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Strategies for Managing Water Demand

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The future economic, social, and environmental costs of meeting the water needs of human populations and supporting economic development will depend on our ability to understand and manage water demands. Water demand management, a relatively new branch of water resources science, offers a promising alternative for sustaining the world's freshwater supplies in the next century and beyond. Past research and experience indicate that appropriate water-demand management policies can improve the existing supply-demand balance in water-stressed regions and also offer multiple benefits to all stakeholder groups. However, significant public and private sector investments in research, development and implementation of water conservation techniques are needed to realize its full potential.This paper uses geographical perspectives to compare different implementation strategies for managing water demands.

Recently, water resource planners have turned their attention to the prospect of an impending global water crisis. Their predictions of widespread water shortages are based on expectations of world population growth and increases in affluence, which will translate into needs for more and more water for domestic supply, industry, hydropower, and irrigation, while global freshwater supplies remain fixed. Using this premise, assessments of available water resources have been conducted and compared to current total withdrawals to predict where and when demand will outstrip supply (UNCSD, 1997; Falkenmark, 1997; UNESCO, 1998; Shiklomanov, 1997). Unfortunately, the limited data on annual runoff and the volume of groundwater reserves as well as the very crude estimates of total withdrawals and usage make the published balances of supply and demand in various countries subject to criticism (Biswas, 1999). Predictions of future conditions are further complicated by the unknown impact that global climate changes may have on water balances and the unclear relationship between future water use and economic growth.

Despite the uncertainties, it is highly likely that the locally available supplies will be judged inadequate in an increasing number of regions and countries. Already in many humid and semi-arid regions with average availability of water, irrigated agriculture, industry, cities, and the environment must compete for available freshwater resources. A frequent outcome of this competition is not the reallocation of available water among sectors but a net increase in freshwater withdrawals, thus leaving less water in natural ecosystems. While on the global scale, annual water withdrawals are estimated at only 8 percent of annually renewable resources (WRI, 1999), the proportion of total runoff that is now captured and withdrawn for human use has reached a level that has significant adverse effects on the functioning of ecological systems in some areas (Falkenmark, 1999). New supply options to alleviate this situation are few and expensive. In fact, desalination or importation from distant sources are often the only technically feasible options remaining.

The prospect of a water crisis has challenged water managers to search for effective ways to satisfy future demands without jeopardizing the long-term sustainability of current water resource systems. During the 1990s, a new management approach has been devised to help meet this challenge. This new framework, known as integrated water resources management (IWRM), has been strongly recommended by the main international conferences on water (ICWE, 1992; UNCED, 1992). Its coordinated plans for the utilization and protection of water resources among many stakeholders represents a holistic approach to water. Without compromising the sustainability of environmental systems, IWRM attempts both to integrate water with related land resources and to optimize economic and social welfare . The IWRM framework also provides for an explicit consideration of water demand management along with water policy and strategy, water legislation and standards, institutional framework, participatory planning and management, allocation across (sub)sectors and conflict resolution, functions and values of water resources, and trans-boundary issues (GWP, 2000). With the current strong political barriers to water exports and relatively high cost of desalination, management of water demand may be the only practicable option for meeting both the current and future water supply needs of water-stressed regions.

Water demand management alternatives can be viewed as a means to enlarge the range of choice into a more holistic framework of integrated water resources management. Today, many water professionals share the view that a better understanding and careful management of water demand is critical to our ability to support the needs of a growing population and economic development without degrading the natural environments and ecosystems that sustain water resources systems. While the practical experience with demand management continues to accumulate, the current state of knowledge may not be sufficient to meet the ambitious goals made in declarations from international meetings of water resources professionals. This paper provides an overview of four complementary strategies for implementing demand management programs.

