involve: (1) water suppliers reducing distribution losses by fixing leaks and lining canals; (2) water users adopting water-efficient technologies that enable them to maintain the same services with less water (e.g., households installing more water-conserving toilets, farmers adopting more efficient irrigation technologies, and thermoelectric power producers switching from wet to dry cooling); and (3) water users changing their habits (e.g., curbing water use for washing sidewalks and cars, taking shorter showers, and switching to less water using crops).

The opportunities to conserve water will vary widely among regions and the time horizon under consideration. Maintenance is likely to provide a cost-effective means of conservation where the supply system is old and poorly maintained. For instance, the Massachusetts Water Resources Authority (1990) has determined that leak detection and repair are among the most economical means of balancing demands and supplies within their service area (see table 3).[5] Implementing such low-cost opportunities for saving water should be part of any long-term planning effort. But investments with lengthy implementation periods provide little relief when drought requires an immediate reduction in use. Short-term reductions are likely to depend largely on changing patterns of water use.

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[5]Lining canals and repairing pipes may increase the quantity of water available to users serviced by the supply system at the expense of others. The impacts on the total quantity of water available in a region depend on whether or not the water lost in the distribution system is available to other users. Seepage may recharge groundwater tables used by other irrigators and leaks may provide wildlife habitat.

Conservation can be encouraged through price incentives, mandated through regulations, or forced because of shortages. Prices provide the primary signals to use or conserve a resource. Individuals and firms increase their use of a resource when the additional (marginal) costs of the resource are less than the additional (marginal) benefits of using another unit of the resource. Likewise, they conserve when the marginal costs of using the resource exceed the marginal benefits it provides. Higher prices discourage increased use and encourage conservation.

Efficient water pricing implies charging users the marginal social cost of the water. The social costs associated with a particular water use can be divided into five components - the opportunity costs, storage, treatment, transport and return flows. The opportunity costs of water are its value in the highest alternative use. The alternative use may involve either withdrawing water from or leaving it in a stream or reservoir. The opportunity costs are universally ignored in pricing water; users do not pay for the water itself. Moreover, when water rights are established and maintained only by withdrawing water, there is incentive to withdraw water even when there is no good use for the water. On the other hand, if the property rights are privately owned, unattenuated, and transferable, the potential sale price represents the owner's opportunity cost. This cost, however, may differ from the social opportunity cost when the best alternative use is to leave the water in the stream for the provision of public goods. Under such circumstances, the private and social opportunity costs will differ unless the government or a private environmental group is a potential buyer.

Table 3: COMPARATIVE COSTS OF WATER SUPPLY / AUGMENTATION ALTERNATIVES PRESENTED BY MASSACHUSETTS WATER RESOURCES AUTHORITY

	Annual $/1000m^3 (a)	Capital Cost (b) ($ millions)	Yield (1000m^3/day
Supply Responses:			
Connecticut River	132 - 211	120 - 220	238
Millers/Tully Rivers	238	135	144
Merrimack River	423	600	454
Conservation and Demand Management:			
Leak Detection & Repair	37	30	114
Domestic Device Retrofit	61 - 148	10	19 - 45
Low-Flow Toilet Retrofit	872	200	64
Industrial & Commercial Conservation	13	0.1 (c)	3 (c)
Improved Use of Existing Supplies:			
Local Sources	90 - 343	16	1.5 - 30
Water Sharing	13 - 132	0.2 (c)	3 (c)
Sudbury Residential Treatment Plant	211	34 - 37	62
FY90 MWRA Water Rate	135	N/A	N/A

Notes:
(a) Annual O&M and amortized capital costs ($1/1000m^3 = $3.785/million gallons).
(b) Figures reflect 1990 costs.
(c) Yields and costs from first years' experience. Actual totals will be higher but within the range shown.

Source: Massachusetts Water Resources Authority, "MWRA Long Range Water Supply Program," January 24, 1990.

Municipal and industrial users generally are expected to pay their share of the costs of treating water to achieve a desired quality, of storing water to increase the reliability of supplies, and of transporting water to the place of use. Irrigators, on the other hand, do not treat their water and their storage and delivery costs are often subsidized. Consequently, irrigation water costs are often very low.

Only part of the water withdrawn from a stream is likely to be consumptively used. The social costs (or benefits) of the return flows depend on their quantity, quality, timing, and location. Return flows from irrigated lands and thermoelectric cooling plants may comprise most of the water supplies of downstream users. As long as the quality of the water is adequate, these return flows produce net social benefits. Untreated municipal and industrial-processing wastes can degrade and perhaps destroy aquatic ecosystems as well as the freshwater supplies of other users. The costs of treating effluent to meet environmental standards or the costs imposed on the environment and other water users as a result of dumping untreated wastes into water bodies are important components of the social costs of these uses. A society's environmental laws determine whether these costs are internalized to the users or are borne by others. Alternative strategies for protecting water quality are considered in the next section.

