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DEMAND MANAGEMENT

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A Strategy for the Implementation of the Mar del Plata Action Plan for the 1990s

LEGISLATIVE AND ECONOMIC APPROACHES TO WATER DEMAND MANAGEMENT

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FOREWORD

In 1977, the United Nations Water Conference was held in Mar del Plata, Argentina, in response to the growing awareness of the need to harness water resources for economic benefit and social needs. A comprehensive series of recommendations, known as the Mar del Plata Action Plan, was drawn up and widely disseminated to developing countries for implementation. During the 1980s, reports were submitted to the Committee on Natural Resources on progress in the implementation of the Mar del Plata Action Plan.

It was clear, even in the early 1980s, that the economic circumstances of the decade were going to have a profound impact on water resources development, particularly in Africa south of the Sahara where countries were hard hit by severe drought and where the debt crisis was most debilitating. Subsequent reports to the Committee on Natural Resources and to the General Assembly confirmed the trend and, despite some recovery from 1987 onwards, the 1980s were dubbed "the lost decade of development" and many countries in fact slipped behind in their ability to manage their water resources for social and economic progress.

In 1987, the Administrative Committee on Coordination Intersecretariat Group for Water Resources (ACC/ISGW), which is the interagency coordinating body for the United Nations, was requested by the Committee on Natural Resources to develop a comprehensive strategy for action at the national, regional and global levels to bring about a renewed commitment to the objectives of the Mar del Plata Action Plan. Due cognizance would be given to lessons learned during the 1980s and the strategy would focus on issues, priorities and the integration of water resources development within the national development planning framework for each country.

In order to formulate proposals for this strategy, a series of in-depth regional assessments together with some sectoral studies were undertaken as part of a UNDP-financed project, executed by UN/DTCD on behalf of UN/DIESA and the members of the ACC/ISGW. Companion reports have been prepared. The reports have been compiled by groups of agencies working in several cross-sectoral areas (in this context, the water resources sector is considered to be made up of major use sub-sectors: agriculture, water supply and sanitation, industrial water use, energy and navigation; and a number of cross-sectoral activities: resources assessment, water quality, planning and management and capacity building, which are common to the main use sub-sectors).

The field entrusted to UN/DTCD was that of overall water resources management. In this context, three reports are presented which highlight particular areas of concern for the water resources sector. The first report deals with "Water management since the adoption of the Mar del Plata Action Plan" and has been prepared by Mr. Terence Lee of the United Nations Economic Commission for Latin America and the Caribbean as a synthesis of the regional assessment reports prepared in conjunction with the Regional Commissions. The second report, by Professor Alvin Goodman of the Polytechnic University in New York, deals with a new approach to "Integrated Water Resources Planning" which will be a dominant theme in the strategy for the 1990s. The third report is by Professor John Boland of Johns Hopkins University, Baltimore, and concerns the important field of "Legislative and economic approaches to water demand management". In its present form, the draft report of the third topic does not yet contain the legislative aspects.

These reports are presented for information as a background to document E/C.7/1991/8 concerning Strategies and Measures for the Implementation of the Mar del Plata Action Plan in the 1990s.

Water Resources Branch
Natural Resources and Energy Division
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I. THE NATURE AND PURPOSE OF WATER DEMAND MANAGEMENT

Water is an indispensable factor in the well-being of peoples, regardless of culture or nation. In all the various kinds of human settlements, few activities are as universal as the striving for adequate supplies of safe water. In the words of a recent UN report:

> Abundance or scarcity of water can mean prosperity or poverty, life or death. It can even be a cause of war. Most countries have deeply worrisome problems concerning the quantity and quality of their fresh water resources, and many countries are suffering from the effects of pollution of their coastal waters. Constraints on the supply of fresh water are increasing, aggravated by droughts, depletion of aquifers, and deforestation, while demand for water is rising rapidly for irrigation, energy generation, industrial production, and urban consumption. (UN, 1990, pp. 88-89)

These issues and conflicts do not depend on any particular history, tradition, or ideology. They affect industrial and non-industrial countries, market and centrally-planned economies, arid and humid climates. The specifics of each problem may change, but the prominence of water-related issues is a constant.

Although water exists everywhere on earth, it is not always found in the quantity and quality, and at the place and time, where needed. As human activity concentrates in urban agglomerations, these problems become more acute. As a result, man has been engaged in collecting, storing, transporting, treating, distributing, and otherwise managing water for thousands of years. While some areas, especially in developed countries, enjoy the fruits of these efforts in the form of easy access to high-quality water, most of the world's population remains unserved, or under-served.

A. Demand management

Through most of human history, managing water has meant managing water supply. Water "needs", once determined, are regarded as immutable: all management efforts are devoted to locating and developing new sources, and to transporting and treating the resulting supplies. Supply expansion is typically pursued until the "need" is satisfied, or to the limits of financial affordability and/or engineering feasibility. Water management, within this limited definition, is largely a matter of financing and construction.

This report promotes a broader view. Rather than seeking a supply adequate for some set of water "needs", water management is concerned with finding an appropriate balance between the benefits of water use and the costs of water supply. "Needs" are no longer measured in cubic meters per day, but in terms of the health and welfare of human populations. Costs are not limited to cash outlays for engineering and construction, but include all adverse effects on the economy, on activities which compete for the basic resources, and on the environment.

Because of the considerable scope of water management, it is helpful to divide the subject into two categories: <u>supply management</u> includes the traditional activities required to locate, develop, and exploit new sources of water in a cost-effective way, while demand management addresses the ways in which water is used and the various tools available to promote more desirable levels and patterns of use.

Distinctions between supply and demand are not always consistent throughout the literature. The precise meaning of these terms depends on the point in the water delivery system where "supply" is defined. For purposes of this report, supply will be defined 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. Actions which affect the quantity or quality of water which arrives at the distribution system entry point are part of supply management; anything which influences the use or wastage of water thereafter is demand management.

This distinction is not universal. For example, one author may describe steps taken to improve reservoir yield as water conservation which is, in turn, generally included within the rubric of demand management. Another writer may consider distribution system leakage reduction as a supply augmentation measure. Both topics are potentially valuable water management actions; the label used to describe them is less important. However, the definition implied above does roughly separate management actions into those which are oriented toward construction, engineering, and operations (supply management) and those which tend to draw on social and behavioral sciences (demand management). There are exceptions in each case, of course.

This report discusses the objectives, techniques, and results of demand management. Supply management issues--no less important to the overall development of water resources--are omitted, with a few exceptions. Since demand management may change the quantity of water which must be supplied, it is occasionally necessary to discuss the impact (on the environment, the economy, etc.) of altered supply requirements.

Demand management is described here as consisting of actions which promote more desirable levels and patterns of water use. It should be noted that most literature on the subject assumes that "more desirable levels" are synonymous with lower levels (see, for example, Rubinstein and Ortolano, 1984). While this is true in many situations, and numerous demand management measures are specifically intended to reduce water use, it need not always be true. There are situations, especially in developing countries, where the public interest may be served by increasing, rather than decreasing, water use. This is almost certainly true where price or other factors cause urban dwellers to purchase water from vendors rather than using a public system. On the other hand, the same water systems may present examples of unnecessary water waste, or of inappropriately high levels of use. Throughout this report, "more desirable levels" should be understand to permit either decreases or increases in water use, as needed.

B. Necessity for demand management

To the extent that demand management actions improve the overall management of water resources, they increase the benefit received from a given use of resources, or they reduce the resources required to achieve a certain benefit, or both. This result, alone, may seem sufficient to argue for demand management. However, there are usually specific, and often more compelling reasons to pursue this strategy. Some common motivations for demand management are listed below.

1. Increases in water use

(a) Urban population growth

Many urban centers have experienced, and continue to experience, very high rates of population growth. This alone is capable of taxing the capacity of existing supply systems, resulting in deterioration of the quality of service and increasing the risk of supply interruption. An equally serious problem, however, is the potential that urban migration creates for high levels of future water use. Where the new migrants arrive in lower economic strata, they may be responsible for relatively little immediate increase in overall water use. As various social and economic problems are addressed, and the migrants and their families become more settled, more often provided with public services, and more prosperous, their average levels of water use can increase many-fold. This can cause a dramatic and often unanticipated increase in water demand in the future, even after high rates of immigration have ended. In all of these cases, demand management may be the best way to address the problem: in some cases it may be the only way.

(b) Industry and agriculture

Some nonresidential uses of water present issues that argue for demand management measures. This can occur in the case of industrial expansion or restructuring, where individual and sometimes unanticipated decisions by firms or government can result in abrupt increases in water use. Since significant supply augmentation often requires some years to accomplish, demand management may be the only means of coping with such changes.

Agriculture presents a different type of problem. Average levels of water use may not be capable of rapid increase, but weather-induced fluctuations from year to year can be very large. Also, because of the practical and political difficulties which usually characterize attempts to set effective prices for agricultural water, use levels and patterns may be very inefficient and ineffective. Demand management measures can be employed to improve this situation.

2. Deterioration in available supplies

(a) Discharged wastes from urban concentrations

Urban activities generate large volumes of liquid and solid wastes, which must be disposed of, either by discharge to surface water or on land. If these wastes are untreated, or inadequately treated, prior to discharge, it is likely that the quality of both surface water and ground water (due to land disposal) will become seriously degraded. At best, water supply systems which depend on these resources must increase levels of treatment and monitoring. At worst, some sources may become unusable for public supply.

Conflicts between supply contamination and water supply quality problems are not limited to developing countries. Numerous supply systems in Europe now face this problem, exacerbated by rising expectations regarding drinking water quality (Gundermann, 1988). Serious impacts can be postponed or, in some special cases, avoided by water use reductions accomplished through demand management. The alternatives include significantly higher costs, water shortages, and/or public health concerns.

(b) Poor consumption practices

The ability of supply systems to meet the water needs of a community is diminished when water is needlessly discharged to waste, or permitted to leak from poorly maintained pipes and fittings. Also, poor usage practices may lead to contamination of the distribution system through back-siphonage. In developing countries, these problems usually arise from misuse of public standpipes. Taps may be left running when not in use, or hoses may be placed in reservoirs or ponds containing non-potable water (see, for example, Kramer, et al., 1987). In developed countries, fire hydrants may be tapped without authorization, with similar results. In all countries, poor construction practices and poor distribution system maintenance result in numerous underground leaks, which may go unrepaired for months or years.

3. Increasing costs of developing new sources

It is generally assumed that new sources of water will become progressively more costly in real (inflation-free) terms, regardless of location or country. This expectation is reasonable in nearly every case because:

(i) The least expensive sources have already been developed;

(ii) New surface water sources are more distant than existing sources, requiring additional expenditures for pumping and transmission;

(iii) Additional ground water sources will usually be at greater depth, requiring more expensive boreholes and higher pumping costs;

(iv) Population and economic expansion normally causes increased pressure on all resources, leading to higher interest rates for capital and higher opportunity costs for other inputs, including land.

4. Critical water shortages

Either the occurrence or the possibility of significant water shortage imposes costs on a community which can easily exceed the value of the water uses at risk. When people and organizations are accustomed to receiving water from a public system, the failure of that system to produce water results in inconvenience, disrupted economic activities, expenditures of labor for water-gathering, and potential sanitation problems. When shortages are expected, people are motivated to avoid activities and lifestyles which depend on constant availability of water. In either case, a substantial fraction of the benefits expected from a public water supply system can be negated by chronic unreliability, even when the actual shortfall is small. Demand management can restore reliability by reducing demand, and can minimize the costs associated with real of anticipated shortages through appropriate drought management policies.

5. Need for cost reduction in the water sector

Government budgetary crises, sometimes coupled with urgent needs in other sectors, may require a reduction in the funds allocated to water supply. Such a reduction may result from an explicit decision to reallocate funds, but it is more likely to occur slowly over time, as water supply budgets are not permitted to increase at the rate of price inflation. One consequence of fiscal reductions is a slow deterioration of service, with reduced maintenance and increased probability of system contamination or water shortage. The application of demand management can postpone or avoid these conditions, by reducing water use in a controlled, orderly way.

6. Reduced carrying capacity in water based environments

The diversion of large amounts of surface water from a lake or stream can lower water level or water flow. When water levels are lowered in any fresh water resource, associated wetlands may be severely affected, even eradicated in some cases. This effect reduces the productivity of water-related ecosystems, and diminishes the ability of these systems to assimilate wastes. To the extent that demand management reduces the need for (1) development of new sources or (2) increased withdrawals from existing sources, it can reduce, postpone, or avoid negative environmental impacts associated with water withdrawal.

7. Cumulative damage to water-based habitats

In addition to the primary impacts of withdrawal from surface water sources (drying of wetlands, etc.), continued withdrawals over long periods may promote cumulative changes in water-based habitats. These generally result from altered flow regimes, including artificially low flows during dry periods. The eventual effect is to deny suitable habitat to some indigenous species. while encouraging development of exotic or less-desirable species which may be better adapted to the changed conditions. To the extent that demand management can reduce withdrawals, such impacts can be similarly reduced, postponed, or avoided.

8. Over-exploitation of natural water supplies

In the case of large ground water aquifers with limited recharge, it is possible to sustain withdrawals much in excess of the recharge rate for long periods of time. Water levels fall, and pumping costs rise, but such a strategy often appears feasible in the absence of low-cost alternatives. The effect of such a policy, however, is to transfer water supply costs to future generations (who must solve the water supply problem after the aquifer is depleted). Proper consideration of future costs may indicate that over-exploitation of the ground water is a very poor option. Demand management can reduce the need for such withdrawals, thus reducing, postponing, or avoiding the negative consequences.

C. Objectives of demand management

Demand management is not a single tool or method, but a collection of techniques, each devised to deal with a particular aspect of water management

The following chapters outline some of the more common purposes of demand management techniques.

1. Improved allocation of water among competing users

The way in which water is allocated among competing users, or classes of users, is of interest for several reasons. The most widely applicable of these is economic efficiency. If water is allocated to low value uses (such as irrigating low value or surplus crops) while higher value uses (new industrial activities, for example) are foregone, the total benefits obtained from a limited supply of water may fall far short of optimum. In other cases, government policy or social objectives may argue for some minimum allocation of water to certain activities, regardless of the value added by water use. Demand management, utilizing pricing and various water conservation or restriction measures, can influence the allocation of water, promoting use in sectors where increased allocation is desired, while discouraging use elsewhere.