Water Demand Management

Efficient Use and Allocation of Water

From a practical viewpoint, water demand management encompasses two interrelated activities: the improvement in technical efficiency of water use and the efficient allocation of available water among competing uses. Improvements in the efficiency of water use are usually undertaken by water providers and water users within the urban, industrial and agricultural sectors. By meeting the existing needs of individual users and uses with less water, such improvements can free up significant quantities of water. The term “efficiency” derives from engineering practice where it is typically used to describe technical efficiency (i.e. the ratio of output to input). The criterion of technical efficiency is useful in comparing various products and processes. For example, one showerhead is considered more efficient than another if it can accomplish the same purpose (i.e. of showering) by using less water or other inputs (e.g. lower water pressure). The water efficiency gains of drip irrigation over furrow irrigation or low flushing volume toilets over traditional toilets can be substantial without diminishing the fulfillment of the original purpose for which water is used. For example, an analysis of end-use data in two North American cities with per capita use rates of 1,412 and 806 liters per capita per day showed that the efficiencies in the major customer sectors ranged from 46 to 85 percent (Dziegielewski, 1996). This implies that the current average rates of water use could decrease by 15 to 54 percent if all customers implemented the efficiency measures that were already used by a significant fraction of customers in each city. However, the efficiency concept is not useful in making investment decisions unless the inputs and outputs are measured in *value* terms. This expression of efficiency is referred to as *economic efficiency*.

Any water that is saved through conservation can be kept in reserve, applied toward the expansion of the same use (by the same user or other users), or reallocated to other sectors. The *reallocation* of water savings and each major sector’s existing water supplies can be viewed as the second level of water demand management. The process of reallocation can be contentious when water users and water providers resist the reallocation of water out of fear of losing their entitlement to water supplies. However, when the potential for saving water through efficient use has been fully exploited and all available water is appropriated, new uses can only be accommodated at the expense of existing uses. Because irrigated agriculture is responsible for the major portion of freshwater withdrawals (about 85 percent on the global scale according to WRI, 1999), irrigation water is an obvious target for reallocation to industrial, domestic, and environmental purposes (Rosegrant and Ringler, 1998). The unmet needs for irrigation water are a special case in some arid regions of the world, where the cost of obtaining water supply through long-distance transportation or desalination may be greater than the cost of importing foods from other regions. In this context, water demand management can be extended to include the management of "virtual" or "constituent" water that is embedded in imported foods (Shuval, 1999).

Stakeholder Benefits of Demand Reduction

In addition to improving the supply-demand balance, demand management alternatives offer multiple benefits, including environmental benefits over and above the economic benefit of lower costs. The tangible economic benefits include the energy savings in water heating and pumping, the foregone costs of water treatment, distribution system capacity, wastewater collection and treatment, as well as the savings in capital expenditures because of deferred, downsized, or eliminated water supply projects. Water savings may also produce environmental benefits by providing increases in the availability of water for streams, wetlands and estuaries. In many cases, demand management programs are beneficial even where there is an abundant supply of water and no gap between demand and supply. Simply stated, the adoption of certain demand management measures can save money both for water providers and individual users.

The analysis of benefits and costs of water conservation measures allows planners and administrators to determine whether various measures can achieve reductions in water use that are *beneficial* to their agency, water users, and the environment. Usually, a formal benefit-cost analysis is conducted in order to determine if a conservation practice is beneficial to all or at least some stakeholders. Results of such analyses are becoming available in the open literature. For example, Howe and White (1999) calculated levelized costs of water savings for 15 different conservation measures for a demand management program in Sydney, Australia, which would achieve demand reductions reaching 38 percent by the year 2011. The levelized costs to the community ranged from AU\$0.0014/m^3 for implementing a showerhead performance standard to AU\$0.70/m^3 for a washing machine rebate program. Similar analysis performed for a water utility in Eugene, Oregon, showed lifecycle levelized costs to the water agency ranging from US\$0.010/1000 gallons (\$0.003/m^3) to \$0.26/1000 gallons (\$0.06/m^3) with the higher end cost for commercial water audits (Davis and Dziegielewski, 1997). However, these costs were more than offset by the foregone long-term costs of capital improvements for some measures.