Water pricing practices in OECD countries generally are based on financial rather than economic efficiency considerations (Herrington, 1987). Water prices are set to recover a supplier's average costs after accounting for any subsidies. Average-cost pricing as practiced by the urban water industry differs from efficient pricing in at least two important ways. First, the supplier's costs are likely to be less than the social costs by at least the amount of the opportunity costs of the water. Second, in a rising-cost industry, marginal costs are higher than the average. For reasons discussed in the section on water development projects, water costs rise sharply as the resource becomes increasingly scarce and the level of water development rises. Thus, long-run marginal water costs are likely to be rising. Short-run marginal costs, on the other hand, may be essentially constant because they do not include the costs of investing in additional supplies. An OECD analysis of water pricing recommends taking a 20 to 30 year perspective and having prices reflect long-term capital costs (Herrington, 1987).

The rate structure as well as the rate level is important for providing incentives to conserve. Water use is not always metered. When users pay only a flat fee for water service, marginal costs are zero and there is no incentive to limit use until the fee is so high that it becomes more profitable to eliminate the service altogether. Users must be able to benefit by reducing their water use if pricing is to provide an effective demand management tool.

Markets and prices work best when supply and demand are elastic (that is, when small percentage changes in price produce large percentage changes in the quantities supplied and demanded). Both supply and demand tend to be more elastic as the time for adjustment increases. In the very short term, it may not be possible or feasible to develop new supplies, to invest in conservation measures, or to adopt new practices in response to higher water prices. With more time to adapt, a variety of responses might be possible. For example, more wells and dams can be constructed; less water- using crops or seed varieties and more efficient irrigation technologies can be introduced; water-conserving showers, toilets, and appliances can be installed; and thermoelectric power plants can shift from wet to dry- cooling technologies.

Marginal-cost pricing and marginal-social-cost pricing in particular would provide stronger incentives to conserve than a fixed fee or average- cost pricing. The impacts on water use would depend on the price- elasticity of demand, which vary with use, location, and time. Table 4 summarizes price elasticity estimates for urban public water for a number of OECD countries. Except for industrial water demand in Rotterdam, the elasticities are all negative and significantly different from zero. And with the additional exception of summer urban water demand in eastern Canada, all the demands are inelastic. A review of municipal water demand studies in the United States indicates that in-house water use is consistently price inelastic while outdoor use during the summer is considerably higher and is elastic in the eastern part of the country (Gibbons, 1986). The combination of much higher rates of water use and higher price elasticities during the summer months suggests that higher prices during peak-load periods might reduce the need for additional storage or distribution capacity. Indeed, higher water rates during the peak season have helped reduce seasonal differences in water use in several communities within the United States (Herrington, 1987).

There is some evidence that price elasticities of demand for irrigation water may be more elastic than for other uses. The evidence, however, is limited and comes largely from the United States, especially California. Average elasticities from six studies range from -0.37 to - 1.50. A study in Mexico indicated that charging by volume or the number of irrigations rather than by a flat rate resulted in more efficient irrigation water use (Herrington, 1987). Pricing schemes for irrigation water commonly provide no incentive to conserve as farmers are charged a fixed fee for a certain share of the water in a canal or stream. The principal exception is groundwater irrigators paying for their own pumps, wells, and energy and making their own pumping decisions. The experience in the Texas High Plains since the mid 1970s supports the view that agricultural water use is responsive to the irrigators' marginal water costs. Sharply higher energy prices combined with declining well yields and