2. Expansion of use into growth-promotion areas

In an effort to direct jobs and income to regions with the greatest needs or opportunities, governments often designate specific areas as economic growth areas. Inducing new activities to locate in these areas, however, involves a number of actions by government, including the provision of positive economic incentives. Water demand management can play a direct role in such efforts through pricing policies with make water available at reasonable cost. Demand management has an indirect role, as well, through practices which improve the reliability and control the overall cost of water supply.

3. Increase in water sector revenues

Through careful analysis of water use, adoption of appropriate tariff structures, and control of costs, demand management increases the net revenue (or decreases the net loss) derived from the water supply sector. This result is especially beneficial in countries where the water sector is constrained by lack of funds, or where surpluses from water supply can be put to good use in other public programs.

4. Postponement of new construction

To the extent that demand management results in lower current or projected water use, construction of new supply facilities can be postponed. This reduces the cost of supply, but it can have other important effects. In non-industrial countries with unfavorable balances of trade, construction delays also conserve scarce foreign exchange otherwise needed for imported equipment. Adverse environmental consequences of certain water supply projects (principally impoundments and diversions of surface water, as well as exploitation of shallow ground water) are also postponed.

5. Drought management

In even the most carefully planned and constructed water supply systems. water shortages are still possible. Temporary reductions in water supply may be due to meteorological drought, source contamination, or facility failures of various kinds. These events, including drought, occur everywhere, in developed and developing countries, in high rainfall and low rainfall climates. It has been said that drought affects more people than any other natural hazard (Wilhite, 1990).

Because demand management can be used to produce lower water use levels, it can reduce the vulnerability of a water supply system to meteorological drought. Another aspect of demand management--drought management planning--can minimize the disruption and cost associated with water shortage. An orderly program of voluntary and mandatory reductions in water use can allocate progressively more water to most important uses, while maintaining the integrity of the distribution system (protecting it from de-pressurization and resultant contamination).

6. Reduction in unnecessary use and wastage

Some demand management measures--including metering, pricing, leak detection, hydrant and standpipe monitoring, distribution system maintenance--are undertaken with the sole purpose of minimizing the wastage or unnecessary use of water. Allowing leaks to persist, or allowing taps to run to waste, increases supply cost for all customers with little or no offsetting benefit. For many customers with building connections, the mere presence of a meter and a metered use-based tariff causes water use to decline significantly, as unnecessary or wasteful uses are eliminated.

7. Conservation of the resource

Conservation can be defined in at least two ways. If the only concern is for the water resource, conservation requires reductions in water use and water losses. These reductions can be accomplished through demand management. A more broadly applicable definition, however, considers conservation of all scarce resources, including water (Baumann, *et al.*, 1984). In this case, water use reductions must be beneficial: they should not conserve water at the expense of other resources. The primary tool for carrying out such a policy is, as before, demand analysis.

8. Water quality control

Water use has implications for water quality in at least three ways.

(i) Withdrawal of quantities of water from natural systems may affect the quality of the remaining water (as well as that withdrawn). Changes in levels and flow regimes of surface water alter habitats and induce changes in biological communities. Withdrawal of groundwater in the vicinity of brackish or contaminated aquifers may cause mixing and subsequent contamination of the water supply aquifer.

(ii) Increasing use of water requires exploitation of additional sources. Where the availability of safe sources is limited, additional supply may include waters of poor quality and doubtful safety.

(iii) As more households, firms, farms, and other activities use more water, more wastewater is produced. The wastewater must be discharged to surface water bodies, sometimes with inadequate treatment or no treatment at all, promoting the deterioration of these resources.

Since all three types of water quality deterioration become worse with increasing water use, they can all be improved by using demand management to reduce water use.

9. Sustainable development

For existing or planned economic development to be viable, it must be in proper balance with the resources on which it depends. This is particularly evident in the case of the water resource. Water supply systems must:

(i) Protect and enhance water related environmental amenities;

(ii) Ensure due consideration for and protection of existing water-based economies (fishing, recreational activities, etc.);

(iii) Be developed so as to maintain safe thresholds of economic viability

Full attention to these criteria requires comprehensive water management, including both supply and demand elements. Supply measures should respect the characteristics and alternative uses of sources, while demand measures insure that only the necessary amounts of water are used.

D. Criteria for ranking priorities

As demonstrated above, there is no single objective for demand management. Instead, there are a number of different and potentially conflicting purposes, each of which has a claim for the attention of the water manager. In practice, therefore, there must be some ranking of issues and of alternative solutions, so that decisions reflect the best compromises and highest priorities.

1. Objective criteria

Of the various possible evaluation criteria, there are some which utilize observable data, so that objective rankings can be obtained. Selected examples of objective criteria follow.

(a) National economic situation: regional and sectoral growth rates

Where water management is expected to impact the growth of the regional economy, or to affect sector development, policies can be evaluated on the basis of projections of key indicators, such as gross domestic output, employment growth, personal income, etc. Demand management proposals can be compared on the basis of their effect on these indicators.

(b) Population growth rates

Population growth rate, often viewed by water planners as a given, can also be seen as an indicator of performance. Where population growth is constrained, directly or indirectly, by water management policies (because of water-related living conditions or limited employment opportunities due to lack of water for industrial expansion) and where increased population growth is desired as a matter of public policy, demand management programs can be evaluated on the basis of their ability to increase population. In other situations, increased urban population may be undesirable, since it decreases agricultural output and creates many social and economic problems in cities. Here demand management may be designed to discourage further growth, and can be evaluated accordingly.

(c) Areas served/unserved with water supply

In many cities in developing countries, large urban populations are unserved or inadequately served by public water supplies, with resulting social, economic, and public health problems. Demand management policies can be evaluated in terms of their ability to expand coverage, whether measured as population served, households served, or area served. It may also be necessary to distinguish between users served by building connections and those served by public standpipes. There may be alternative levels of standpipe service, depending on average spacing, or maximum distance to dwelling units.

(d) Costs of developing new supplies

An important motivation for demand management in many situations in the need to reduce the cost of planned new supplies. This is accomplished by reducing demand so that needed facilities can be deferred and/or reduced in size. The degree of cost reduction, net of the cost of implementing the demand management program, provides a useful criterion for measuring the effectiveness of any proposed demand management program.

(e) Worsening or newly recognized water quality problems

As noted above, water supply systems can be associated with adverse impacts on source water quality or on the quality of water bodies receiving return flows. Various objective measures of water quality may be used to describe these effects, including dissolved oxygen, biochemical oxygen demand, temperature, total dissolved solids, and pathogen indicators. When demand management practices are undertaken for the purpose of reducing these impacts, the water quality measures are used as evaluation criteria.

2. Public policy/political will

To be successful, demand management programs should be consistent with public policy and politically feasible. Since many demand management measures reallocate water and cost responsibility (as compared to the prior situation), their will be those who gain from the program and those who lose. Political decision-makers must be sure that the benefits enjoyed by many are perceived to be large enough to justify the adverse effects on the few. Programs which satisfy these criteria are much more likely to be implemented.

3. Social pressures/user demand

Some demand management programs are devised in response to public pressure for changes in water management practices. This may reflect discontent over proposed supply expansion projects, reaction to rising water costs, or dissatisfaction regarding existing allocation of water. The degree to which a demand management plan addresses and satisfies the concerns of the public and of water users is an indication of its likely success.

4. Environmental and sustainability requirements

Water demand management programs may also be judged on the degree to which they meet environmental objectives, or satisfy sustainability requirements Numerous individual criteria can be defined within these subject areas, including some which may be represented by objective indicators. The most desirable programs, however, are those which consider environmental and sustainability issues in a comprehensive way, producing improvements over a range of indicators, rather than focusing on a few narrow issues.

E. Sustainable sector development and resource conservation

Further issues arise where water sector plans must be developed against a background of national economic and social goals, combined with a need for sustainable development incorporating full consideration of resource conservation. These considerations arise most strongly in demand management, due to impacts on expectations of and controls over future water use.

1. Urban water use

Future water supply needs in urban areas are often regarded as fixed, and other public policies are adjusted accordingly. Where sustainable development or conservation issues dictate, future water use can be constrained, either in total or in terms of per capita use. Demand management measures are then adopted which insure that actual water use does not exceed the planned limit. Planned water sources, supply facilities, etc., can be sized accordingly, saving investment as well as resource use.

2. Agricultural water use

Supply constraints on agricultural water use need not lead to shortages and economic disruption. Demand management measures may include more efficient irrigation practices, altered cropping patterns, and alternative land uses, so that water use targets are met at minimum social cost. In this way, the resource can be conserved without excessive impacts on other scarce resources, and adverse environmental effects of return flows are reduced.

3. Industrial water use

Projections of future industrial water use should consider not only product type, production quantities, and employment, but may also reflect changes in water use practices. These include recycling, elimination of unnecessary water use, and more water-efficient processes. The result is conservation of the resource, and reduced hydraulic loading on industrial waste treatment facilities and on receiving waters.

4. *In situ* water uses

Sustainable development requires an appropriate balance among all surface water uses, including such *in situ* uses as maintenance of biological communities, flow regulation for downstream uses, and water quality maintenance. These uses compete with withdrawal uses for the available water in the stream. When urban, industrial, and agricultural uses are excessive, in-stream uses suffer. Conversely, when demand management is used to insure that withdrawal uses are no larger than necessary, more water is available for in-stream uses.

5. Return flow impacts

Nearly all water uses are associated with return flows. These range from the wastewater collecting in an urban sewer system to the irrigation return flow percolating into ground water tables, then discharging in a nearby stream channel. Where demand management is used to constrain future levels of water use, and to influence the allocation of water among uses, returns are similarly reduced and/or reallocated. In some cases (urban wastewater), the quantity of pollutants delivered is not changed to any significant degree, although in other cases (crop irrigation), leached minerals may be reduced by lower flows. Since the rate of return flow is a function of water use, demand management strategies intended to modify water use also modify return flows.

II. TECHNICAL TOOLS FOR DEMAND MANAGEMENT

Demand management takes many forms, ranging from water allocation by legislative action to appeals for voluntary conservation. Later chapters discuss demand management measures which create incentives for voluntary changes in the level or pattern of water use. This chapter discusses various means for directly affecting the way in which water is used, through direct regulation or through changes in technology, operation, or voluntary behavior. These measures are generally intended for situations where the purpose is to reduce water use. The only exception is the group of behavioral measures, which can be employed to increase or decrease water use, as needed.

Most tools discussed here are utilized as a part of a long-term demand management strategy. However, some measures, especially those involving voluntary change in behavior or mandatory restrictions on water use, may be invoked on a contingent, or temporary basis as part of a drought management plan. Effectiveness, as well as public acceptance, of certain tools may be considerably greater under crisis conditions than would be the case for long-term implementation.

A. Reductions in water losses

Once water enters the distribution system, reductions in losses have exactly the same impact on system performance as reductions in water use. They differ from water use reductions in one respect, however: there is usually no involvement with or effect on water users. Leakage is, by definition, wastage. Since no beneficial use is lost, the only consideration is the relationship between the cost of repair and the value of the water saved.

Experience shows that many, if not most, water distribution systems contain numerous opportunities for cost-effective water loss reduction. Still, aggressive loss reduction programs are the exception, not the rule. It is assumed that inconvenience and cost make such programs as leak detection and repair unpopular, despite the possibility of later savings (Berk, *et al.*, 1981). Lack of familiarity with methods and equipment may also be a factor.

1. Leak detection and repair

Every water system experiences occasional large leaks, usually the result of breakage or other major failure of a water main. Such leaks usually announce themselves by loss of system pressure and water discharge from the ground, sometimes accompanied by soil erosion and subsidence. Leaks of this kind are repaired promptly because they must be, if service is to continue. Unless the number of such events is excessive, the amount of water lost in this way is relatively small.

Of much greater importance are the many small leaks which go undetected for years or indefinitely, and which can result in large cumulative water losses. Small leaks may be caused by pipes perforated by corrosion, faulty joints between pipe lengths (due to poor materials, poor construction practices, and improper bedding), improperly installed taps, deteriorated service connections, or faulty hydrant valves. A frequent cause of leaks of all sizes is accidental damage inflicted during construction of buildings and roads (Ayoade, 1987). Visual evidence of such leaks is rare; the water may percolate into the soil, or be carried away in streams and storm drains.

Detecting small leaks requires a systematic, long-term program, using portable flow measuring instruments (such as pitometer tubes), listening devices, and other techniques. The entire distribution system should be covered at least once. Thereafter, the frequency of monitoring can be adjusted to reflect the probability of locating significant numbers of leaks. If some portions of the distribution system show high rates of leakage, they can be monitored more frequently; other areas may be surveyed less often.

Once leaks are detected, repairs should be made where feasible. If the detection equipment can also estimate the approximate volume of leakage, it may be possible to balance repair costs against expected savings. Other criteria are also used. One U.S. study suggests that repairs are justified when:

(a) A leak is found with flow in excess of 250 gallons per day per inch diameter per mile of pipe (0.23 cubic meters per centimeter diameter per kilometer length); or

(b) Night flow in a particular pipe is in excess of 50 percent of average daily flow (New England River Basins Commission, 1980).

In the absence of flow data for leaks, repair priorities must be based on other factors, such as repair cost, traffic disruption, etc.

Postel reports results of leak detection and repair programs in various countries (Postel, 1985). In Vienna, a leak detection and repair program reduced water use by 64,000 cubic meters per day. A 1983 pilot program in Manila reduced water losses in one district from 50 percent to 40 percent of total production. Based on this experience, the city planned a full scale program which was expected to reduced overall water losses to 30 percent, freeing enough water to serve an additional 1 million people.

2. Identification of illegal connections

Unauthorized use of water can occur in many ways. The most overt method is to install an illegal connection to the distribution system. The illegal connection may be a branch from an existing, legal customer connection, it may involve connection to an underground main, or it may involve a pipe or hose connection to a public standpipe. In all cases, water is supplied to users who pay no charges and have no reason to use water wisely or to avoid wastage.

Illegal connections can be discovered in several ways. A systematic inspection of the distribution system, such as that implied by a leak detection program, may reveal many illegal connections. In metered systems, other such connections can be discovered by careful analysis of data from customer and distribution system meters. Tampering with public standpipes is usually relatively easy to detect. Some systems report significant reductions in lost water by simple removing illegal hose connections from standpipes (Kramer, et al., 1987).