Demand Management Measures and Programs

Any activity, practice, technological device, law, or policy that can potentially reduce water use may be considered a demand management (or conservation) measure. Hundreds of different measures can be found in the literature (Dziegielewski, et al., 1993a). Several methods of grouping individual measures are possible. One frequently used method is categorization by the purpose of water use to which the measures apply. Examples of technologies and efficient water use practices that can be employed to reduce water use for the major sectors of users are listed below:

- *Domestic use:* low-flow showerheads, shower-flow restrictors, toilet-tank inserts, faucet aerators, low- and ultra-low flush toilets, dual flush toilets, insulation of hot-water pipes, horizontal axis washing machines, low-pressure supply connections, pressure-reducing valves, water-efficient landscape designs, efficient landscape irrigation practices, and other devices.
- *Industrial use:* counter-flow washing and rinse systems, reuse of process water, recirculation of cooling water, ozone treatment for cooling towers, treatment and reuse of blowdown, water recycling.
- *Agricultural irrigation:* micro-spray and drip irrigation systems, soil-moisture sensors, laser-assisted field leveling, evapotranspiration-driven irrigation schedules.
- *All uses:* metering of water use, rehabilitation of water delivery systems, leak detection and repair, pressure reduction in distribution systems.

These individual measures can serve as building blocks in the formulation of "implementable" demand management programs, which can be viewed as the

Table 1. Demand Management Implementation Strategies and Programs

Strategy	Implementation Program
Public Education	Primary and secondary school programs Promotional campaigns and events Mass media advertising campaigns Dissemination of information through personal contacts Outreach programs to educate water users and help them install conservation hardware Xeriscape garden demonstration
Water Management Programs	Meter testing and replacement program Leak detection and repair program Distribution system audit program Tax incentives, subsidies, and rebates for adoption of conservation measures Social conservation incentives and disincentives program
Government Regulation	National water management laws and policies Water rights and priorities of use statutes Government enforced performance criteria and standards Local conservation codes and ordinances Water use restrictions and bans during emergencies
Economic Incentives	Water pricing and rate-making policies Tradable water rights Regional water markets and water banks Subsidies and rebates to water users Cross-subsidization of agricultural conservation Tax credits and incentives Penalties for excessive use (quotas) Privatization of water supply sector

Source: Dziegielewski and Baumann (1992), Dziegielewski et al (1993a)

counterpart of supply side alternatives. Each program includes such elements as:

1. specific measures to be included (i.e., program contents),
2. definition of the target population of water users (i.e., program participants),
3. incentives for participation,
4. modes of information dissemination and contact with water users,
5. schedule for program implementation and its duration,
6. specification of agencies that are responsible for program implementation, and
7. program evaluation plan.

However, demand management measures and programs differ from supply-side options in several important respects. First, the amount of water savings that can be attributed to individual measures is small when compared to typical supply development alternatives. Some demand reduction measures may not make a significant difference in the supply and demand balance unless they are implemented in concert with other measures. Second, many measures have a significant cost of implementation and their effectiveness in producing water savings has to be checked against the cost of supply augmentation. Third, most conservation measures require the cooperation of water users who must adopt conservation technologies and efficient water-using behaviors. Gaining a widespread adoption of various measures is a significant challenge for water management institutions and governmental agencies with limited experience in dealing with the general public. Fourth, the number of possible measures greatly exceeds the number of supply-side options. The choice of appropriate measures usually requires screening of as many as several hundred possible actions in terms of their potential for saving water and their cost effectiveness. Finally, water demand management can be implemented not only by water users and suppliers at the local level but also by various agencies at different levels of government. For this reason, it is important to identify and evaluate alternative strategies for their implementation. Such strategies are discussed below.

Implementation Strategies

In general, the strategies for the implementation of demand management are separated into "command and control" approaches, which rely on laws and regulations and "voluntary" approaches involving economic and social incentives that encourage water users to adopt efficiency measures. In this paper, four broad strategies for implementing demand management programs are identified and discussed. They include public education, water management, government regulation and economic incentives. Table 1 gives examples of typical demand management programs that are usually undertaken within each strategy.

The list of specific demand management programs under each strategy in Table 1 is by no means exhaustive. Many innovative approaches are being developed and tested by various entities. The following sections provide a brief overview of the important aspects of each strategy.