Table 4: PRICE ELASTICITIES FOR URBAN PUBLIC WATER SUPPLY

Country	Location	Type of Study	Estimated Price Elasticity		Reference
Australia	971 households in 20 groups in Perth	readings over 1976-82; pooled x-section and time series	Overall:	-0.11	Metropolitan Water Authority, 1985
Australia	315 households in Perth	x-section (hypothetical valuation technique)	in-house: ex-house: overall:	-0.04 -0.31 0.18	Thomas, Syme and Gosselink, 1983
Australia	metered	x-section (?)	winter:	-0.36	Gallagher and Robinson, 1977
Australia	137 households in Toowoomba, Queensland	1972-3 to 1976-7 pooled cross-section and time series	short-term: long-term:	-0.26 -0.75	Gallagher et al., 1981
Canada	Urban demand eastern Canada	x-section 1960s	winter: summer	-0.75 -1.07	Grima, 1972
Canada	Municipal demand Victoria, B.C.	time series 1954-70	winter: summer: mid-peak: year-round:	-0.58 zero -0.25 -0.40	Sewell and Roueche, 1974
England and Wales	411 firms in Severn-Trent	water-saving investment in 1972-78		-0.3	Thackray and Archibald, 1981
England and Wales	Industrial (metered) consumption England and Wales	time series 1962-80	year-round:	-0.3	Herrington, 1982
Finland	Municipal demand Helsinki	time series 1970-78	year-round:	-0.11	Laukkanen, 1981
Netherlands	Industrial demand, Rotterdam	time series 1960s and 1970s	"no price elasticity demonstrated"		Rotterdam Water Authority, 1976
Sweden	69 domestic residences in Malmo	14 readings each over 1971-78; pooled cross-section and time series	year-round:	-0.15	Hanke & de Mare, 1982
United States	2159 households in Tucson, Arizona (water use per household)	42 readings each over 42 months, July 1976-Dec. 1979; pooled cross-section and time series	year-round:	-0.256	Martin, Ingram, Laney & Griffin, 1983
United States	Domestic use in Tucson, Arizona	time series Jan. 1974-Sept. 1977	year-round (1): (log model) (linear)	 -0.27 -0.45/ -0.61	Billings and Agthe, 1980
United Sates	Residential use in 21 study areas, eastern and western United States	cross-section early 1960s	winter: summer: (east) summer: (west)	-0.06 -0.57 (2) -0.43 (2)	

(1) Price included volumetric price of sewer use and the whole tariff schedule (increasing block was assumed to change in the same proportion as 'marginal rate' changes)

(2) Changes in marginal price (= marginal block rate) only, although intramarginal rate structure allowed for in demand function. These elasticities represent significant reductions on these estimated from the same data fifteen years earlier (when the intramarginal rate structure was not allowe for): -0.23, -0.86 and -0.52, respectively (see Howe and and Linaweaver, 1967, and Howe, 1982).

Source: OECD, "Pricing of Water Services," Paris, 1987.

increasing pumping depths resulted in higher water costs which in turn contributed to a large decline in irrigated acreage and the adoption of more efficient irrigation practices and crops requiring less water.

Equity considerations have been an obstacle to marginal-cost water pricing. Higher water prices would impact the poor most acutely. However, subsidizing the use of a scarce resource such as water is an inefficient way of promoting social goals. Special provisions can be made to protect low-income groups without eliminating incentives to conserve. Increasing block pricing that charges a low price for some minimum level of use and sharply higher prices on larger levels of use might meet these equity concerns while providing large water users with added incentives to conserve.

Marginal-cost pricing in an increasing-cost industry results in "excess" profits. For publicly-owned utilities, these profits could support the general treasury, perhaps making it possible to reduce taxes. For privately-owned water suppliers, a similar outcome might be achieved through taxes that transfer the excess profits from private to public coffers. These "excess" profits might be directed to social purposes in ways that do not distort the incentives to use water.

In view of the short-term inelasticity of demand, very large price changes would be needed to balance supply and demand during periods of drought. Consequently, the principal tools for limiting water use during periods of extreme drought are appeals to civic responsibility, education, and restrictions. Policy responses to drought often start with appeals for voluntary conservation and, if conditions deteriorate, then restrict use. Non-essential outdoor uses such as watering lawns and washing cars and sidewalks are usually the first to be curbed; businesses may also be required to reduce use by specified amounts. Restrictions often take the form of limiting water use during droughts to some fraction of their former use. This approach may discourage long-term conservation because it penalizes those who conserved prior to the drought.

Utilities are often reluctant to increase prices during drought but may be forced to for financial reasons. Increasing water prices serves two important functions during drought; it encourages voluntary conservation and it helps maintain the supplier's revenue. Even though sales are depressed by drought, costs may rise if suppliers develop expensive supplementary sources of water.

In spite of the potential advantages of markets and prices for adapting to long-term changes in the supply and demand for water, regulations dominate policies designed to deal with expected increases in water scarcity. Communities in the United States facing problems in developing additional supplies are imposing water-conserving standards for items such as showerheads, toilets, and appliances that use large amounts of water. Massachusetts requires all new construction and remodeling to install toilets that use no more than 6.1 liters (1.6 gallons) per flush. Several other localities have adopted similar legislation, and both houses of the Congress have introduced bills to establish national standards for the manufacture and labeling of certain plumbing products. Proponents of this regulatory approach argue that manufacturers would not produce water- conserving products in large enough quantities to achieve economies of scale in the absence of requirements to meet water-conserving standards. Or if they were produced and marketed, consumers would not buy them because water prices are too low. This latter argument, however, might be turned around to support the introduction of marginal-cost pricing and the use of price incentives to encourage voluntary adoption of water-conserving measures.