B. Improved operation and maintenance

The way in which a water distribution system is operated and maintained has important implications for demand management programs. For water conservation measures (including technical measures and economic incentives) to be fully effective, the water system must be perceived as reliable. Where operational deficiencies or other non-water related events (electricity failures, for example) result in intermittent loss of water pressure, users are motivated to store rather than conserve water, and appeals for conservation may fall on deaf ears. The tendency is to use water liberally when water is available. Industrial and large commercial users may develop their own supplies (Ayoade, 1987).

On the other hand, investment in water using appliances is discouraged by unreliable supply, resulting in some compensating reduction in water use. Also, water cannot be used at times when water is not available. Still, unreliable supply is costly to the community and likely to frustrate most attempts to properly manage the demand for water.

Water supply systems represent very large capital investments which should be protected by adequate and effective maintenance procedures. Inadequate maintenance leads to slow deterioration of the facilities, giving way eventually to unreliability, failure, and/or the need to replacement large parts of the original investment. In some cases, deteriorating pipes may cause health concerns (Ellingsen, et al., 1987). One of the consequences of poor maintenance practices is a high incidence of leakage throughout the distribution system. Although many leaks can be repaired in a cost-effective way, prevention is much preferable to any cure.

Some writers have pointed to excessively high supply pressure as a factor in water losses and unnecessarily high water use (Flack, et al., 1977; New England River Basins Commission, 1980). Distribution system pressure is partly a function of topography and design, and partly related to the way in which the system is operated (definition of pressure districts, pumping protocols, etc.). Where system pressure cannot be reduced, it is possible to install pressure regulating valves on individual buildings. System pressure reductions are preferable, however, since losses from small leaks are also reduced.

C. Dual distribution systems

Where technical or economic factors constrain the supply of potable water, it is possible to restrict that supply to those uses which require high quality (human consumption, food preparation, some industrial processes, etc.). Other water uses can then be supplied, through a second and wholly separate distribution system, with lower quality, non-potable water. This second water supply may come from more contaminated sources, from brackish groundwater, or it may consist of treated wastewater.

In practice, dual distribution systems usually convey non-potable water to outdoor (irrigation) uses and selected industrial applications. Where the potable supply is sufficient, water supplied to buildings is usually entirely potable. This approach reduces the cost of the non-potable distribution system while minimizing the opportunities for connections to the wrong system or inadvertent cross-connections. Still, the use of a dual distribution system greatly increases the required capital investment. Operating costs may increase or decrease depending on the source and treatment cost differentials between the two supplies, and on the extent of the non-potable distribution system.

Dual distribution systems have been used in many places, especially by cities in arid environments with access to mineralized groundwater. In the U.S., dual distribution systems are used in Utah, Idaho, Washington, California, Montana, Wyoming, and Colorado (Leconte, et al., 1988).

D. Low water use technology

Most uses of water are accomplished with the aid of some type of device, such as a tap, shower spray head, or water closet. Depending on the design of the device, more or less water may be needed to perform the same function. One approach to water conservation is to require or promote the use of devices and appliances designed for low water use. In this way, less water will be required for the same purposes, with little or no inconvenience to the user.

Aerator/flow restrictors. These devices are placed on kitchen and bathroom taps to provide a controlled, but restricted flow. U.S. practice includes flows as low as 0.5 gallons per minute (1.9 liters per minute) for bathrooms to 4.0 gallons per minute (15 liters per minute) for kitchen or laundry taps. Water savings are associated with flow-oriented uses (washing hands, etc.) but not with volume-oriented use (filling containers).

Shower spray nozzles. Water used in showering can be reduced by devices which have two characteristics: (1) flow restriction and (2) high velocity, finely divided spray. Spray nozzles which include only the flow restriction, and which provide a low velocity spray, rinse poorly and do not give the same sensation as a conventional shower spray. The result is user dissatisfaction, longer showers, and (in some cases) removal of the device. High velocity devices apparently avoid these problems. Typical U.S. devices restrict flow to 3.0 gallons per minute (11 liters per minute). Reductions in water used for showering lead to savings in energy costs, since less water must be heated.

Water closets. Because of the relatively large amount of water used, most literature on water saving devices focuses on water closet design. The most common innovation is a redesign of the trap and bowl to permit flushing with a smaller volume of water. In the U.S., standard designs are now available which flush with 6 liters of water. Older water closets are easily retrofitted with a variety of displacement devices intended to reduce flush volume. These include solid objects, plastic containers weighted and filled with water, and plastic dams.

Another design is the dual flush fixture, where moving the handle in one direction provides a low-volume flush for liquid waste; the other direction produces a conventional flush. Dual flush toilets have been in use in Great Britain for many years (Bailey, et al., 1969). Typical flush volumes are 4/9.5 liters. Further possibilities include water closets that flush with the aid of a vacuum (usually combined with a vacuum collection system) or with compressed air. Most of these devices are capable of flushing with as little as 0 5 liters of water. Fixture cost and maintenance are expected to be higher than for more conventional units.

Thermal insulation. When hot water is drawn from a household tap, it may be necessary to run several liters to waste before the temperature rises to the desired level. Accordingly, many studies have found it beneficial to insulate hot water pipes between the heater and the furthest point of use. This practice is most beneficial in locations with cold winters, and where central hot water heating systems are common. Where applicable, the resulting water savings are accompanied by energy savings, since less water must be heated.

Pressure reduction. Where pressure regulating devices are installed at each building, pressure can be reduced to the practical minimum for the uses expected. This may result in some reduction in flow-oriented uses, but few published results support this. Leakage volumes are reduced significantly by lower pressure. Within a building, however, it is almost always preferable to locate and repair the leaks.

Water-using appliances. Clothes washers and automatic dishwashers, where installed, account for significant water use. Various makes and models of these appliance may require quite different volumes of water for the same task. One study of U.S. clothes washers reports water requirements ranging from 38 to 69 gallons (144 to 261 liters) per cycle for an 8 pound (3.6 kilogram) load (Postel, 1985).

Lawn and garden irrigation. Where landscaped areas are provided with permanent or semi-permanent irrigation systems, a number of devices are available to control water use. The simplest are timers used to turn irrigation systems on and off at predetermined times. More elaborate irrigation systems may use soil moisture sensors to determine the ending time. In some climates, water use can be reduced dramatically by drip irrigation systems, where the water is not sprayed into the air, but conveyed by pipe to the root zone of the plants.

Landscape design. The quantity of water required for lawn and garden irrigation depends upon the extent and type of shrubs and grasses, as well as climate and short-term weather conditions. Irrigation requirements can be reduced by restricting irrigable area, by restricting the amount of turf grass, and by incorporating more drought-resistant plants into the overall design. In arid and semi-arid climates, the use of native vegetation (as opposed to shrubs and grasses from more humid areas) may substantially reduce irrigation water use.

Recycle systems. Many proposals have been made for systems to recycle "gray" water (wastewater from sinks, baths, and showers) for flushing toilets or irrigating lawns and gardens. If implemented, this would result in a significant reduction in the net water use of the household. This strategy has never been widely adopted, probably due to capital costs and ongoing maintenance requirements.

Commercial and institutional applications. Most commercial and institutional water uses are similar to those which take place in private residences. Accordingly, similar water saving devices are employed. Some differences occur in food preparation: restaurants or institutional kitchens may require different techniques for saving water used to wash dishes, for example. Recycle systems are more likely to prove feasible in these applications.

Industrial applications. A wide variety of water saving devices can be considered for industrial applications. This includes all of the devices applicable to other sectors, since industrial water use includes use for sanitary purposes, washing, food preparation, etc. Where the public water supply is used as process water, additional approaches are possible. Changes in production technology may reduce water requirements, and provide higher recycle ratios. Where workers make use of taps or hoses, the use of flow restrictors or spring-loaded taps will provide savings. Opportunities for use of non-potable water for cooling or other purposes can also be exploited.

The U.S. literature contains many descriptions and evaluations of water saving devices and appliances. One early survey reviewed and compared evaluations of several dozen devices, concluding that published results were often inconsistent and occasionally implausible (Baumann, et al., 1979). Lists of available devices were included in several handbooks published in the late 1970s. One particularly comprehensive example included descriptions of virtually every water saving appliance and device available in the U.S. at that time, numbering in the hundreds (Nelson, 1977). The most thorough empirical study of the performance of water saving devices appeared in 1984 (Brown & Caldwell, 1984).

Similar analysis and surveys have been published in Australia (see, for example, Stallman, 1986). The devices differ from U.S. in some respects, due to differences in plumbing fixture standards. Claimed water savings also differ, reflecting fixture design and somewhat dissimilar patterns of water use.

Few generalizations can be made concerning water use reductions expected from water saving devices. The reduction is dependent on existing country standards for plumbing fixtures and on typical water use patterns. In the U.S., for example, water closets sold prior to 1980 typically required 20-30 liters per flush. Adoption of fixtures with 13 liter or, more recently, 6 liter flushes provides a dramatic reduction. This is further emphasized by noting that toilet flushing accounts for some 45 percent of household water use in the U.S. In a country where standard water closets require only 10 or 15 liters per flush, and where the number of daily flushes per person is smaller, the savings obtained from improved design are more modest.

Conversely, U.S. studies seldom claim that installation of aerator/flow restrictors on kitchen and bathroom taps can produce significant savings. This reflects near-universal prior use of fixtures with aerators and relatively well-controlled flows. In a country where typical household taps produce uncontrolled, non-aerated flows, this simple device could be quite effective.

E. Behavioral changes in water use

Water use behavior can differ markedly from one individual to another, even among those who have made the same structural choices. Differences are evident for every type of water use, ranging from sanitary use to outdoor irrigation. Routine, more than conscious decision making, controls much of this behavior. In the absence of external stimuli such as price increases or water shortages, there is little reason to analyze or change behavior.

Where demand management objectives dictate changes in individual water use behavior, several approaches can be taken. Legislative or other means can be used to _require_ changed behavior (restrictions, prohibitions). Economic incentives can be provided to _induce_ different behavior. Communication with water users may _persuade_ them to alter water use habits. The first two categories are discussed in later chapters; the third category is outlined here.

Attempts to influence water use behavior through direct communication are usually associated with water conservation programs. Water use can be reduced in this way, but the same methods can be applied with equal effect to efforts to increase water use, should such an objective be adopted. Communication can be accomplished in several ways:

(1) Direct contacts by mail or water bill insert;

(2) Indirect contacts through organizations, community leaders, or schools;

(3) Through the news media, including newspapers, radio, and television.

Regardless of the means of communication used, two kinds of messages are possible.

Motivation. Users are told why it is important for them to adopt new water use habits. In the case of water use reductions, imminent shortages or the promise of higher water supply costs in the future are usually effective in alerting some part of the population of the need to review water use practices. Where water use is deemed inadequate, users must be told why it is inadequate and what the consequences of continued low use will be.

Information. Once users accept the need to review and possibly modify water use behavior, they must be told how to do so. Information on water use practices, available water saving devices and appliances, and implementation requirements can be promulgated to all users. Those who are properly motivated will make use of this information to establish new water using behavior.

F. _Restrictions, rationing, and prohibitions_

Water enterprises and local governments sometimes impose mandatory water conservation measures on users or groups of users. Some possible kinds of mandatory measures are described below. No attention is given here to the origin of the necessary authority, or on the conditions and limitations that accompany it.

Land use restrictions. Nearly every aspect of land use planning and development has an impact on future water use. Where water is scarce, growth control measures can be used to limit in-migration, reducing future pressures on a limited resource. Per-capita water use can be reduced by measures which promote comparatively dense, multi-family housing. Both land use and economic development policies may be used to discourage growth of water-intensive industrial activities. Except in crisis situations, it is probably not reasonable to restrict growth and development for reasons of water supply alone. The effect of such policies is usually to relocate persons and activities to other areas. All consequences of these policies should be considered, including water supply implications for the alternative growth locations.

Allotments. When the quantity of water demanded threatens to exceed the quantity supplied, one strategy is to ration available water among users and user classes. Sometimes such rationing occurs by default, where excess use causes the distribution system to lose pressure from time to time. This form of rationing is highly inefficient (high-value uses are lost along with low-value uses), promotes inefficient use when water is available (water storing, disregard for conservation efforts), and creates public health problems (distribution system contamination, unsanitary storage). Where customers are metered, rationing can be accomplished by allotting a specific quantity to each customer. Enforcement is effected by reading the meters before and after the allotment period, imposing large fines for exceeding the allotment. Allotments may be uniform for all members of a user class, or they may be based on each customer's prior use (e.g., 50 percent of actual usage in the same month of the previous year).

Prohibitions. Another way to mandate reductions in water use is to simply prohibit certain uses altogether, or to prohibit them at specified times. Examples include prohibitions on outdoor use of water by residential users. These are sometimes implemented for all such uses for the duration of a drought or on certain days. In the U.S., alternate day prohibitions on outdoor use are common in the humid areas, while less restrictive measures may be used in the arid Southwest. For example, Tucson (AZ) has banned outdoor uses on Wednesdays (Martin, et al., 1984). Other prohibitions may apply to the public sector, by banning water use in parks, along highway borders, or in fountains. Certain commercial or industrial activities may be prevented from using water (car washes, swimming pools). In water crises, additional activities may be prohibited from using water, as necessary to avoid system failure.

G. System management

Demand management measures include various activities, ranging from leak detection and overall system maintenance to public information campaigns and water use prohibitions. For each demand management scenario, there is a set of techniques which will achieve the required result at least overall cost and/or with minimum disruption and inconvenience. Identification of these preferred measures, and verification of their effectiveness, requires that system management meet certain minimum standards.

Among these requirements is the need to have current and accurate information on the level and pattern of water use. This means, at a minimum, that all customers be metered, and that meters are read regularly and receive reasonable maintenance. Water sources should also be metered, so that the quantity of water sold can be compared to the quantity produced. In large systems, metering of water entering portions of the distribution system may also be helpful. Meter readings must also be recorded in a form that makes them available for later statistical analysis. Water use patterns (water use by customer class, by location, by time of year, etc.) can be analyzed and used to predict the effectiveness of various demand management measures.

Since many demand management measures are directed to specific water uses or classes of water users, estimates of their effectiveness or social impact require knowledge of the quantity of water use affected. This knowledge can only be obtained from customer meters. Also, effective system management may require information about the spatial pattern of water use, so that existing facilities can be operated and new facilities designed to maintain adequate service. Again, a major source of such data is meter readings.