Public Education

Public education and dissemination of information about the need to conserve water and about the best conservation practices represent an effective and the least controversial approach to implementing demand management. Changing behaviors associated with high water use and encouraging the use of water-saving devices and practices often are seen as the most effective means to achieve a reduction in water use. Public information and education campaigns continue to be popular means of encouraging water users to adopt and maintain long-term water conservation measures and behaviors. Such campaigns usually attempt to persuade water users to conserve water, and they also provide users with information on how to do so.

Research and water industry experience suggests that the public acceptability of demand management practices depends on the type of proposed measures and the current water supply situation in the community or agricultural region. During drought or other water emergencies individual users may be willing to adopt a wide range of short-term measures, including practices that require changes in their normal economic activities and lifestyles. However, only a subset of such measures is acceptable for permanent adoption.

While technological devices are often readily accepted by individual domestic users, the savings in water resulting from their use is small compared to those that can be achieved by behavioral changes, especially under water-shortage emergency conditions. Past research into conservation behavior has identified several motivating factors that should be considered while designing effective water conservation campaigns. White (1966), Bruvold (1979), and Berk et al. (1981) have identified several important pro-conservation attitudes. These attitudes pertain to the following conditions and characteristics of measures that are promoted:

- *Seriousness of water supply situation:* Consumer attitude surveys conducted during and after major drought episodes have shown that belief in the seriousness of water shortage in the community is a necessary condition for persuading consumers to conserve.

- *Efficacy of efforts:* Consumers are more likely to engage in conservation if they know how much water they could save by doing so and if they are convinced of the importance of their personal efforts in lessening the impacts of critical water supply situations.

- *Choice of equitable measures:* Conservation campaigns are likely to be more effective if the conservation measures (whether voluntary or mandatory) are perceived as equitable, i.e., that all members of the community are required to make sincere efforts to conserve. Mandatory measures, if enforced, often are seen as being more equitable than voluntary measures.

• *Social commitment:* Water conservation campaigns are most effective if they seek to strengthen group identity and to educate consumers regarding the undesirable impacts of self-interested behavior on group welfare. Studies in social psychology demonstrate that educating and informing consumers about the undesirable long-term consequences of self-serving choices is effective in fostering strong group-oriented behavior and attitudes.

• *Cost and inconvenience:* The perceived effort and inconvenience to consumers is directly linked with conservation behavior. Consumers first adopt those measures that require a minimum cost or sacrifice.

These pro-conservation attitudes do not exhaust all the possible motivations for stimulating water conservation behaviors. Others may relate to one's environmental ideology, or to the perception of the role of government in mediating the impacts of water shortages (Sims et al., 1982). Research on the motivations of water users for conserving water is an important requirement in the formulation of effective messages to direct the attention of consumers and businesses to water and persuade them to adopt conservation behaviors.

Water Management Programs

Generally, water supply systems, especially piped urban systems, are designed to deliver water "on demand" as the system operators have no direct control over the quantity of water taken from the system by the customers. Accordingly, water demands are taken as given quantities that have to be matched with supplies. The droughts of the mid-1970s in the United States and Great Britain demonstrated that water demands are not "given" but can be increased or decreased through water management interventions. Water providers were able to restrain water demands by persuading water users to temporarily reduce their water use while allowing distribution systems to remain fully pressurized. The cooperation of the majority of water users allowed water suppliers to avoid the usual method of using system shutdowns in order to reduce water use.

The management-based strategy includes a number of effective practices and programs that fall under the direct responsibility of water supply agencies. Both the public and private organizations that deliver water to cities, farmers, and industries usually can improve the efficiency of water use by following several practices of good water management. The most important of these is the appropriate monitoring and accounting for water flows. Since a significant percentage of water withdrawn from natural sources is lost before it reaches the point of use, investments in leak detection and repair can increase the available supplies at a reasonable cost without the administrative and legal burden of acquiring new supplies.