Regulatory measures also have been the primary approach for reducing groundwater depletion. Market incentives lead to inefficiently high rates of exploitation of common property groundwater stocks. Pumping taxes might be used to adjust these incentives, but governments have been more inclined to restrict groundwater use than to discourage it through tax incentives. New Mexico has long imposed limits on groundwater pumping, and Arizona's Groundwater Management Act of 1980 represents the nation's most comprehensive plan to curb and eventually eliminate groundwater mining. California and Texas are the only western states that do not restrict groundwater pumping. The sharp reductions in groundwater use in the Texas High Plains over the past fifteen years suggest that economic factors will eventually curb the rate of groundwater mining even in the absence of regulation.

Mercer and Morgan (1989) compare the welfare effects of four alternative water rationing schemes: physical rationing which provides users with a fixed maximum quantity of water; lifeline with increasing block rates which maintains a relatively low price for a minimum quantity but sets prices for larger quantities high enough to limit use to the desired amount; rationing with a provision that water can then be bought and sold; and pure price rationing which raises the price to all consumers by the same amount. Using a supply and demand framework, they examine the welfare implications for six different income classes of each scheme when a representative California water district experiences a 20 percent reduction in supply. Their analysis suggests that reliance on the price mechanism in one form or another is clearly superior to a strict rationing scheme. If the revenue loss to the district is not viewed as important, rationing with resale minimizes the total welfare loss. This scheme results in the same water consumption pattern as with pure price rationing. However, rationing with resale is preferred because it imposes no welfare loss on the two lowest income classes. If revenue captured by the district is crucial, then the pure price rationing scheme is preferred. The administrative problems and costs, which are not addressed by Mercer and Morgan, are likely to pose a major obstacle to the implementation of a rationing with resale scheme.

A combination of regulatory and voluntary measures are likely to be included in a comprehensive demand management strategy. After four years of study and negotiation, a coalition including urban water agencies, environmentalists, and elected officials in California proposed adopting a mixture of regulatory and incentive measures to encourage conservation. The regulatory approach would be used to prohibit car washes, commercial laundries, and decorative fountains that fail to recycle, and to require the installation of toilets using 6.1 liters or less per flush. Commercial, industrial, institutional, governmental, and multifamily residences would be required to use water-conserving landscaping, and construction permits would not be released without a water-efficiency review. Voluntary conservation would be encouraged through pricing policies, rebates for replacing old toilets with ultra-low flush models, and educational programs. Meters would be required for all new connections and whenever a property is sold (Muir 1991).

Protecting Instream Flows and Water Quality

Providing for the instream and environmental values of water involves both allocating water for instream rather than withdrawal uses and limiting the quantity and toxicity of the pollutants that reach these waters. The environmental values of a stream or lake depend on both the quantity and quality of water. Moreover, the capacity of a water body to assimilate pollutants without adversely affecting its value is positively related to the volume and rate of flow of the resource. While these interdependencies are important, the discussion first considers the allocation of water for instream use and then the level of pollution.

As was discussed earlier, the system for acquiring water rights provides the framework for the allocation and use of the resource. Under a permit system of water rights, instream flows can be protected by denying permits for withdrawals that are not deemed to be in the public interest. The agency entrusted with issuing water rights is responsible for protecting instream flows and their environmental values. Riparian rights provide some protection for instream flows by preventing withdrawals that might unduly inconvenience downstream land owners, but it is left to the courts or a government agency to balance the overall benefits and costs of a withdrawal or water project. The prior appropriation doctrine provides no protection to instream flows because water rights are established only by removing water from a stream.

The prior appropriation doctrine adopted in the western United States encouraged the settlement and economic growth of the region and the development of its water resources for irrigation and other withdrawal purposes. This doctrine, however, neglected the importance of free-flowing streams (Shupe, 1989). For the past several decades, the federal and state governments have attempted to reach a better balance between instream and withdrawal values in the allocation of surface waters. Most of the prior- appropriation states now have public agencies empowered to establish rights to instream flows. The National Environmental Policy Act of 1969, which requires all federal agencies to undertake an environmental impact statement as part of their water project evaluation, changes the burden of proof regarding environmental impacts. Previously, opponents of water development projects had to show the project would have major adverse environmental impacts. Currently, proponents must demonstrate that the project is environmentally benign or that every effort has been made to mitigate its adverse impacts. Under the Wild and Scenic Rivers Act of 1968, Congress can preclude water development projects that would excessively damage an area's natural amenities by designating a river or stretch of a river as wild and scenic. The Clean Water Act of 1972 and the Endangered Species Act of 1973 also have become potentially powerful instruments for protecting instream flows (Frederick, 1991a).