Meter readings can also be used to indicate the possibility of significant leakage, or of large illegal connections. Pinetown, South Africa, noted that water losses had reached 16 percent in 1973 (Mills, 1990). This triggered a vigorous demand management program, including meter repair and replacement, metering of fire connections, monitoring of night flows and other leak detection activities, and adjustment of system pressure. As a result, system losses declined slowly from 16 percent to 5 percent over the next 14 years.

Unmetered or partially metered systems may be unable to install meters for all customers within a reasonable period of time. In this case, it is essential that the sources and the largest customers be metered first (Katko, 1990). Metering of smaller customers can follow later, as time and budgets permit.

If any customers are metered, it is important that the meters be properly maintained. In the absence of any attention, small customer meters typically run slower and slower, under-registering water use by large amounts, until they finally stop. One study in Indonesia found nearly 50 percent of the meters unreliable or out of order (Kramer, et al., 1987). Inaccurate meters bias any data that may be collected, and undermine the use of economic incentives based on pricing. In both cases, the appropriate and effective use of demand management measures is frustrated by malfunctioning water meters.

III. ECONOMIC TOOLS FOR DEMAND MANAGEMENT: TARIFFS

A. The role of tariffs in water supply

It is customary for public water systems to levy charges on those who receive water service. Several kinds of prices, fees, and assessments may be applied, as specified in the water tariff. Where meters are installed, at least part of the total charge is based on metered water use. Other tariff elements may be fixed or they may be based on the type of water user served, the size of the water user's property, the value of the property, or the number and type of water using fixtures installed. While the original purpose of most water tariffs is to provide funds for operation of the system, the role and importance of tariffs goes far beyond revenue collection.

Where buildings are served by both water and wastewater systems, the respective services are not separable. In an economic sense, they are "bundled" services: virtually every indoor use of water requires the use of the wastewater system to carry away the waste; virtually every use of the wastewater system implies that water has been used. Both water and wastewater systems are commonly financed, in whole or in part, through user tariffs.

While these tariffs are often developed and implemented separately, they are functionally inseparable. They are but two parts of the same object. The same principles, considerations, and impacts apply to both tariffs individually and collectively. Consequently, the term "water tariff", as it is used in this chapter, will refer to the combined water and wastewater tariff.

1. Tariffs as a source of revenue

Virtually all water systems depend on the tariff for a substantial fraction of needed revenues. For many systems in developed countries, tariff revenue is sufficient to cover all costs, both operating and capital. In developing countries, tariff revenue often falls short of covering the full cost of water supply. This may be a conscious policy decision or it may have happened inadvertently, due to inadequate management attention.

The deliberate adoption of a tariff which will not cover all costs reflects a decision to shift costs from water users at the present time to some other group or time. Subsidies may be obtained from local government, from regional or national governments, or from bilateral and multilateral aid organizations. Costs can be shifted in time by borrowing. If the future debt service is to be funded through the tariff, the effect of borrowing is to shift costs from present to future water users. If some or all of the debt service will be paid from subsidies, costs are shifted both in time and to other entities.

Costs, of course, remain the same no matter how they are financed. The only variables are who bears the cost and when. Each type of financing allocates costs in a different way. Water tariffs allocate cost in approximate proportion to cost accountability (those who impose higher costs bear higher costs), although individual tariff designs may differ in the degree to which they accomplish this. Use of tax revenue allocates incremental subsidy costs according to the general tax incidence throughout the community, region, or nation. Subsidies from outside the country shift the cost to others, except to the degree that the presence of subsidies for water service reduces subsidies available for other essential activities.

While subsidies for water service are commonplace in the developing world, it is probable that conscious decisions to finance water service in this way are much less widespread. The usual circumstance is that the water tariff, originally intended to produce adequate revenue, has become inadequate for any of a number of reasons. Metered water use may be under-billed because of broken meters, poor meter reading practices, or flawed billing procedures. Bills may be issued but not paid because of inability for enforce payment. The tariff itself may be left unchanged despite rising costs and general price inflation, leading to steadily falling real revenues. All of these factors erode tariff revenue, requiring the water system to seek subsidies or find ways to shift costs to the future.

2. Effect of tariffs on the level and pattern of water use

The impact of tariffs on water use can be considered in two categories: inframarginal effects, and marginal effects. The inframarginal effect results from the total cost of securing and maintaining a connection to public water and wastewater (where applicable), including the cost of some minimal level of water use. If this cost exceeds the financial ability of the household, or seems excessive by comparison to any possible alternatives (such as illegal connection to a neighbor's system, use of water vendors, etc.), the household will not connect. The number of households and businesses who fail to connect for this reason, or the total water use foregone by those who do not connect, is the inframarginal effect of the tariff.

The marginal effect is driven, not by the total tariff, but by that portion which sets a variable charge for water use. This applies only in the case of metered systems, and refers to the price paid per metered unit of water. This price may vary from customer to customer, or from one time to another, depending on the design of the tariff.

Other things being equal, water use is expected to decrease with rising price, and to increase with falling price. The response of water use to price is measured as the price elasticity of water demand, as follows:

$$\eta = \frac{\partial Q}{\partial P}\frac{P}{Q} \approx \frac{\%\Delta \text{ in quantity}}{\%\Delta \text{ in price}}$$

Where: η = price elasticity of water demand
P = price of last unit of water used
Q = quantity of water used per period

According to the approximate definition of elasticity, then, it is equal to the percentage change in quantity that will result from a given change (say one percent) in price.

Many estimates of price elasticity are available in the U.S., Canadian, and Australian literature. A survey of and synthesis of more than 50 studies performed in the U.S. yields the consensus estimates shown as Table 1. Only a few studies attempt to measure short run elasticity (the transitional response

Table 1. Consensus Estimates of Price Elasticity of Water Demand in U.S.

	Short Run Elasticity	Long Run Elasticity
Residential Use		
Indoor use	0.0	0.0 to -0.10
Outdoor use -- Eastern U.S.	n/a	-1.30 to -1.60
-- Western U.S.	n/a	-0.70 to -0.90
Commercial and Institutional Use		
Individual categories	n/a	-0.20 to -1.40
Industrial Use		
(for water supplied from public system)		
Individual categories	n/a	-0.30 to -6.71
Aggregate industrial	n/a	-0.50 to -0.80

Source: Boland, *et al.*, 1984.

prior to complete adjustment by consumers to a new price). These are generally inconclusive, except in the case of indoor residential use, where the short run elasticity is estimated at zero (no response to price).

The relatively high elasticity for outdoor residential use reflects the discretionary nature of this use, especially in the Eastern U.S., where the normally humid climate makes lawn and garden irrigation strictly optional. Commercial and industrial water use display a very wide range of elasticities, including some categories that are rather inelastic and others that are quite responsive to price. In the case of industrial process uses, demand on the public system is more elastic when feasible alternative supplies are available.

Elasticities in Canada and Australia tend to resemble those shown on Table 1, due to general similarity in life style and water use patterns. Because residences are not usually metered in Great Britain, most elasticity studies focus on industrial use. Published results are within the ranges shown on Table 1.

Relatively few studies have been reported for developing countries, and these are often flawed by data inadequacies. The sense of these studies, however, is that indoor residential demand may be more elastic than observed in U.S. experience. Estimates in the -0.30 to -0.80 are usual. This is consistent with the greater importance of the cost of water in the household budget, and the relative acceptability of some substitutes for water use.

3. Economic efficiency

Because water use is determined, in part, by price, it is necessary to consider this relationship when setting price, and it is possible to use price (that is to say, tariff design) as a demand management measure. One reason that the impact of price on water use must be considered in tariff design arises out of concern for economic efficiency.

Economic efficiency in the water sector is achieved when water users obtain the largest possible aggregate satisfaction from the use of water, given some fixed level of cost (including financial, environmental, and other external costs). Economic efficiency is promoted whenever someone derives a benefit from the use of water which exceeds the cost of that incremental water, and it is hindered when the benefit is less than the cost. Since water users respond to the price signals contained in the tariff, those prices should reflect the incremental cost of supply (marginal cost).

Prices which are set too high will discourage potentially beneficial uses (the benefits gained would have exceeded the incremental cost of supply). Low prices encourage low value uses which do not produce benefits equal to the cost of supply. In either case, economic efficiency suffers.

4. Tariff-induced transfers of income

Each water user, by virtue of the level and pattern of water use, imposes certain costs on the system. Similarly, each water user, as a consequence of level and pattern of use and the design of the water tariff, makes certain payments to the water system in return for service. If the cost imposed is not the same as the amount paid, a transfer of income has occurred. Transfers can be defined for individual customers, for groups of customers (customer categories), or for all customers taken together.

When all customers collectively fail to pay the total cost of water supply (as in the case of subsidies), income is transferred from those who provide the subsidy to water users. If some category of water user (residential customers, for example) is charged more than the cost of supply, and other categories pay less, income is transferred from the high price group to the low price groups. The same relationship holds for individual customers: if any customer pays less than the properly allocated cost of supply, that customer receives a transfer of income from other customers, or from the grantor of a subsidy.

Transfers of income are inevitable in any tariff design, but attempts may be made to minimize them. Deliberate transfers are sometimes arranged, as when low income residential users are offered low prices for the first blocks of usage. Sometimes residential and commercial users are required to subsidize industrial users. More often, the tariff causes inadvertent income transfers by failing to match either the level or the pattern of supply costs.

5. Fairness and acceptability

If tariffs are to be effective vehicles for demand management, they must be perceived as fair and be otherwise acceptable to the public. If the existing tariff has not been unduly controversial, proposing a similar tariff is unlikely to create an impression of unfairness. This is true even where the existing tariff creates significant transfers of income. If the proposed design is noticeably different from the existing tariff, however, a different standard applies. Once the status quo is disturbed, the public may become more interested in the way in which costs are allocated. The tendency is to view prices and charges that are uniform across all customers in a class as fair, even where underlying costs are not uniform. Conversely, the public often views charges which differ from class to class (residential vs. industrial, for example) as fair, even where the costs are the same.

It is more difficult to predict what tariff features will be unacceptable for reasons other than fairness. Certainly, large increases in the level of charges are often unacceptable, except where the public has already been convinced of the necessity of such increases.

A water system may have good and adequate reasons for introducing a tariff which collects substantially more revenue and incorporates much more differentiation in charges among groups of customers, as compared to the prior tariff. It may even be possible to implement the tariff, regardless of perceptions of unfairness and unacceptability. These negative reactions can be reduced, however, by effective communication of the reasons for the changes.

6. Revenue stability, tariff stability, and feasibility

Revenue stability, apparently meaning total revenue which remains relatively constant from year to year, is a frequently mentioned criterion for water tariffs. This leads to an inappropriate emphasis on fixed, rather than variable charges, and does not insulate the water system from deficits which may arise in the case of an unexpected increase in demand.

A more appropriate consideration is net revenue stability, which refers to the difference between total revenue and "out-of-pocket" cost. Stable net revenue means that the water system does not swing from surplus to deficit--or vice versa--as economic activity, weather, or water supply conditions change. Net revenue stability requires that revenues track costs: when costs rise, revenues should rise; when revenues fall, costs should fall. A tariff which reflects both the level and the pattern of cost should provide reasonably stable net revenue.

Another stability issue concerns the tariff itself. Frequent changes in the tariff are usually considered undesirable by water managers, government, and the public. The only exception may be the use of annual across-the-board increases to keep the tariff current with price inflation. Changes in the basic structure of the tariff should be much more infrequent. The more often such changes occur, the more likely is public controversy, and the less political will may be available to impose unpopular changes. Tariffs which prove infeasible in this way, and cannot be implemented, contribute nothing to water management.

7. Resource conservation

Water conservation has been defined by some writers as occurring whenever water use is reduced (U.S. Water Resources Council, 1978). This implies that the goal of resource conservation is to reduce use at all costs, or at the expense of other scarce resources. Baumann, *et al.*, (1984) define water conservation as "any *beneficial* reduction in water use or in water losses" (emphasis added). The word "beneficial" indicates that the benefits of reducing water use cannot be outweighed by costs imposed on other resources

Tariff changes which act to increase the price charged for water use (at some time or to some customers) cause a reduction in water use. Those changes are beneficial if the foregone water use would have produced benefits smaller than the incremental cost of supply. This condition can be insured by designing a tariff in which all prices are set equal to the incremental cost of the service supplied. In this case, if the tariff reduces water use (because users do not value the uses as highly as the cost), the reduction will be beneficial. Incorporating resource conservation criteria into tariff design, therefore, can be seen to be identical to consideration of economic efficiency, provided all costs--internal and external--are considered in both cases.

B. Tariff design

1. Single and multi-part tariffs

The simplest possible form of water tariff would one a fixed charge levied each month on each water customer. Another possibility, applicable to metered customers, would be a price per unit of metered water use. Both of these are described as single part tariffs, since each contains only one type of charge. The charges themselves may be vary from one user class to another, or from one season to another. Since each customer faces only one charge at a given time, the single part tariff description still applies.

If these two charges were combined, so that each customer paid a monthly fixed charge as well as a price for metered water, the result would be a two part tariff. Other elements could be added, such as an annual assessment based on property value, a minimum charge in excess of the fixed charge, etc. Multi-part tariffs may have two, three, or more components.

Where wastewater service is provided, the true tariff faced by consumers is the sum of water and wastewater elements. Except in the simplest case (water is sold at a single price per metered unit and the wastewater charge is a uniform percentage surcharge on the water bill), combined water/wastewater tariffs have a multi-part form.

2. Block and increasing rate tariffs

Charges for metered water use may be uniform rates, where all water is sold to a given customer at the same price, regardless of the quantity used. otherwise, a number of non-uniform rates are commonly used.

(a) Decreasing block rates

If water use per billing period is divided into a number of discrete blocks, separate prices can be set for each block. If price falls with increasing use, the result is a decreasing block rate (or declining block rate). For example, a four-step decreasing block rate design might appear as follows:

Water Use/ billing period (cubic meters)	Block Price ($/cubic meter)
0 - 5	1.05
5 - 10	0.90
10 - 50	0.75
all over 50	0.50

A customer whose use is 17 cubic meters in the billing period pays $5.25 for the first 5 cubic meters (5 times $1.05), $4.50 for the second 5 cubic meters (5 times $0.90), and $5.25 for the last 7 cubic meters (7 times $0.75). The total bill is $15.00.

Other examples might have as few as two blocks, or as many as seven or eight. Blocks may be relatively small compared to household consumption, so that typical residential customers terminate their use in the second or third block. Blocks may also be relatively large, with the intention of segregating most residential users in the first block, commercial and institutional users in the middle blocks, and industrial users in the highest blocks.