Metering of water deliveries to individual users is another important management practice. When water is metered, appropriate quantity charges can be levied on water users, thus providing an incentive to reduce or eliminate unnecessary or wasteful uses. Also, the amount of unaccounted-for water (a measure of both leakage and unmetered uses) in a water distribution system can be assessed. In the United States, the unaccounted-for water (UFW) is typically reported to range from about 15 to 25 percent, with losses in older systems reaching 40 or even 50 percent of water production. The American Water Works Association has established a guideline for UFW of a maximum of 10 percent, but few urban water providers manage to stay at or below this standard. With the new technologies for measuring flows and storing data, metering costs are declining and should soon be affordable to water supply agencies and water users in both developed and developing countries. Special measurements of the volumes of water applied toward specific end uses can serve as a basis for conducting assessments of the technical efficiency of water use. Finally, reliable measurements of the volumes of recycled and reused water and return flows are also important and have to be included in the assessments of water use and withdrawals. Some demand management measures such as pressure reduction, both within the distribution system and at individual user taps, lie within the responsibilities of water utilities and can be treated as part of their management activities.

Water agencies also have a role in areas where the demand for water is not met due to limited coverage of water supply and sanitation services. Plans for satisfying these "unserved" demands are an important component of demand management as are reductions in water use and losses in areas or sectors with "fully served" demands. For example, the Durban Metro Water Services agency in South Africa has developed and implemented two alternative water delivery systems (low pressure and semi-pressure systems) that provide safe drinking water supply to the urban poor who live in the squatter communities within the metropolitan area of Durban. In low pressure systems, up to 200 liters of water per day are delivered free of charge to ground tanks installed outside of individual houses. The semi-pressure system delivers water to roof tanks with the 6 m^3/month of free water and a rate of approximately R$2 (Rand) for each cubic meter above the minimum allowance. These innovative systems provide adequate water supply while avoiding the wastefulness of fully pressurized standpipes or leaking residential fixtures.

Governmental Reforms and Regulations

Governments play an important role in water demand management by creating a receptive regulatory environment and providing economic incentives for the adoption of conservation practices. However, few national policies exist at the present time. The primary focus of those that do exist is on the discharge of water after it is used. Both bottom-up (economic) and command-and-control (non-economic) policy options are available to governments. While privatization of the water sector through tradable permits and pricing strategies is slowly gaining political acceptability in many countries, government regulation and subsidies for research into conservation technologies are necessary to put these options into practice.

In some countries, there is a growing interest in activity relating to water conservation. These activities come in the form of legislative mandates and programs that are adopted by water management institutions. In the United States, the federal and state governments have accepted water conservation as a "good policy" for water resource management. As a result, water conservation mandates have become nearly ubiquitous and most federal water agencies have some water conservation responsibilities (Martin et al., 1994). The Federal Energy Policy Act of 1992 is an example of the national effort to mandate uniform water efficiency standards for plumbing products (Vickers, 1993). Legislatures in almost all of the states have also followed the federal statutes. They have passed or are developing statutes that are aimed at improving the efficiency of water use.

Government mandates are often seen as a critical factor in the adoption of water conservation. However, the effectiveness of government mandates is dependent on an understanding of the national water resources situation. National programs of collecting and publishing reliable data on water use are an important prerequisite for the development of policies and regulations aimed at water demand management. At present, the limited data on water use in many countries are of poor quality and are usually restricted to estimates of water withdrawals.

As with any regulations, national conservation laws and policies may have unintended consequences. Current regulatory environments in many countries negate water demand management objectives. For example, the recently privatized water utilities in England and Wales lack a direct economic incentive to reduce demands because financial outlays for water conservation measures are not allowed to be counted as a capital expenditure on which the utility is guaranteed a rate of return on investment (Howarth, 1999). The scientific community has an important role in conducting case studies to examine the response of the water sector to past policy reforms.