The United States paid a high price in foregone benefits because of its initial neglect of some of the environmental impacts of its water investments and uses. While recent legislation provides powerful levers for introducing environmental values into water allocation and development decisions, the nation continues to pay a high price for its inability to introduce environmental values into these decisions in a balanced and expeditious manner. In many cases, these values are introduced either through legislation that makes instream values preemptive over any other water uses or through long and costly legal proceedings. In other situations, these values continue to be ignored and shortchanged by institutions rooted in an era when water left in a stream was assumed to have no value.

Markets have played a limited role in providing for instream flows. Private environmental organizations and government agencies have purchased water rights for instream flows in some areas. Government purchases of water rights to provide environmental values have been employed in basins where water is already fully allocated and the rights of existing users have to be terminated to restore instream flows. Purchasing rather than condemning existing water rights may be quicker and perhaps even less expensive when a voluntary transfer can avoid a lengthy legal struggle. Moreover, by making the costs of providing these services explicit, the voluntary approach may make public agencies more readily accountable for their actions.

Regulations have dominated the efforts of the OECD countries to protect their waters from pollution (Organisation for Economic Co-Operation and Development, 1989). Technology-based effluent standards were the principal tool established in the United States under the 1972 Clean Water Act to achieve the ambitious goal of restoring all navigable waters to a "fishable and swimmable" condition. At the time, the large quantities of conventional pollutants (such as fecal coliform bacteria and organics which create biochemical oxygen demands) that were being dumped directly into streams and lakes by industry and municipalities were perceived to be the principal threat to these waters. Under the 1972 legislation, industry was required to adopt the "best practicable control technology" within five years and the "best available technology economically achievable" within a decade. New industrial sources were held to the even stricter standard of "best available demonstrated control technology." Municipal discharges were required to undergo secondary treatment within five years and the "best practicable waste treatment technology" within a decade (Freeman, 1978).

Although the objectives of the 1972 act have not been attained, curbing and treating these point-source discharges produced important (but unquantified) water quality benefits. But these achievements have come at a high cost. Total water pollution control costs (in 1986 dollars annualized at 7 percent) increased from about $9.9 billion in 1972 to an estimated $42.4 billion in 1990. About 92 percent of these costs are incurred in response to federal mandates (U.S. Environmental Protection Agency, 1990). Even though most of these costs have been spent to reduce and treat industrial and municipal wastes, these point sources continue to be significant sources of water pollution and large additional expenditures are planned to control point discharges. However, these investments have encountered diminishing returns in their ability to restore the nation's waters to a fully usable status (Smith, Alexander, and Wolman, 1987).

Nonpoint pollutants from farms, urban areas, construction sites, landfills, and septic systems are now the principal sources of both conventional and toxic pollutants reaching U.S. waters (U.S. Environmental Protection Agency, 1987). These pollutants are difficult to control because there is no single point where they can be collected and treated. The problems as well as the solutions generally involve land-use management.

Regulation of farming practices to achieve water-quality objectives is likely to be particularly inefficient unless the regulations can be readily tailored to the wide diversity of farm-level and water-quality conditions. Limited and sporadic efforts have been made to encourage farmers to adopt more environmentally-benign practices. In the United States these efforts have taken the form of paying farmers to adopt more environmentally-benign management practices or to remove highly erosive land from production. Economic incentives might be particularly useful in controlling the adverse economic impacts associated with irrigated agriculture. Erosion, sedimentation, and water-quality degradation associated with irrigation are virtually eliminated when the water applied to a field is limited to levels that can be full absorbed within the root zone of the crops. And the cost of water is one of the most important determinants of the quantity of water applied and the irrigation practices used (Frederick, 1991b).

Stricter standards for the construction and use of landfills, surface impoundments, and underground storage tanks should reduce the threat that new development would pose to water quality. But millions of previously existing sites already are potential threats to water quality. Sites deemed to pose the greatest hazards to human health and the environment have been placed on a national priorities ("Superfund") list for long-term remedial action. Efforts to restore contaminated aquifers to drinking water quality have been expensive and the long-term results have been problematic. Few sites have been cleaned up with the $7.5 billion spent so far. The list of sites identified for clean up grows much faster than the available funding. Under existing criteria, more than 20,000 sites are expected to require Superfund clean up with costs totalling $600 billion or more. In the absence of major advances in groundwater restoration technology, a policy of triage in which the less valuable and more difficult to clean aquifers are abandoned, at least temporarily, as unsalvageable would make better use of the limited resources available for protecting and restoring water quality.