(b) Increasing block rates

When block prices rise with increasing water use, the result is known as an increasing block rate (or inclining block rate, or progressive rate). An example of a four-step increasing block rate follows:

Water Use/ billing period (cubic meters)	Block Price ($/cubic meter)
0 - 5	0.50
5 - 10	0.70
10 - 50	0.95
all over 50	1.20

The total bill is calculated as for the decreasing block rate example: each block price is applied to water used in that block, and the totals are summed across blocks.

As in the case of decreasing block designs, the size and number of blocks used varies widely. It should be noted that the use of a minimum charge creates a de facto increasing block rate. For example, a tariff which contains a uniform price of $0.75/cubic meter and a minimum charge of $3.00/billing period can be represented as a two-part tariff containing a fixed charge of $3.00 and the following increasing block rate:

Water Use/	Block Price

billing period (cubic meters)	($/cubic meter)
0 - 4	0.00
all over 4	0.75

This reflects the fact that, until the minimum is satisfied, increasing water use adds nothing to the total bill.

(c) Mixed block rates

Mixed rates occur when elements of both increasing and decreasing block designs are used in the same tariff. Usually, the price first increases, then decreases. This may result from the use of a minimum charge with a decreasing block rate, or it may reflect a desire to offer low prices to the smallest and largest customers. An example of a mixed block rate follows:

Water Use/ billing period (cubic meters)	Block Price ($/cubic meter)
0 - 5	0.70
5 - 10	1.10
10 - 50	0.95
all over 50	0.65

(d) Increasing rate tariffs

Another way to provide a price which is progressive with respect to water use is the increasing rate tariff. Unlike block rates, each user pays the same price for all water used in the billing period, but the price increases with increasing use. For example:

Water Use/ billing period (cubic meters)	Price ($/cubic meter)
0 - 5	0.70
5 - 10	0.80
10 - 15	0.90
15 - 20	1.00
20 - 25	1.20
all over 25	1.40

A customer whose use is 17 cubic meters per billing period pays $1.00/cubic meter for all use: 17 times $1.00 - $17.00.

Increasing rate designs are seldom used. The major US example is the 100-step water/wastewater design adopted in 1978 by Washington Suburban Sanitary Commission (Hyattsville, MD). Decreasing rate designs would be possible, but are not used since they result in "free" water as each step transition is approached.

3. Seasonal differentials, seasonal surcharges

Since both water demand and cost of supply vary according to time of year (both demand and cost are high during hot, dry weather), it may be desirable to vary prices as well. This requires the definition of seasons, and the adoption of differentials or surcharges which reflect the desired price variations.

A year can be divided into two or more seasons for this purpose. The only limitations are those of meter reading sequence and frequency. Where meters are read progressively throughout the system, with approximately the same number read each day, the minimum feasible season is at least two or three billing periods in length. For example, a billing period of one month would permit a minimum three-month season. A billing period of three months supports a minimum six-month season. If meter readings are concentrated into a period shorter than the billing period, shorter minimum seasons are possible.

When different prices are set for different seasons, assuming the same customers and the same use levels, the tariff is said to incorporate a seasonal differential. The seasonal differential may apply to all customers or to a single customer class; it may apply to all use, or only to specific blocks (for example, to the last block in a decreasing block rate).

An alternative strategy is to use the same rate design year-round, with the additional of a surcharge which applies only in certain seasons. A common form of the seasonal surcharge is to apply it on a customer-by-customer basis to any use in excess of some multiple of the previous season's use. In a two-season design, the surcharge may apply to summer use in excess of 130 percent of the previous winter use by the same customer. In effect, this provides an increasing block feature where the block size is set individually for each customer.

4. Contingent tariffs

Other charges may be incorporated in tariffs for contingent use: they are not active until triggered by some external event or announcement. Drought surcharges fall in this category. The tariff may provide for a surcharge on all charges in the event of drought: the surcharge applies to water used after an announcement of the beginning of the drought, and it terminates when the end of the drought is announced.

Conservation payments may also be provided in a tariff. Water users who demonstrate a reduction in use below a specified level (prior average use, for example) receive either a lower price or a lump sum credit. This tariff provision is inactive until proof of conservation is provided.

5. Other tariff elements

In addition to seasonal differentials, described above, other price differentials are commonly incorporated into water tariffs. Prices may differ between user classes (residential vs. commercial vs. industrial), creating class differentials. Prices may vary from place to place in the service area, creating zone differentials. These differentials may reflect political boundaries, pumping zones, historical precedent, or other criteria.

C. Tariff development

Water tariffs are meant to accomplish many things. They should raise the necessary revenue, promote economic efficiency, insure equity, appear acceptability and politically feasible, and contribute to resource conservation. These objectives are at least partly contradictory in all applications, requiring compromise in order to achieve a practical tariff. The need for compromise may be especially noticeable in developing countries (Katko, 1990).

In order to define needed compromises, tariff development must have a starting point. Some method must be used to develop a tentative tariff, which can then be refined after consideration of the various objectives and constraints. In most cases, the basis of tariff development is cost. This section describes the several measures of cost used for this purpose, as well as alternative methods for devising a tariff.

1. Cost of service studies

Tariffs fulfill many functions, and can be judged by many criteria. If there is one standard that outranks all others in importance, in the view of experts and public alike, it is that tariffs should be based on cost of service (Bonbright, et al., 1988). Very few would argue that the cost of rendering service is irrelevant, although stipulations are sometimes applied: costs must be necessary and prudently incurred, not all costs should be recovered through the tariff, etc. More importantly, there are a number of alternative definitions of cost, and little agreement as to which of them are relevant to tariff design.

(a) Embedded cost studies

Cost of service studies are undertaken to identify and measure the cost of providing water and wastewater service. Most studies adopt one of the two major notions of cost: embedded cost and marginal cost. Embedded cost studies consider the past total cost of providing service. Both variable and fixed costs are examined, including sunk costs (irretrievable investments in facilities which have no alternative use). Cost estimates are backward-looking, in that they are based entirely on actual experience. Embedded cost studies determine the total revenue that would have been required to own and operate the system in the recent past.

The simplest type of embedded cost study produces a single number: total cost. More often, cost is allocated among a number of services. A fully distributed cost of service study allocates cost by customer class, and sometimes by area served or season. All costs are allocated, both variable and fixed. Since only variable direct costs can be causally related to a specific service, all other costs (common costs, fixed costs, sunk costs) must be allocated on the basis of some assumed relationship. Various assumptions are made, and they account for the numerous formulae used to distribute fixed costs in embedded cost studies. One expert noted the existence of 29 such formulae in 1953; the number may have increased since then (Bonbright, et al., 1988) No allocation of fixed cost can be supported on the basis of causality; the allocations adopted reflect notions of equity or fairness, not of cost responsibility.

(b) Marginal cost studies

Marginal cost studies address only avoidable incremental costs: those costs that would not be incurred if the level of a particular service is reduced by a small increment. Cost estimates are forward-looking: they are projections of what costs will be in the immediate future, not what they were in the immediate past. Marginal costs measure the addition to total cost of providing one more unit of service, or the reduction in total cost if one unit is not provided. Since fixed costs (including sunk costs) do not, by definition, vary with service provided, they are not considered in marginal cost studies. No allocation of fixed costs is necessary or needed.

Since marginal costs refer only to the last units of service produced, omitting consideration of fixed costs, they bear no necessary relationship to average cost of service. Where several water sources are available, and are used in order of increasing unit cost, the marginal cost of water supplied will likely be greater than the average cost. On the other hand, the cost of distributing water is dominated by large investments which are fixed with respect to additional water delivered; marginal distribution cost is likely to be small by comparison to average cost.

Capital costs are included in marginal cost to the extent that changes in the level of service would change the size or the timing of future investments Because the precise relationship is difficulty to define or measure, several approximations to marginal investment cost are used (Saunders, et al., 1977).

Marginal costs are associated with specific services. Accordingly, the results of a marginal cost study include costs for each service, possibly differentiated by season or by place. Costs are not disaggregated by customer class, unless the service offered to one class is distinct from another.

The usual practice is for cost of service studies to consider only costs borne, sooner or later, by the water or wastewater agency. Costs borne by others, including environmental costs and subsidies, are not included. To this extent, cost of service studies understate true social cost. Subsidies are incorporated later by reducing revenue targets, but environmental and other external costs are generally ignored.

2. Embedded cost-based tariffs

Embedded cost studies provide a revenue target, which may be further allocated by customer class, location of service, or time of year. The target is for a particular time period, usually in the recent past. The revenue target(s) may be decreased to reflect the availability of subsidies, or increased to provide for planned accumulation of surplus.

The choice of specific tariff elements and the fraction of total revenue to be collected from each are normally dictated by other considerations, such as prior practice. The charges contained in the tariff are adjusted, often proportionately, so that the total revenue expected to be collected is equal to the target. The adjustment is performed for each customer class, service area, and season, as needed. In the case of block-type rates, block sizes and the relationship of successive block prices are usually chosen arbitrarily, although some rule-of-thumb may be used.

3. Marginal cost-based tariffs

Marginal cost studies do not provide a revenue target for the design of tariffs. The target, often disaggregated by customer class or service area, is usually obtained from an embedded cost study performed for this purpose. Revenue target adjustments are made as described for embedded cost pricing. Once the revenue target is available, the marginal cost study is used to design the tariff.

Three types of marginal cost are usually identified. Marginal customer cost is the incremental cost of permitted another customer access to the system, apart from the cost of supplying any water or capacity to that customer. Customer costs vary from one size of customer to another, but do not change by season or (usually) by location.

Marginal commodity cost is the incremental cost of supplying another unit of water to some customer in the distribution system. This cost may vary by season and by location in the system, but not by type or size of customer. Marginal capacity cost is the cost of providing another unit of capacity. Capacity cost usually applies to the peak season only, and is zero at other times (excess capacity is expected to be available off-peak). While it may vary by location, it is unrelated to the size or type of customer likely to use the capacity.

The nature of the marginal costs identified in the study determines the tariff elements used. The presence of marginal customer costs justifies the use of a periodic customer service charge, set equal to the marginal cost. Marginal commodity and capacity charges both support the use of charges for metered water use. If the cost varies between seasons, the charge should be seasonally differentiated. Marginal capacity costs are recovered through capacity charges or through water use charges levied during the peak capacity season.

The usual form of a marginal cost-based tariff is a water price which is uniform across customer classes, but differentiated by season and possibly by location, plus a periodic service charge. Block-type rates are inconsistent with marginal cost notions, since they differentiate price according to individual prior use, a factor which cannot account for cost differences at the time of use.

Once all of the marginal costs have been accounted for in the tariff design, other elements (such as fixed charges, assessments, etc.) are adjusted to achieve the revenue targets. This adjustment may include the use of "negative fixed charges", where total bills are reduced by some fixed amount to achieve the proper total revenue. In certain unusual cases, constraints on other tariff elements may make it impossible to achieve revenue targets in this way. In this case, economic theory provides the "Ramsey pricing" rule for making optimal adjustments to the marginal cost-based prices (Bonbright, et al., 1988).

4. Other tariff bases

Other bases for tariff design can be described, including some which do not depend on any measure of cost. The most common of these can be termed an adjusted status quo approach. Beginning with an existing tariff, revenue is increased or decreased by making a series of small, trial-and-error adjustments to the current charges. A uniform, across-the-board increase may be applied, or selected elements may be increased more than others. The results do not reflect any notion of cost, but rather indicate what is thought to be possible and feasible.

Tariff design can also be based on capacity reserved for individual customers, or on property values. Tariffs consisting entirely of fixed charges ("flat rate" tariffs) are sometimes based on plumbing fixtures or property frontage.

D. Selected tariff designs

The rate elements discussed above can be combined in many ways to produce an almost unlimited number of unique tariff designs. Available surveys indicate considerable variety in actual tariff forms. A 1983 survey of U.S. practice found that multi-part tariffs were used by 65 percent of water systems and 74 percent of wastewater systems (Boland, 1983). Among the water systems, uniform (unblocked) commodity charges were reported by 21 percent, decreasing block rates by 43 percent, and increasing block rates by 8 percent. The remaining 28 percent used mixed block rates, multiple charge types, or had no commodity charge. For the wastewater utilities, 84 percent used uniform commodity charges, and 12 percent had decreasing block rates.

Canadian practice is to use decreasing block rates almost exclusively (Katko, 1990). However, recent trends in other developed countries have been away from decreasing block designs. They are being replaced by uniform and increasing block tariffs.

There are apparently no comprehensive surveys of tariff design practice in developing countries, but anecdotal evidence suggests widespread use of increasing block designs, and comparatively rare incidence of decreasing block rates.

The following paragraphs present some hypothetical tariff designs, with comments on their most important characteristics. In every case, charges are stated in U.S. dollars, quantities are in cubic meters, and the billing period is assumed to be one month.

1. Uniform, two-part tariff

A typical uniform, two-part tariff for a residential customer would appear as follows:

SERVICE CHARGE:	$5.00/month
COMMODITY CHARGE:	
for all water use	$1.20/cubic meter

As a demand management measure, this tariff presents each customer with the same incentive to use or to conserve water regardless of prior use, location or season. In general, a uniform commodity charge favors economic efficiency, resource conservation, net revenue stability, equity, and fairness; it tends to minimize unwanted transfers of income. These general characteristics are strong if the charge is based on marginal cost, and if seasonal variation in marginal cost is small. If the charge is based on embedded cost, the listed advantages may be less noticeable, depending on the divergence between the actual charge and the marginal cost.

2. Decreasing block tariff

Decreasing block tariffs can have many forms. The following is a simple, three-block design with relatively small differences between blocks. No fixed charge is included.

SERVICE CHARGE:	none
COMMODITY CHARGE:	
0 - 5 cubic meters/month	$1.50/cubic meter
5 - 10 cubic meters/month	$1.20/cubic meter
all over 10 cubic meters	$1.00/cubic meter

Use of this design to manage demand would result in quite dissimilar incentives to conserve water. The price faced by small customers (those whose use does not exceed 5 cubic meters/month) is 50 percent greater than that faced by the largest customers. If customers with relatively large amounts of low-value, discretionary use are more likely to be found in the third block, they will be among those with the smallest incentive to conserve.