Economic Measures

Water Markets

Market forces, which treat water as a commodity, offer an effective way of reallocating limited water supplies among competing uses. Both the rights to the use of water and the actual volumes of water can be exchanged in market transactions within regions where water laws permit such transactions. Market transactions involving the voluntary transfers of water supplies are increasingly common within geographical areas where the existing supplies are fully appropriated and the cost of developing new supplies is high. When the available supplies are low, spot markets for water have also appeared, thus facilitating water transfers among individual water users.

For example, during the six-year drought in California, an emergency water bank was created where 850,000 acre feet (1.048 km^3) of water was sold by farmers to urban users and environmental resource agencies during the first year of the bank's operations (Dziegielewski et al., 1993b). The state government served as the water broker that paid \$125 per acre foot (\$0.10/m^3) and sold the water at \$175 per acre foot (\$0.14/m^3) with additional charges for some long-distance deliveries. These prices compare very favorably to the marginal cost of additional water supplies of some urban areas in the state at \$0.50/m^3. The California experience demonstrated that: (1) water markets will work even when severely controlled by the government and constrained by existing water law, (2) water has high value for many buyers, and there are sellers who are willing to sell significant amounts of water at the right price, and (3) third-party interests in market transactions can be protected.

Market forces are proving to be an effective mechanism for increasing the productivity of water and reallocating the water saved. While voluntary water transfers may not obviate the need for additional water development, market negotiations create an incentive for stakeholders to consider the opportunities for regional cooperation and implementation of integrated water resources management plans. Voluntary water transfers will likely play an important role in managing future water demand, including the growing demand for water in recreational and environmental uses.

The economic framework, in which water is treated as an economic good or commodity is not free from criticism. Critics of the economic approach to water management usually argue that the value of water in environmental uses, which support ecological functions, are often unduly discounted in economic decisions because it is difficult to assess the economic value of ecological services (Gleick, 1998). Others also argue that water is not simply a commodity but also a natural resource that is perceived by many as a human entitlement (UNESCO, 1998). Thus, in addition to its economic value in competing uses, water as a resource may also hold some intrinsic values, including important cultural and religious values. The biggest challenge for water professionals will be to devise the institutional arrangements for water markets with appropriate arrangements for the protection of third party interests and for minimization of adverse environmental effects of water transfers.

Water Pricing

Pricing is an effective strategy for demand management as long as the water-rate structures contain strong incentives to conserve water. The development and implementation of pricing strategies aimed at achieving economic efficiency and demand management could become the most important option for balancing water supply and demand in the future. Water providers can encourage consumers to conserve water by reforming water rates or introducing surcharges to deter high usage of water, or by establishing fines as a deterrent to wasteful water use practices. Economic theory suggests that consumers respond to economic incentives by assuming behaviors that maximize their

Table 2. Price Elasticities of Water Demand

Demand Category	No. of Studies	No. of Estimates	Range ofElasticities*	Most LikelyValue**
Combined urban demand	25	93	-0.11 to -0.50	-0.40
Residential demand	58	256	-0.18 to -0.50	-0.33
Single-family only	24	94	-0.22 to -0.48	-0.31
Nonresidential demand	15	160	-0.27 to -0.87	-0.54
Commercial	6	53	-0.24 to -0.92	-0.34
Industrial	19	101	-0.33 to -0.88	-0.58
Institutional	3	54	-0.24 to -0.94	-0.47
Agricultural irrigation	10	34	-0.24 to -0.97	-0.46

Source: Author's construct based on a review of 120 published studies of price elasticity of water demand in the United States.
* The range shows the 25th and 75th percentile in the distribution of reported estimates.
** The median value is shown as the most likely value.

economic self-interest. In one of the earliest studies of urban water demand, Metcalf (1926) documented the relationship between water use and price, which implied that price elasticities of demand was in the range of -0.40 to -0.65. A substantial body of literature has been published since to confirm that consumers respond to changes in the price of water (Boland et al., 1984). Estimates of the price response relationship range between -0.2 and -0.9 with higher (absolute) values in industrial and agricultural uses. These values of price elasticity indicate that a 1.0 percent increase in price would result in a 0.2 to 0.9 percent decrease in water use. Table 2 shows the range and most likely values of price elasticities of water demand for several types of water users.