High costs and limited water-quality improvements are not unique to the U.S. experience with regulatory measures. Similar experiences prompted the OECD Environment Committee to declare in 1985 that their approach to environmental protection will "seek to introduce more flexibility, efficiency and cost-effectiveness in the consistent application of the Polluter-Pays Principle and a more effective use of economic instruments in conjunction with regulations" (Organisation for Economic Co-Operation and Development, 1989).

In theory, economic instruments such as taxes, charges, subsidies, and markets would improve the cost-effectiveness of achieving a given level of pollution control or water quality. For instance, use of effluent charges rather than regulations would give polluters the option of continuing to pollute and paying a penalty or taking actions to avoid polluting. Economic instruments give polluters flexibility to adopt the least-cost response and incentives to develop new pollution control technologies. If the penalties accurately reflect the social costs of the pollutants and if the distributional impacts are unimportant, society would be indifferent as to whether an individual pollutes and pays a fine or invests to eliminate the pollution.

In practice, there are a number of obstacles to designing, implementing, and enforcing efficient incentives for controlling water pollution. The design is complicated by the problems of measuring with any accuracy the level of effluent fee that would provide the desired level of water quality or that would equate the polluters' costs of polluting with those of society. The impacts of a given set of economic instruments on water quality would be uncertain. Implementing a socially-efficient effluent fee would encounter considerable resistance as the fee would be much higher than any imposed by the OECD countries to date (Organisation for Economic Co-Operation and Development, 1989). And enforcing a fee that varied with the quantity and quality of effluent discharged over some time would be difficult to monitor and enforce.

Balancing the potential efficiency advantages with the practical limitations of economic instruments has led to a mixed approach to water- pollution control within the OECD countries. In 1976 Germany passed an Effluent Charge Law which combined a system of effluent charges and discharge permits. The charges were expected to approximate damages and encourage certain levels of treatment. In fact, however, discharge permits remained the principal means of achieving desired water-quality levels while the effluent charges served primarily as a way of raising the funds to cover the costs of program monitoring and subsidies for investments in treatment plants (Bower and coauthors, 1981 and Brown and Johnson, 1984). The 1980s brought a significant expansion in the use of economic instruments for water-pollution control. But these instruments supplement rather than replace existing regulations in most cases. Moreover, regulations remain the primary means of limiting pollution and emission levies are based more on financial than economic efficiency considerations (Organisation for Economic Co-Operation and Development, 1989). Instruments that are coming into common use include effluent charges, levys on the use of fertilizers and other chemicals that threaten water supplies, and subsidies and tax reductions to encourage investments in pollution control.

Tradable permits to pollute water have not yet been introduced in the OECD countries (Organisation for Econcmic Co-Operation and Development, 1991) although the concept has considerable theoretical appeal at its simplest level. Society decides how much pollution it is willing to accept and issues or sells tradable permits to pollute that are consistent with their desired water quality. The equity implications of the scheme can be altered through the initial distribution of the permits. As a market in the permits develops, the price encourages development of improved control technologies and indicates to existing and potential polluters how much they should invest in pollution reduction. Market forces produce the desired water quality at the lowest possible cost by equalizing the marginal costs of control among all polluters (Russell, 1981). If anyone were allowed to purchase the permits to pollute, environmentalists would be able to buy cleaner water. The real world, however, is not so simple and the efficiency implications of a market in permits to pollute water supplies are not so straight forward. If the permits were tradable throughout a river basin, trades might shift the location of pollutant discharges and, thereby, alter the quality of the water at different points along the river. This problem might be reduced by diminishing the area within which the permits can be traded. But as the size of the market declines, the opportunities for and potential benefits of emission trading also decline. And if the permits are limited to particular monitoring points, the scheme would differ little from one of emission controls. Despite its potential drawbacks, controlled tradable pollution permits are receiving increased attention as a way of reducing the costs of improving water quality. The concept was adopted in the latest amendments to the U.S. Clean Air Act, and it is being considered for controlling water pollution in several OECD countries (Organisation for Economic Co-Operation and Development, 1991).

Subsidies for investments in pollution-control equipment and adoption of less-polluting management practices have been a common instrument for promoting water-quality goals. Subsidies, for obvious reasons, are popular with polluters. But in addition to burdening public treasuries, they distort investment decisions. For instance, an evaluation of a federal program to subsidize the construction of wastewater treatment facilities in the United States concluded that the subsidies resulted in larger, more sophisticated plants, less local involvement and pressure to contain costs, longer construction periods, and less innovative reuse of effluents (Congressional Budget Office, 1985).