The decreasing block tariff levies different prices on different users, based on each customer's prior use. It is, therefore, inconsistent with marginal cost pricing principles and with the goal of economic efficiency. This design also creates significant transfers of income among individual customers; to the extent that high income users are larger users, the transfers are likely to be perverse (moving income from low income to high income households). If the third block price is less than the avoidable cost of water service, fluctuations in demand due to weather or economic activity will result in large changes in net revenue: rising demand will reduce net revenue, and vice versa.

In cases where it is desirable to promote increased use by some large customers (to promote industrial activity, for example), the decreasing block tariff may be useful. Past U.S. practice has been to justify this design in this way, arguing (incorrectly) that the unit cost of serving large customers is low. If subsidies are the purpose, there is likely to be an alternative, less damaging way to accomplish the same end in virtually every case. Industrial customers can be grouped into a class and offered a low uniform charge, while all other customers pay a higher uniform charge. Also, lump sum subsidies can be offered, through the water tariff or other means, avoiding distortion of the metered use pricing mechanism altogether.

3. Increasing block (progressive) tariff

A typical increasing block tariff, combined in this case with a fixed charge, is as follows:

SERVICE CHARGE:	$5.00/month
COMMODITY CHARGE:	
0 - 5 cubic meters/month	$0.80/cubic meter
5 - 10 cubic meters/month	$1.20/cubic meter
all over 10 cubic meters	$1.50/cubic meter

As in the case of the decreasing block design, the increasing block tariff provides users with quite dissimilar incentives to conserve water. In this case, the largest customers face a price some 88 percent higher than that applying to the smallest users. This arrangement may have the advantage of directing high prices to some users with significant low-value, discretionary use, but the resulting conservation must be balanced against higher water use encouraged by the much lower price offered to other customers.

Like other block-type designs, the increasing block tariff bases price differentials on prior use, and is thus inconsistent with the principles of marginal cost pricing and the goal of economic efficiency. Transfers of income among customers are comparatively large, although more likely to flow in an acceptable direction (high income to low income households). Nevertheless, the last blocks are not populated exclusively by high income households; they also include large households, regardless of income. If the third block price exceeds the avoidable cost of service, net revenue stability will be poor (increases in demand will increase net revenue, etc.).

Increasing block tariffs can be used to impose conservation incentives on some target group of large users, and they give the appearance of reflecting rising unit cost. The latter notion is incorrect, since unit cost rises with respect to either total water supplied, or time. Increasing block blocks rise with an individual customer's water use in a billing period; they are almost invariant with respect to increases in total water use or with respect to time. If higher prices can be justified for some group of users, it is preferable to identify that group as a separate class and set a uniform commodity charge at whatever level is desired.

4. Seasonal tariff

Seasonal differentiation can be applied to any tariff design. This example uses a uniform rate, with fixed service charges, for this purpose.

SERVICE CHARGE:	$5.00/month
COMMODITY CHARGE:	
Winter (meters read Nov-Apr) for all water use	$0.90/cubic meter
Summer (meters read May-Oct) for all water use	$1.50/cubic meter

The seasonal tariff shown has all of the characteristics of a uniform tariff, except that it is capable of more accurate representation of the pattern of cost. To the extent that the seasonal differential reflects the seasonal change in avoidable costs (including capacity costs), this tariff provides a stronger impetus for economic efficiency, resource conservation, net revenue stability, equity, and fairness; also, it minimizes unwanted transfers of income. As a demand management tool, the seasonal rate is more flexible than other designs. A seasonal rate could be used to reduce water use during the peak season, or to promote increased water use at off-peak times, as needed.

E. Other uses of water tariffs

1. Demonstration of willingness to pay for water service

Many urban areas face critical problems in several sectors, including health, education, housing, and public infrastructure. Public funds are scarce, and cannot be allocated to activities that do not produce benefits at least equal to the cost. This is true for operating funds, and especially true for capital investment, where borrowings and subsidies are constrained. In the absence of benefit information, many agencies apply an affordability criterion, where investment in the water sector is limited by some fraction of consumer households' disposal income. This criterion has been questioned, especially in the light of recent findings that amounts paid to water vendors may be several times the "affordable" limit for individual households (Katko, 1990).

One of the most elemental characteristics of a tariff is that it requires water users to reveal something of their willingness to pay for water service. The total revenue collected from the voluntary portions of a tariff (excluding any taxes or assessments levied on non-users) represents a payment in exchange for a service. As such, it is a lower bound estimate of the total benefit users expect to receive from that service.

A tariff designed to recover the full cost of water supply will, if implemented and if the expected revenues are collected, provide the information needed to confirm the reasonableness of the allocation of funds. Furthermore, it will recover those funds so that net disbursements from the public treasury are unnecessary.

Tariffs which recover a part of the total revenue requirement demonstrate a part of the needed benefits. Even this information can be useful. Seasonal differentials may reveal a willingness to pay for seasonal capacity that justifies the capital investment. Industrial users can be required to pay the full cost of service even when residential users are not, thus justifying extension of service to these customers. If the metered water use price is based on marginal cost, increased use will produce incremental revenues which justify the added expense, without subsidy from other users or other parties.

2. Incentives for efficient provision of water service

Effective water supply management is based on numerous decisions about how much capacity to provide, when to provide it, and to whom. Optimally, these decisions will be made so as to produce the largest possible net benefit. While the cost of supply projects may be known, the benefits are seldom considered. Project sizing and timing, then, is based on arbitrary criteria, and the results may fall well short of the goal of economic efficiency.

Tariffs create the possibility of testing the feasibility of projects before they are committed. If a new facility is need to provide for summer season peaks, a properly constituted seasonal rate can demonstrate willingness to pay the cost of the facility before it is built. If improvements to service are being considered for a certain area, a tariff can be constructed which will confirm the existence of potential benefits.

Marginal cost-based tariffs produce patterns of revenue which match the costs of the system to the benefits obtained. If users value a certain service highly, they will be willing to pay a high price which will, in turn, induce the water agency to make the necessary investments for continued service. Where consumers do not value a service to this extent, revenues collected will be limited to maximum willingness to pay. If this results in a reduced revenue stream, the agency will be motivated to avoid investment in this area.

3. Encouragement of decreased water use

Tariffs implemented for metered systems must inevitably affect the level and pattern of water use. When commodity charges are generally higher than those previously in effect, water use falls; when charges are generally lower, water use rises. If some charges are higher and others lower, components of water use will decrease and increase, respectively. Most frequently, tariffs are modified for the purpose of reducing water use. There are at least three circumstances in which this result may be sought.

(a) To reduce supply cost

The goal may be to reduce the overall level of water use, in the interest of reducing current and future costs of water supply. This may suggest an across-the-board increase, where every type of water use receives the same relative incentive to reduce use. If it is current operating costs that are of concern, though, it may be preferable to induce relatively large reductions at the times, or in the places, where unit costs are highest, with little or no reduction created elsewhere or at other times. This can be accomplished by adopting a seasonal rate (if the high cost periods are associated with a particular season) or a zoned rate (with high prices in high cost areas). These approaches are consistent with the approach of marginal cost pricing, which seeks to produce a given benefit at minimum cost.

(b) Drought management

In the event of a temporarily reduced supply of water, the result of no action will be a supply failure, with loss of pressure and dewatering of the distribution system, accompanied by economic dislocation and health threats. When a shortage first appears imminent, a better strategy is to reduce water use in an orderly and efficient way until demand and supply are once again in balance. Various voluntary and mandatory conservation measures can be adopted (see chapter II) in the course of drought management. These measures can be replied upon to reduce water use sufficiently by themselves, or in concert with tariff changes.

Increases in the commodity charges included in the tariff, where feasible, offer several advantages over other measures which achieve the same water use reductions. Tariff changes produce minimal impact on economic efficiency, since water use reductions can be expected to occur for the lowest valued uses only. Implementation cost is negligible, and public awareness is almost guaranteed. Finally, this method lends itself to a trial and error process until the desired reduction has been achieved.

(c) To maintain water quality

Both water withdrawal and wastewater discharge can have deleterious impacts on water quality, whether at the source or the discharge location. Undesirable environmental effects associated with water withdrawal can be reduced (or sometimes eliminated when they are confined to one of a set of multiple sources) through tariff provisions which lead to decreased use. Where the environmental effects are confined to certain seasons, decreased water use can be confined to the affected season through seasonal rates.

Impacts of wastewater on receiving bodies of water can be also reduced by lowering water use through tariff changes, provided that the impacts are at least partly related to hydraulic loading (as opposed to contaminant quantities). These reductions can be limited to critical seasons, or to areas served by the particular sewer systems. Tariff provisions which require industrial users to pay full cost (while subsidizing residential users), may promote both water (and wastewater) conservation and increased recycling

4. Encouragement of increased water use

Just as water use reductions are sometimes sought, there are circumstances in which water use increases would be desirable. In most cases, these increases can be obtained by altering the tariff. Some examples follow.

(a) Opening up of new development areas

Attempts to foster economic development in specified areas have often foundered for lack of financial feasibility. Typically, prospective residents or businesses find start-up costs too high to justify relocation. Water tariffs with zonal differentiation can be used to favor those who locate in a particular area, thus contributing to the incentive to move there. If these adjustments include a reduction in the commodity charge, another result will be increased water use.

(b) Improvements in hygiene

For cities in developing countries, especially those with large rural-to-urban movements, residential water use may be at or below the level necessary to support proper hygiene. Tariffs can be designed to promote water use up to some point, encouraging increased water use in such cases. This is most often done by means of an increasing block structure, but uniform rates applied to properly defined customer classes may also be effective.

(c) Promotion of agriculture in new irrigation areas

As in the case of new development areas in and near cities, the existence of new irrigation projects may not result in planned levels of agriculture. Among the reasons for this might be high start-up costs as well as the continuing cost of using water from the irrigation system. The adoption of a suitable tariff, perhaps supported by subsidies from government or from other users, can do much to persuade prospective irrigators of the advantages of the new areas.

IV. ECONOMIC TOOLS FOR DEMAND MANAGEMENT: OTHER INCENTIVES

Water use responds to many kinds of economic incentives, including the tariff provisions described in the previous chapter. This chapter discusses additional economic incentives which can be implemented outside of the structure of a tariff. Some of these measures are more narrowly focused and more flexible than tariff provisions. Others are more broadly applicable.

A. Economic tools for management of domestic demand

1. Difference between metropolitan areas and small communities

Patterns of domestic water use, and the applicability of various demand management tools, vary widely from one community to another. Small communities tend to have homogeneous use patterns. Since most water users behave in similar ways, demand management targets can often be met using only one or a few measures. However, unit supply costs are higher for small systems, making demand management an attractive alternative in some situations. But small systems also have few technical or analytical resources, limiting their ability to identify and implement appropriate management tools.

Large metropolitan areas, on the other hand, demonstrate considerable diversity in levels and patterns of domestic water use. This is particularly true in developing countries with substantial rural-urban migration. Recent arrivees, especially those living in squatter communities, may not have access to building connections. Depending on the distance from residence to public standpipe, per capita water use may range from 2 to 70 liters per day (Postel. 1984). In the same city, others may live in modern housing equipped with a full range of water using appliances, drawing as much as 350 liters per day per person. Suburban dwellers with detached housing units and lawns and gardens can account for as much as 1,000 liters per day per person.

Demand management tools applicable to large urban areas range from measures intended to encourage increased water use in low income areas, to severe disincentives for low value uses in high income areas. Nearly every kind of management measure can be considered for possible application, and aggressive demand management programs may require simultaneous implementation of a number of programs. Water agencies serving metropolitan areas are more likely to be aware of management possibilities, and to have the ability to evaluate and implement various measures. Nevertheless, most water agencies of all sizes fall well short of effective management of demand.

2. Incentive payments for water use modification

Domestic users of water will sometimes agree to modify use levels or patterns in return for a cash payment. If enough users participate in such a program the water system, in turn, may be able to postpone or avoid construction of new facilities. In order to qualify for an incentive payment. water use modifications should be <u>continuing</u> and <u>verifiable</u>. A continuing modification is a commitment on the part of the user to sustain the changed pattern of water use for the foreseeable future. This may involve the installation of equipment, or the permanent adoption of new water use habits.

A verifiable modification is one that can be observed and monitored by the water agency, using readily available information.

Many kinds of incentive payments can be devised, provided the above conditions are met. Three examples are described below.

(a) Voluntary quotas

A household may voluntarily accept a limit on the amount of water that can be used in any billing period. The limit is set for each participating user at a level below prior use and, once set, is fixed thereafter. It may be in effect for each billing period, or only during certain peak months. The household receives an incentive payment, usually on a periodic basis (each year or each billing period), so long as the quota is not exceeded. If the quota is exceeded, the incentive payment is not made and a penalty may be applied.

With sufficient participation, voluntary quotas can be effective in reducing the level of water use year-round, or during the peak season. Funds for the payments are obtained by increasing the water tariff paid by all customers. This increase is in lieu of the increase that would otherwise be sought if capacity were expanded.

(b) Flow restrictors

A flow restrictor can be placed in a household service line, limiting the maximum rate at which water can be withdrawn. The restrictor may be in the form of a pressure reducing valve, a constant-flow valve, or a simple orifice A household which accepts the installation of such a device may be rewarded by a periodic incentive payment, so long as the device remains installed (Occasional inspection may be necessary.) Penalties for removal are possible, but not generally needed.

If the restriction is sufficiently severe (maximum flows on the order of 5 liters per minute may be required), and if a significant number of households participate in the program, the result may be a noticeable reduction in peak demand on the distribution system. This, in turn, may permit the agency to defer or avoid investment in distribution and storage facilities. As in the case of voluntary quotas, the incentive payments are financed by other users, who are spared the expense of new construction.

(c) Landscape subsidies

Where residential lawn and garden irrigation is commonplace, it may be possible to reduce the quantity of water required for this purpose through landscape design. This can be done by limiting the amount of turfgrass (through use of low water use groundcover, gravel borders, etc.) and using drought-resistant shrubs and grasses. Incentive payments can be provided for specific landscape features. In semi-arid environments, for example, payment may be made for properties without humid climate trees or shrubs (those using "desert" vegetation). Payments may be made on a square meter basis for gravel plots. Incentives may be provided to owners of high water use properties to assist them in re-landscaping with drought-resistant species.

In all of these examples, the payments may be periodic but are more often implemented as a single, one-time payment. In this way, a single inspection of the property is sufficient to qualify the household for a payment. The result, given sufficient participation, is a reduction in water use during peak irrigation seasons (hot, dry weather).