While these elasticity coefficients indicate that demand is relatively inelastic with respect to price, significant increases in price would lead to major reductions in demand. During water shortages, rationing through pricing has proven to be a very effective strategy for achieving significant reductions in demand. For example, during the 1988 water shortages in Santa Barbara, California, the price was raised 27 times above the normal level (from US\$0.39/m^3 to \$10.40/m^3) to deter all but the most essential uses of water in the city (Ferguson and Whitney, 1996). These pricing relationships are consistent with the reports from developing countries where people who have to purchase small quantities of water from private vendors are willing to pay as much as 50 times more per unit volume of water as residents who purchase large quantities through piped connections to the city system (Lovei and Whittington, 1993; Whittington, et al, 1998).

Water tariffs and charging mechanisms are usually designed to simultaneously meet many objectives such as revenue sufficiency and stability; stability of rates over time; equity and fairness; administrative efficiency; or political acceptability (Boland and Whittington, 1997). Objectives such as economic efficiency and demand reduction rarely receive sufficient attention in the rate-making process. For example, fixed charges for water service and "lifeline" water rates that are often used to address the issues of fairness or revenue stability may inadvertently eliminate an important incentive to conserve water.

Research on the acceptability and effectiveness of conservation-oriented water tariffs is necessary in order to encourage the water industry to adopt rate designs that maximize the economic incentives for water conservation and also achieve balance among other salient policy goals (Beecher and Shanaghan, 1999). Current approaches to pricing focus more on meeting revenue requirements and allocating the historical costs of water supply to users rather than on providing appropriate price signals to water users. In absence of appropriate accounting for water scarcity values and including these values in marginal quantity charges, water users often fail to conserve water as actively as they might.

Leveraged Approaches

The four different demand management strategies can be used either separately or in combination. Experience suggests that a simultaneous reliance on two or more strategies may have some synergistic effects. For example, water savings from a combination of a conservation-oriented water tariff and a city-wide plumbing fixture retrofit campaign are greater than the sum of savings from either water rates or retrofit when implemented alone. Public education campaigns are often undertaken to reinforce the effectiveness of water tariff reforms or hardware distribution programs. Considering these synergistic effects, the greatest effectiveness of water demand management can be achieved when all four strategies are pursued simultaneously.

Future Directions

The role of water demand management in averting potential water shortages will become increasingly important. However, to take advantage of its full potential, water demand management has to be fully incorporated into water management practice. The following general recommendations are offered with the aim of identifying and supporting the most promising areas of research and policy development.

1. While further development of water-efficient technologies is possible and will likely continue, the potential for technical improvements and entrepreneurial innovation is hampered by the low potential returns on investments. The low cost of water supply to households, industries, and farmers does not provide much of an economic incentive for innovation. An important role of national governments is to provide funds for research and technology development.

2. National programs of collecting and publishing reliable data on water use are an important prerequisite to the development of policies and regulations aimed at water demand management. At present, the limited data on water use are of poor quality and are usually limited to estimates of water withdrawals. Reliable measurements of the volumes of water deliveries as well as recycled and reused water and return flows and spatially referenced GIS data are important and have to be included in the assessments of water use and water withdrawals.

3. Scientific research and data collection efforts continue to fall short of the critical needs to support the professional practice and implementation of water demand management alternatives. Only a few scientific studies of the impacts on water use of large scale conservation programs have been conducted. More research in program evaluation will be needed to support the development of analytical tools that would enhance the ability of water planners and managers to design and implement programs and policies that would produce significant gains in the current levels of productivity of water.

In summary, further improvements in the efficiency of water use hold great potential for helping to solve the current and future problems of water scarcity in various regions of the world. An appropriately guided water demand management program within the integrated water resources planning framework can achieve such improvements. Water demand management may be the new frontier on the way to achieving a long-term balance between the available freshwater supply and its use for human development. However, there is much to be learned about the social, economic, legal, institutional, and political ramifications of water demand management. Geographic research in water resources has an important role in advancing this understanding and guiding the development and implementation of sound solutions in the next century.

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