The OECD countries have been on the forefront of efforts to protect and improve instream flows and water quality. These efforts in part reflect the increasing values these countries are placing on the environmental services provided by water. In contrast, many of the developing and former centrally-planned countries view water quality and the environmental services of instream flows as luxuries that they cannot afford. This view suggests that developing and using water for social and economic purposes conflict with environmental water uses. While there are tradeoffs among water uses, the conflicts over development and environmental objectives breakdown when water supplies are allowed to degrade to the point that they become hazardous to human health and undermine water-based economic activities. At this stage, protecting and restoring water resources are not only compatible with social and economic development, they may represent the most critical component of a well- designed strategy to manage the demands on a region's water resources.

VIII. DEMAND MANAGEMENT AND WATER RESOURCE PLANNING

The increasing scarcity of the resource and the growing government role in protecting and allocating it create a need for comprehensive planning to take account of competing demands and opportunities for coordinated management. Even when a country favors voluntary means of encouraging transfers and conservation, the government (in addition to defining and enforcing property rights) has an important role in dealing with externalities associated with private water uses and transfers, in providing for the public goods provided by instream flows, and in regulating the prices of monopolistic suppliers.

Numerous agencies, both public and private, are likely to be involved in the decision making process affecting the development, allocation, and use of a country's water resources. Most of these agencies engage in some form of water planning as a prelude to decisions about water development activities. Local communities and private industries plan for water and sewage service, and national, regional, and private agencies plan investments for activities such as navigation, hydropower, irrigation, and flood control. However, project-by-project and sector-by-sector planning may lead to conflicting and inefficient investment decisions. In the absence of prices reflecting resource scarcity, planning that encompasses natural hydrologic regions is necessary to ensure that the opportunity costs associated with alternative water uses are considered. Comprehensive planning should include a strategy for demand management, opportunities for coordinated management of existing facilities to improve safe yields and water quality, and provision of water for public goods. Moreover, water planning should be integrated with planning for land use and other activities affecting and affected by water development. For example, an integrated resource plan should take account of the impacts a reservoir would have on neighboring land values and development activities as well as the impacts land use activities might have on water quality and the magnitude and frequency of floods.

The possibility of a greenhouse-induced climate change raises new challenges and perhaps added justification for comprehensive water planning. A global warming would accelerate the hydrologic cycle, increasing both precipitation and evapotranspiration rates. While the regional impacts of a global warming are uncertain, they are likely to include changes in precipitation and runoff patterns and in the intensity and frequency of storms. The hydrologic uncertainties are compounded because relatively small changes in precipitation and temperature can have sizable effects on the volume and timing of runoff, especially in arid and semiarid areas (Frederick and Gleick, 1989). On balance, renewable water supplies are likely to decline under a greenhouse warming because at any given time more of the globe's water supply would be stored in the atmosphere rather than in the soils, surface reservoirs, and oceans. The capacity of the atmosphere to hold water increases exponentially with temperature; an increase in the global temperature of 3 degrees Celsius would increase atmospheric moisture by 30 percent (Rind, 1991).

Uncertainties as to the likelihood of a greenhouse warming and its regional hydrologic implications present a dilemma for water planners. The traditional assumption (that precipitation and runoff patterns in the future will be similar to those in the past) underlying the design and management of water storage and transport facilities becomes increasingly suspect. Additional infrastructure for storing and transporting water may be a desirable means of dealing with future hydrologic change. Moreover, the long planning and construction periods characteristic of water projects argue for planning early to adapt to the hydrologic impacts of climate change. But when even the direction of change is uncertain, infrastructure investments are apt to be costly and ineffective. This dilemma provides added justification for developing institutions that will facilitate the reallocation of scarce water supplies in response to whatever changes the future might bring in supply and demand conditions.

The United States illustrates both the need for and the difficulties of achieving coordinated water planning. The Water Resource Planning Act of 1965 was intended to address the problems of fragmented responsibilities for water planning and development. This act provided for coordinated planning through the establishment of a national Water Resources Council and river basin commissions that were expected to coordinate federal water activities. The 1965 legislation also provided the states with financial assistance for water planning. The Congress, however, never used the Water Resources Council and the river basin commissions for their intended purpose (National Water Commission, 1973). The experiment, which illustrates the obvious point that planning can be effective only if it contributes to better laws and decisions by water agencies, was aborted in the early 1980s when the Council and the commissions were zero funded. The current chaotic water policy situation in the United States has been described by Foster and Rogers (1988, p. 9) as follows: "... eighteen federal agencies, in seven departments and seven independent agencies, currently exercise responsibility for water programs and projects. They operate under policies enshrined in individual legislative acts. At least twenty-five separate water programs, and some seventy separate Congressional appropriations accounts, have been identified. These programs are governed by more than two hundred federal rules, regulations, and laws". In addition the individual states have their own water agencies and regulations.