3. Discounts for purchase of low water-using appliances

Chapter II describes various plumbing fixtures and water-using appliances that have been designed for low water use. The purchase and installation of this equipment can be mandated or left to voluntary action by individual households. In the latter case, the rate of adoption can be increased by providing economic incentives beyond those implied by the tariff. These incentives take the form of either discounts or rebates on the purchase of fixtures and appliances. In the first case, payments may be made direct to retailers to compensate them for discount pricing practices. Under the second strategy a rebate is paid directly to the purchaser on presentation of satisfactory proof of purchase (proof of installation may also be required).

Increased adoption rates for these devices result in lower average levels of domestic water use, permitting the water agency to defer or avoid capacity expansion. The incentive payments are financed by increasing the tariff level for all customers, who would otherwise have to pay the cost of new facilities. Incentive payments must necessarily be made to all who install the equipment, including those who would have done so in the absence of the payment.

B. Economic tools for demand management in agriculture

Agricultural water use is particularly difficult to manage by means of the economic incentives provided by tariffs. Two reasons are:

(1) Agricultural water use is seldom priced on a volumetric basis (actual usage is either not measured or not used as a basis for charges); and

(2) agricultural tariffs in many countries incorporate large subsidies.

Economic incentives that can be provided outside of the tariff structure, then, are of particular interest.

1. Production projections

Most agricultural irrigation uses methods similar to those first developed 5,000 years ago: flooding fields, or channeling water through narrow furrows. Water flows by gravity across a gently sloping field, seeping into the soil along the way. Most of these systems fail to distribute the water evenly, and use an excessive amount of water. By some estimates, as little as half of the water applied to the field actually benefits the crops (Postel, 1985). Once water has been allocated to a farm there is usually no reason, either economic or operational, to use less.

Assuming that the irrigation system has some ability to measure the quantity of water delivered to a particular farm, it is possible to use production projections to create an economic incentive for careful use. Water requirements are projected for the next growing season, taking into account acreage, cropping patterns, and existing irrigation practices. In the case of flood or furrow irrigation, it is assumed that the fields are properly leveled and graded, so that unnecessary waste is avoided. The projections are conservative, in that they assume efficient use of water. Each farmer is entitled to receive the projected quantity of water at the usual cost. Any use in excess of the projected quantity causes a large penalty charge to be imposed. This produces irrigators with a clear incentive to use no more than the minimum necessary quantity of water.

Another approach is to prohibit any use of water in excess of the projected amount. The State of Arizona (U.S.) uses this method, calculating the minimum amount of water needed to grow the planned crops (the "water duty"). Irrigators may not exceed the calculated water duty, but may carry over unused amounts from year to year (Emel & Yitayew, 1987).

2. Incentives for purchase of low water-using irrigation systems

Flood and furrow irrigation systems involve little capital investment, and have low operating costs. They require large amounts of water, however, because of uneven distribution and high evaporation rates. Improved systems are available, requiring pumping, pipe systems, and various kinds of devices to deliver the water to the plants. All of these involve capital investment and additional operating costs; all reduce the required amount of water. The most capital-intensive system--drip irrigation--requires the least water. Incentives for investing in improved irrigation systems are often small or entirely absent, depending on the tariff and the amount of subsidy it incorporates.

One way to promote adoption of more efficient irrigation systems is to create a tariff that includes a volumetric price and recovers the full cost of supply, as described in Chapter III. In the absence of such a tariff, it is possible to provide incentives for purchase of improved systems using either discounts or rebates. The government can offer the equipment to farmers at a discounted price. Alternatively, farmers who do buy and install the equipment may receive a cash payment, or rebate, to partially compensate them for the cost. Incentives can also be provided through the tax system, by offering accelerated depreciation or tax credits to those who have installed the equipment. Any of these methods should increase the number of farms which adopt more efficient practices, reducing the water required for irrigation.

Another economic strategy for stimulating adoption of low water-using irrigation systems is to make the availability of low-interest loans contingent on the purchase and installation of improved irrigation equipment. Conditions attached to such a loan could include minimum standards of quality for manufacture and installation of such equipment (Chandrakanth & Romm, 1990).

3. Penalties or surcharges for polluting the supply

Return flows from agricultural water use introduce contaminants into receiving waters in a number of ways. Where water is used for stock watering and uses other than irrigation, return flows may carry animal wastes into nearby streams. This problem is probably best addressed through improvements in drainage, waste flow detention, or treatment. It is generally not responsive to water management strategies.

A quite different water quality problem arises from the discharge of irrigation return flows into surface water, or percolation into ground water.

As a result of flushing, mineral leaching, and evaporation, irrigation return flows often have high total dissolved solids as well as pesticide and fertilizer residues. Wherever return flow volumes are significant compared to dry weather streamflow, or where significant amounts reach ground water, water quality problems are likely to ensue. While these problems are usually associated with increased salinity and nutrient levels, or pesticide residues, toxic minerals sometimes appear. Severe impacts on wildlife due to irrigation-derived selenium appearing in surface water have been reported in the western U.S. (National Resource Council, 1989).

Irrigation return flows are controlled in various ways. Any measure which affects irrigation water use, including those discussed above, affects the quantity and therefore the quality of return flow. Lower water use without change of technology reduces the volume of return flow, while increasing the concentration of dissolved solids. Improved water use technology can reduce evaporation and minimize the wetted soil area, leading to lower solids concentrations and reduced leaching. But whether lower water use, by itself, improves water quality depends entirely on circumstances.

Just as measures which affect irrigation water use also influence pollution from return flows, measures devised to control return flows influence water use. Where return flows can be observed (point source discharges to surface water), penalties or surcharges can be applied to either quantities discharged, or to various measures of pollutant load including maximum concentrations. Analysis of the total impact of such measures is complex. Incentives to reduce the quantity of water discharged lead to reduced water use and to more efficient irrigation methods. An incentive to reduce the maximum concentration of pollutants in the return flow creates a further incentive for increased water use and less effective irrigation methods, provided irrigation technology is not changed. If the response to this restriction is a change in technology, substantially lower water use may result.

4. Incentives for use of lower-quality water

Many opportunities exist for utilizing low quality water, principally recycled wastewater, for irrigation. Even vegetable crops can be irrigated in this way, if sufficient wastewater treatment is provided. A decade-long study in Monterey County, California, demonstrated the feasibility of using effluent from an advanced wastewater treatment facility--at one-fifty the cost of a new freshwater source (Postel, 1989).

Where treated wastewater is available in the vicinity of irrigated agriculture, tariffs can be devised which reflect the incremental cost (the cost of transmission plus additional treatment, if needed). In some cases this price will be below existing agricultural water (depending on the size of the subsidy); in most cases it will be below the cost of agricultural water from new sources.

5. Introduction of low water-using crops

Irrigated crops associated with relatively high water use per hectare include rice, sugarcane, maize, vegetables, mulberry, and fodder of various kinds. Depending on the climate, there may be alternative crops which can produce comparable economic benefits with lower water use (e.g., groundnuts, sunflower, sorghum, ragi). Dissemination of information concerning these crops, combined with the existence of an appropriate tariff for irrigation water use, will often lead to changes in cropping patterns, and reductions in overall water use. In some cases, it may be necessary to demonstrate successful cultivation and to develop markets for the new crops.

Additional economic incentives may be used to promote alternative crops, including differential pricing for water or, in the case of groundwater irrigation, differential pricing for pumping energy (Chandrakanth & Romm, 1990). These strategies are appropriate where the usual prices for water or electricity include a significant subsidy.

6. Incentives for changes in land-use patterns

Another way to control the use of water for irrigation is to influence the allocation of land to irrigated agriculture. Land which is marginally productive, or which is located some distance from the main irrigation works, might fail to produce net income which justifies the use of water. Subsidized irrigation tariffs promote inefficiencies of this kind, yet it is often difficult to remove the subsidy.

Marginal land can sometimes be removed from production by offering the owner a payment, contingent on the land remaining fallow for the coming growing season. The U.S. has long made use of such payments (called "set-aside" payments) to manage agricultural output. So long as the payment does not exceed the total subsidy that would have applied to water used on the land, then the result will contribute to overall efficiency.

Instead of payments for non-production, subsidies can be granted to development for alternative use. Payments can be made for maintenance of acceptable wildlife habitat, or for conversion to public use of some other type. Tax policy can also be used to create incentives to abandon agriculture on marginal or remote cropland.

C. Economic tools for demand management in industry

Industrial water use includes water needed for manufacturing processes and water used in thermal-electric power plants. Considered as a whole, industrial water use is the second largest sector world-wide, after agriculture. Within the industrial sector, the largest single use is for cooling water in nuclear and fossil fuel-fired power plants. Unlike agriculture, where a large fraction of water used is consumed (evaporated or transpired into plants), much of the water used in industry is discharged as wastewater, sometimes after a single pass through a cooling process ("once-through" cooling).

Due to pollution control laws and industrial re-structuring, industrial water use in developed countries is generally static or declining. In the developing world, however, where industrial water use in often less than 10 percent of total withdrawals, attempts to expand industrialization may lead to rapid increases. This is particularly true if new manufacturing firms in those countries, operating under severe capital constraints, choose low cost but water-intensive technologies. Industrial water use in Latin America, for example, is projected to increase by 350 percent between 1975 and 2000 (Postel, 1984).

1. Tax rebates on recycling or waste treatment equipment

The experience of developed countries has been that constraints on water use, or economic incentives for lower water use, lead to greatly increased recycling ratios within industry. Instead of using water once, it may be used two or three or ten times in some manufacturing processes. The installation of cooling towers allows cooling water to be reused perhaps twenty-five times before being discharged.

Also, requirements for more complete waste treatment have often led to increased recycling, as firms realize that the treated wastewater is suitable for many processes. The firm has as strong incentive to use the wastewater, rather than pay for additional water input (purchased from a public system or withdrawn, treated, and pumped from a private supply).

Adoption of recycling and improved wastewater treatment facilities can be directly promoted, using tax policy to create economic incentives. This can be done by liberalizing deductions: the firm may be permitted to depreciate the capital cost of recycling or treatment facilities over a very short period. It can also be accomplished through tax credits: on proof of investment in the proper facilities, the firm is allowed to reduce its taxes by an amount set by the government. In both cases, the result is an increased incentive to invest in, and use, water saving processes and practices.

2. High use surcharges

Firms can also be encouraged to reduce water use by levying a surcharge on all water used in excess of some chosen base amount. If the base amount is set equal to the water requirements of the industrial process, provided all water saving processes and methods are in use, then the firm will pay a penalty only if it fails to adopt all possible water-saving practices. The level of the surcharge determines the amount of water savings to be expected, as the firm make investments in order to avoid paying the extra charge.

3. Penalties and fines for polluting industries

As noted above, any fines or penalties levied on industrial discharges of water-borne pollutants create an incentive to reduce water use. If penalties apply to the volume of wastewater discharge, then the firm will be motivated to increase recycle ratio, thereby reducing the final volume. If the quantity of pollutants is the issue, penalties will promote the construction of improved wastewater treatment works. These new facilities will produce higher quality effluent which will, in turn, be more attractive for internal recycling, rather than discharge.

modified to isolate all costs associated with water supply, and then to categorize those costs by function (as described above). This change will begin the development of an improved financial data base, suitable for later use in demand management evaluation.

(d) Customer metering. Ultimately, effective management requires that each customer be provided with a properly maintained meter. Several criteria can be used to determine the sequence of installing (or rehabilitating) customer meters. Considerations of revenue enhancement and political acceptability may dictate installation according to decreasing customer size. Industrial and large commercial customers would be metered first, followed by other commercial, institutional, and large residential customers. Small users and low-income areas would be metered last. On the other hand, development of a data base suitable for demand management planning requires that at least some meters be installed within all customer groups, so that sectoral water demand can be estimated. A compromise strategy would install a broad, cross-sectional sample of meters first, then proceed to complete metering in the sequence noted above. All meters would be read, but none would be used for billing until that customer class was fully metered.

(e) Billing and collection. As customer metering progresses, attention must be given to the billing and collection system. As described above, bill must be rendered accurately and promptly and payment must be enforced. Specific procedures and policies are needed to insure these results.

V. IMPLEMENTATION AND ADMINISTRATION OF THE POLICY

A. Allocating public expenditure

In developing a demand management policy, a water agency must choose among numerous legislative, regulatory, technological, and behavioral measures, each with a unique set of advantages and disadvantages. A properly designed demand management program can make a major contribution to the efficiency with which water is supplied, or to any of several other objectives, while imposing but minor cost or inconvenience. A badly conceived program, on the other hand, may be both ineffective and burdensome.

Procedures for the systematic analysis of potential demand management measures have been proposed in the context of long-term water conservation (Baumann, *et al.*, 1980) and drought management (Dziegielewski, *et al.*, 1983). The analysis described in these sources can be divided into three phases: preliminary screening, measure-specific analysis, and plan development.

Preliminary screening is intended to narrow the list of all possible demand management measures to those which are likely to be of use in a particular situation. Each potential measure is described and a preliminary assessment made of its applicability, technical feasibility, and political and social acceptability. If a measure is not applicable (e.g., it addresses a water use that is not present in the community), or if it is not feasible (it is unlikely to function as desired under local conditions), then it can be omitted from further consideration. Similarly, the presence of significant barriers to implementation by reason of political policy or public perception disqualifies the measure. Restraint should be exercised here: in some cases, dissemination of information about a demand management measure can remove apparent barriers.

Measure-specific analysis considers individual demand management actions, determining the impacts expected if each were implemented alone. An implementation plan is developed, including time schedules and estimates of the coverage (the fraction of target water users who will adopt or be affected by the measure) and costs of implementation. Determinations are made of the fractional change in affected water use. These data, combined with an estimate of total water use in the affected sector, lead to an estimate of the effectiveness of the measure (the amount by which water use will decrease or increase if the measure is implemented as planned).

Next, other advantageous and disadvantageous effects are identified and estimated. These include the degree to which the proposed measure will promote other objectives, such as reallocation of water among sectors, improvement of water quality, resource conservation, promotion of sustainable development. Disadvantageous effects include implementation cost and any related movement away from stated objectives. Also, some measures may create inconvenience or other costs for water users.

After all potential measures have been screened and analyzed in this way, *plan formulation* begins. In this step, measures are combined in various ways, based on knowledge of their measure-specific characteristics, to achieve the objectives of the demand management plan. As they are combined, attention is given to possible interactions: water use reductions resulting from two measures implemented together may be less or more than the sum of reductions for the measures implemented alone. Interactions may occur for other characteristics, such as implementation cost.