The results of this situation are manifested in growing water conflicts, inefficient resource use, and an inability to respond expeditiously and effectively to changing conditions. For instance, U.S. policies rooted in an era when providing inexpensive water was viewed as an important means of settling and developing the West now lock large quantities of federally-subsidized water into relatively low-value agricultural uses that commonly have adverse environmental impacts and sometimes aggravate problems of surplus crops (Frederick, 1991a). Another example is the outdated management criteria that give navigation (which requires large quantities of water and accounts for less than 2 percent of the total system's benefits) a high priority in the operation of the Missouri River reservoir system while imposing high opportunity costs on other potential water users (U.S. Army Corps of Engineers 1990).

IX. CONCLUSIONS

The costs, both financial and environmental, of using water have risen sharply in recent decades, and they will continue increasing as demands on the resource outstrip supplies. Only the magnitude and nature of these costs are in doubt. When water is underpriced and its allocation is restricted by law and tradition, more of the costs are reflected in inefficient water use, lost development opportunities, and higher costs for new water users. When water can be used freely for disposal of wastes, more of society's costs take the form of deteriorating aquatic ecosystems and health problems associated with contaminated supplies. On the other hand, when the costs are borne by users of the resource and there are opportunities to transfer water voluntarily among alternative uses, then the resource is used more efficiently, the highest-value uses are assured of an adequate supply, and a region derives greater net benefits from its scarce water supplies.

Demand management--which includes transferring water among alternative uses in response to changing supply and demand conditions, introducing appropriate incentives to conserve, and protecting instream flows and water quality--provides a means of controlling the magnitude and nature of these costs as water becomes increasingly scarce. For most resources, markets and market-determined prices enable supplies to be transferred to those uses offering the highest returns and provide incentives to conserve. Efficient water markets, however, are rare, and the nature of the resource makes it difficult to establish such markets. Institutional arrangements rooted in an era when water was not considered to be scarce often dictate use, and owners of non-transferable water rights usually lack much incentive to conserve. Well functioning water markets would make use more responsive to changing conditions and encourage conservation, but they may ignore the impacts of a transfer on third- parties and public goods. Although no institutional arrangement is likely to be ideal for all circumstances, voluntary transfers should be encouraged where third-party impacts either can be ignored or assessed and incorporated into trade decisions without imposing high transaction costs.

Water use cannot exceed the available supply. When demand exceeds supply at the prevailing price, voluntary reductions in use can be encouraged through higher water prices and by public appeals for conservation. Forced reductions in use can be induced through regulations and planned or unplanned shortages. Metering is essential for pricing to be an effective demand management tool. But even when water is metered, equity concerns often keep prices well below the marginal social costs that would encourage efficient use. Increasing block pricing might satisfy equity concerns by providing a minimum level of supply at a low price while conservation is encouraged by much higher prices for larger quantities of water. Water use is more responsive to price in the long run when users have sufficient time to make water-conserving investments.

Regulatory measures have dominated the efforts of the OECD countries to protect streamflows and water quality. The results of these efforts have been characterized by significant but often disappointing water quality benefits and by very high costs. These costs have led many poor countries to neglect efforts to protect their water resources. Such neglect, however, is very shortsighted. When water quality is allowed to degrade such that it is hazardous to human and ecological health or it undermines water-based economic activities, protecting and restoring water quality is not only compatible with, it may be necessary for, social and economic development.

Many countries are now seeking more cost-effective means of achieving water quality objectives. Effluent fees might provide incentives to adopt and develop least-cost measures to control pollution. Although the impacts of an effluent fee on water quality are uncertain, fees that are set only to cover monitoring and enforcement costs are likely to provide little inducement to incur the high costs often required to protect freshwater supplies. Subsidies have been used to encourage pollution control investments, but this approach distorts incentives and depends on the availability of public funding. Tradable permits to pollute would establish the allowable quantity of pollution and provide incentives to achieve this level at the lowest possible cost. The equity implications of a tradable permit scheme could be adjusted by auctioning the permits or granting them to specific groups. Environmental interests could purchase a higher level of water quality under a scheme that allows all interests to bid for pollution rights.

As freshwater supplies become increasingly scarce, relying more on prices and markets to allocate and protect supplies would appear to offer major advantages in many situations. But even if prices and markets are the primary tools for managing water demand, government would still have an important role in defining and enforcing property rights, providing for public goods and third-party interests, and regulating the prices and profits of monopolistic suppliers. Furthermore, comprehensive basinwide water resource planning may be required to avoid conflicting and inefficient investment decisions.

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