Once the water use impact of the complete plan is known, data on incremental supply cost can be used to determine the economic benefit associated with the demand management plan. For water use reductions, this may include short run cost savings associated with reduced use levels, as well as long run savings from deferred or avoided capital outlays. The impact of the plan on other objectives can be determined at this stage, as well as the cost and other disadvantageous effects of implementation.

When followed carefully, this procedure can identify and discard plans which fail to achieve all objectives, or which achieve the objectives at unnecessarily high cost. The development of alternative plans facilitates trade-offs among objectives. For example, alternative plans which meet the same cost reduction goal may imply different allocations of water use among geographical areas, or different impacts on specific user sectors. Also, the implied cost of a particular objective can be determined by comparing the net costs of alternative plans which either satisfy or omit that objective, but are otherwise similar.

B. Ensuring pre-requisite conditions exist

The ability to predict the impacts of alternative demand management plans, and to successfully implement the selected plan, depends on a number of factors. Among these are the existence of reasonably accurate information on current and anticipated future patterns of water use, and a firm commitment to the goals of the policy. The existence of water use data, in turn, depends on the existence of meters, and the way in which the metering program is administered. Water users will react to the incentives provided by tariffs only if they expect to pay for the water used.

1. Metering and administrative follow-up

Since demand management measures generally apply to specific classes or types of water use, estimates of effectiveness require knowledge of expected water use for the affected class or group. The availability of such information requires that water users be at least partially metered. (In the absence of universal metering, it is possible but much less desirable to estimate use from metered samples.)

Administrative procedures should provide for follow-up and action in the case of missing or suspiciously low meter readings. Meter readers should be supervised and rotated through different assignments, to minimize the possibility of unauthorized estimated readings. Where estimated readings are necessary, they should be clearly marked in the data base. Unless individual problems with malfunctioning meters or missing readings are addressed promptly, they will quickly proliferate until the usefulness of the entire data base is in question.

2. Enforcement of sanctions

A water agency should have a clear understanding of available sanctions for non-payment of water bills. In most cases, sanctions include the right to terminate service to a non-paying customer. This authority must not be used arbitrarily or inconsistently, or it will quickly become difficult to apply any sanction. A standard procedure should be adopted, incorporating follow-up requests for payment, warnings, then termination, with set time periods between the steps. Some flexibility can be provided in cases of genuine economic hardship. The policy should be administered consistently, regardless of the economic or social status of the customer. Once this principle is established, experience indicates that actual disconnections for non-payment are rare.

3. Consistent public policy

The analysis described above assumes that water users, confronted with demand management initiatives, will react in certain predictable ways so as to maximize their well-being under the new restrictions. This is a reasonable expectation where customers believe that the policies have been adopted for a purpose, and where they expect the policies to be maintained and enforced. In the absence of these assumptions, the effectiveness of proposed measures is greatly reduced, and may be impossible to estimate.

An important component of any demand management plan, then, must be a long term commitment on the part of political leadership and water sector management to pursue a consistent policy with respect to water management. Short term experiments without commitment impose costs, but produce few or no benefits.

C. Record-keeping, billing, and collection systems

1. Importance of adequate water use and financial records

As noted above, effective analysis and implement of demand management plans depends on the existence of water use data. However, metering alone does not provide the needed information. Meters must be maintained in working order, so that the number of slow or stopped meters is minimized. Meters must be read regularly and accurately, so that the recorded data can be relied upon. It is important that actual reading dates be recorded along with the register data, so that water use can normalized across irregular billing periods. All data should be recorded and preserved in a form (e.g., in computer files) that facilitates statistical analysis.

Water agencies should also maintain financial records in a way that permits identification of potential or actual cost savings attributable to demand management. In most cases, this can be accomplished by observing two rules:

(a) All water supply costs and only water supply costs should be recorded. Records should omit costs associated with non-water supply functions or with services performed for other public agencies. They should include the cost of services performed on behalf of the water agency by other governmental units.

(b) All recorded costs should be assigned according to function. Labor, material, and capital costs associated with water sources should be separate from those associated with treatment, or pumping, or distribution system maintenance, etc. Remaining costs, not clearly related to any specific function, should be recorded as administrative and general costs.

When financial records are kept in this way, it is possible to estimate the incremental cost of changes in the level and pattern of water use, and thus to evaluate and compare alternative demand management plans.

2. Need for effective billing and collection practices

An effective meter-reading program should be matched by an equally effective billing and collection process. Water bills should be rendered promptly after meters are read, and payment must be enforced. Where bills arrive months after the billing period has ended, or where sanctions for non-payment are vague or non-existent, the economic incentives provided by the tariff are weakened or nullified. Thus, the effectiveness of a whole class of demand management measures may be lost due to problems with a single administrative function.

As noted above, appropriate sanctions for non-payment are an important part of billing and collection programs. Where no adequate sanctions are available, legislative action may be required. Otherwise, the water agency should make effective and consistent use of the authority that it has.

3. A strategy for incremental improvement

Urban water agencies, particularly in developing countries, often lack many or all of the programs and policies described here as prerequisite to demand management. Yet these same agencies are among those with the greatest need for effective programs. The very fiscal and operational constraints which create that need now block the development of improved metering and record-keeping needed to implement a solution.

Clearly, everything cannot be done at once. Agencies which find themselves in this dilemma must develop a strategy for incremental improvement, first making the changes which produce the largest net benefit, then proceeding to the next step, etc. One possible strategy is outlined below:

(a) Source metering. Insure that all sources (treatment plants, well, etc.) are provided with operational and reasonably accurate meters, and that meter readings are recorded on a regular (e.g., daily) basis. Knowledge of the amount of water entering the system is prerequisite to any development or evaluation of demand management schemes, and may be useful in identifying opportunities for leak reduction.

(b) District metering. Where feasible, meters should be provided for discrete geographical areas within the service area. This is most often accomplished by installing meters at distribution pumping stations. Data from these meters can be used to provide early estimates of sectoral water use (where the area served by the meter is largely residential, industrial, etc.), and to further improve identification of opportunities for leak reduction.

(c) Improved financial records. Financial records and reporting can be

VI. CONCLUSIONS

A. The advantages of effective demand management

In the past, water management has consisted largely of those supply management activities required to locate, develop, and exploit new sources of water in a cost-effective way. This report describes the practice demand management, a set of tools intended to promote more desirable levels and patterns of water use.

While competent supply management is no less important than it has been in the past, a number of trends and conditions argue for increased management of demand. These include the rapid increases in water use observed in many parts of the world, continuing deterioration of available water supplies, increasing costs for new sources, actual and threatened water shortages, limitations on funds available to the water sector, and environmental impacts of new supply development.

Demand management is not a single tool or method, but a collection of techniques, each designed to deal with a particular aspect of water management. One unifying purpose which links all of these tools is the intention to produce water more efficiently: a given level of service must be rendered at the smallest overall cost. In addition, some specific objectives can be cited. These include improved allocation of water among competing uses and areas, better control of water revenues, postponement of new construction, drought management, reduction in unnecessary use, conservation of the resource, water quality control, and sustainable development.

There is, therefore, no single objective for demand management. Instead, there are a number of different and potentially conflicting objectives, each of which has a claim for the attention of the water manager. Evaluation and ranking of alternative solutions, therefore, must be based on a number of criteria. These include objective factors, such as impact on economic indicators, on patterns and rates of growth of population, coverage of service offered, reduction of new supply costs, and impacts on water quality problems. Demand management measures are also evaluated in terms of public policy, user demand, and environmental requirements.

Further issues arise where water sector plans must be developed against a background of national economic and social goals, combined with a need for sustainable development incorporating full consideration of resource conservation. Specific attention must be paid to each sector of water use, including *in situ* uses within streams and return flow impacts. Demand management figures prominently in this assessment, due to the importance of future use levels in each sector.

B. Technical tools

The way in which water is used can be directly affected through changes in technology, operation, or voluntary behavior. In the past, changes of this kind have been sought in order to reduce water use. Some of the tools discussed--e.g., the set of behavioral measures--can be used to increase or decrease water use, as needed.

Reduction in water losses is an important part of any demand management plan. This can be accomplished by leak detection and repair programs, identification of illegal connections, and reduction in system pressure Improved system operation and maintenance practices also contribute to the effectiveness of demand management, in part by increasing system reliability. Where applicable, dual distribution systems can be used to distribute sub-potable water to certain uses (such as park irrigation and industrial use), thus reducing the demand on the potable water system.

A wide range of low water use devices and technology is available, numbering in the hundreds of individual fixtures and devices. These include flow restrictors of various kinds, low water use water closets, water-saving appliances, and devices for lawn and garden irrigation. The effectiveness of these devices varies widely, depending on the size of the water use category affected, and the conventional design of plumbing fixtures in the affected country. U.S. experience indicates the possibility of large reductions in domestic water use for some applications.

Rather than mandating or promoting the adoption of some water saving device, it is possible to motivate water users to adopt new water use habits. Contact can be made through a number of media, and the message generally consists of motivation plus information as to how to modify water use. Water use can also be modified through mandatory restrictions, such as land use restrictions, water allotments, and certain prohibited uses.

The design and implementation of a demand management program requires knowledge of current levels and patterns of water use. This means, at a minimum, that all customers should be metered, and that meters should be read regularly and receive adequate maintenance. Water sources should be metered, as should relatively homogeneous sectors of large systems. Only in this way can the potential for and effectiveness of demand management measures be fully understood.

C. The role of tariff policy

Public water systems customarily levy charges on those who receive water service. These charges, as expressed in the tariff, were originally meant only to raise revenue for the operation of the water agency. Revenue generation remains an important function of tariff policy, which determines not only who pays the costs of operating the water system, but when those costs appear after they are first incurred. Additional purposes of tariffs are now widely accepted.

Because, in metered systems, water use responds to the level and structure of prices, tariff design is a factor in determining the level and pattern of water use. Tariff design is, therefore, a demand management measure. Other criteria for setting tariffs include economic efficiency, income transfers, fairness, acceptability, net revenue stability, and revenue conservation. When resource conservation is defined as "any beneficial reduction in water use or water losses" it leads to consideration of the marginal cost pricing rule as implied by the economic efficiency goal.

Various tariff designs can be considered, including uniform rates, decreasing block tariffs, increasing block tariffs, and increasing rate tariffs. Seasonal and spatial differentiation may be added, including the use of seasonal surcharges. Further possibilities include the use of contingent features, such as drought surcharges, triggered by some external event.

Most tariffs are based on some measure of cost. Total costs, as modified by planned subsidies or surpluses, usually form the basis of the total revenue requirement. Embedded cost studies, often including allocation among customer classes, support one type of tariff design. Another approach bases tariffs on marginal costs, which reflect the incremental cost of water in the immediate future.

A uniform, two-part tariff provides the same incentive to use more or less water to each customer; it also promotes net revenue stability, equity, and fairness while minimizing unwanted transfers of income. When the uniform commodity charge is derived from marginal cost, the uniform rate also promotes economic efficiency and resource conservation. The addition of a seasonal factor generally improves the characteristics of this type of rate.

Block-type tariffs create dissimilar incentives for water use, and generate transfers of income among groups of customers. These rates are also incompatible with marginal cost pricing principles, since price differentials are not based on cost differences. Block type rates do permit some degree of tailoring of prices to groups of customers, but the groups are not well segregated in the usual block design. Uniform rates, differentiated by class of customer, are more effective in this regard.

D. Other economic tools

Water use also responds to economic incentives which can be implemented outside of the structure of a tariff. These incentives can be narrowly focused, or more flexible that tariff provisions. In other cases, they may be more broadly applicable.

In the case of domestic demand, it is possible to provide incentive payments for certain kinds of water use modification, provided that modifications are both continuing and verifiable. For example, payments might be made to water users who commit themselves to voluntary quotas, who permit installation of a flow restrictor, or who make certain permanent changes in lawn and garden landscape design. Another domestic water use strategy is to provide discounts for the purchase of low water-use appliances.

Agricultural water use can be addressed in various ways, including penalties for water use in excess of a stated amount, subsidies for the purchase of low water-using irrigation equipment, and various incentives promoting the use of lower-quality water, low water-using crops, or improved cropping patterns.

Industrial water users can be encouraged to contribute to water management goals by means of tax rebates on certain recycling and waste treatment equipment, high use surcharges, and penalties for discharging pollutants.

E. Recommendations

In developing a demand management policy, a water agency must choose among numerous legislative, regulatory, technological, and behavioral measures, each with a unique set of advantages and disadvantages. A properly designed demand management program can make a major contribution to the efficiency with which water is supplied, or to any of several other objectives, while imposing but minor cost or inconvenience. A badly conceived program, on the other hand, may be both ineffective and burdensome.

Procedures are available for systematic consideration of demand management measures, and for integration of those measures into demand management plans. When followed carefully, these methods can identify and discard plans which fail to achieve all objectives, or which achieve the objectives at unnecessarily high cost. The development of alternative plans allows consideration of trade-offs among objectives or among different allocations of impacts across geographical areas or user classes.

The ability to predict the impacts of alternative demand management plans, and to successfully implement the selected plan, depends on a number of factors. Among these are the existence of reasonably accurate information on current and anticipated future patterns of water use, and a firm commitment to the goals of the policy. The existence of water use data, in turn, depends on the existence of meters, and the way in which the metering program is administered. Meters must be maintained in working order, and meter reading procedures must ensure reasonable accuracy. Sanctions for non-payment must be consistently and fairly enforced. Water users will react to the incentives provided by tariffs only if they expect to pay for the water used.

Another important component of any demand management plan is a long term commitment on the part of political leadership and water sector management to pursue a consistent policy with respect to water management. Short term experiments without commitment impose costs, but produce few or no benefits.

Planning and evaluation of demand management measures often requires incremental supply cost data. Financial records can be upgraded to support the development of these data by insuring that all water supply costs and only water supply costs are recorded and that all costs are identified according to function.

Urban water agencies, particularly in developing countries, often lack many or all of the programs and policies described here as prerequisite to demand management. Yet these same agencies are among those with the greatest need for effective programs. The very fiscal and operational constraints which create that need now block the development of improved metering and record-keeping needed to implement a solution.

Clearly, everything cannot be done at once. Agencies which find themselves in this dilemma must develop a strategy for incremental improvement, first making the changes which produce the largest net benefit, then proceeding to the next step, etc. Properly conceived, such a policy can produce steady and largely self-financed improvement in water management.

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