8

Economic Principles for Water Conservation Tariffs and Incentives

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1. Introduction

Water conservation creates no water. It manages water and water scarcity. Water conservation shifts water and water scarcity across people, their water uses, space and time. Water is scarce when it is insufficient to satisfy all the valued uses that different people have for water. Valued uses include water for drinking, cleaning, industry, transporting waste, recreation, and sustaining environmental goods such as habitat, ecosystem and aesthetic services.

Water scarcity is most obvious in droughts (Kallis, 2008), but scarcity is routine even where water appears physically abundant. Water is scarce in Chicago, Illinois, even though it lies adjacent to a lake containing more than 1,180 cubic miles of water (Ipi & Bhagwat, 2002). Conflicts between people who want water for *in-situ* uses such water for recreation and ecological services and people who want water to withdraw water for people, agriculture and industry are common in both humid and arid environments (World Commission on Dams, 2000).

People manage water scarcity through any number of formal organizations and informal groupings. These organizations and groups are water management institutions. Legislation, law and regulation establish formal institutions. Formal institutions include municipal water agencies, water districts, corporations and local governments. Other institutions emerge informally out of customs, habits, histories and the politics of water problems. Informal institutions include urban water markets that arise in neighborhoods that are not served by a municipal network (Crane, 1994) and the patterns of priorities, rights and expectations that guide irrigation in traditional societies (Ostrom, 1990). Legislation and law often intervene to recognize, modify and transform informal institutions into formal ones (cf. Coman, 2011).

Different institutions have different effects on water conservation. Within one irrigation district, farmers may face 'use-it-or-lose-it' rules. Use-it-or-lose-it rules force farmers to use their water seasonal allocations in a given year or forfeit the unused portion (Spangler, 2004). In another district, rules may be set up so that farmers may leave unused allotments in a reservoir and stored for future use. The two irrigation districts may have the same consequences under normal conditions. When a prolonged drought occurs, farmers in the first district may watch their crops shrivel from water scarcity, while farmers in the second district draw on their banked water and enjoy a normal crop year.

Rules, fees, restrictions and institutional policies make some actions beneficial and others relatively costly. The relative benefits and costs of different actions are economic incentives.

Incentives encourage some behaviors and discourage others. Incentives may shape behavior in ways that are consistent with objectives but they can also lead to behavior that is entirely unexpected.

Municipal water systems use tariffs to collect the revenue necessary to sustain and expand a water system but some tariff choices inadvertently create incentives that weaken financial sustainability. For instance, municipal water systems often adopt water tariffs that supply a subsistence quantity of water for a payment that is less than the cost of provision. When small users predominate, provision below cost eventually makes service financially infeasible. Reliable service areas then shrink to service only higher income neighbors and the poor are left to purchase water at many times the highest fees charged by the water agency (Rogerson, 1996; Komives et al., 2005; Saleth & Dinar, 2001).

Conservation is effective when incentives are consistent with conservation goals. Economic analysis of incentives is part of integrated water management (Snellen & Schrevel, 2004). Economic principles help identify the relative values of water in different uses and set up processes to balance water uses in ways that are consistent with its scarcity value and conservation goals. Analysis of benefits and costs is an inherent part of sustainable investments. The water resource investments required to satisfy the thirsts of cities and towns or irrigate agriculture cannot be sustained without the careful financial management of benefits, costs, revenues and expenditures.

The objectives of this chapter are to identify the economic principles central to water resource management and to examine how these principles are used in the process of designing water conservation tariffs and incentives. Tariffs are the pricing mechanisms used by municipal water agencies to raise revenues from water use. The analysis examines how tariffs may be structured, set and implemented to provide incentives for efficient water conservation.

The primary economic principles are opportunity cost, demand, deadweight loss, trade, and third-party effects. Opportunity costs are the building blocks of economic cost and valuation. Opportunity cost is not a physical or accounting concept. Opportunity cost is a relative value concept based upon the value of a resource in its next best use. It is the value forgone by using a resource in a particular way rather than in its next most valuable use. Opportunity cost may be higher or lower than the value of a resource in its current use. When the opportunity cost of water is higher than its value in a current use, water is wasted.

User demands are the sources of water value and deadweight loss is a measure of value lost in the misallocation and waste of water. Demand is a relationship between a user's willingness to pay for an additional unit of water and the quantity of water available to that user. Demand value is a marginal or incremental concept; it measures the amount a user is willing to pay for the last unit of water consumed or used. For example, a thirsty person finds the first few sips of water highly valuable, but as a person's thirst is satisfied, additional swallows are successively less valuable. Deadweight loss combines demand values and opportunity cost to define an economic index of water waste.

Trade is a response of economic agents, people and firms, to a wasteful allocation of water. Water is wasted when water remains in low value uses while high valued uses go without. Economic agents find ways to trade and move water to higher valued uses when it physically possible and when they are empowered by law and custom to take ownership of the value of water. Trade requires physical infrastructure and the ownership and entitlement rules that support trade. Lack of infrastructure and mismatched rules and institutions are barriers to trade, standing in the way of an efficient allocation of water.

Third-party effects occur when upstream or downstream water users are not taken into account in water-use decisions. Water flows and water qualities connect different users in complicated and sometimes unforeseen ways. An upstream use of water may affect the quantity or quality of water available to downstream users. Water withdrawals by municipalities may reduce instream flows for recreation and ecological services. These unintended and unaccounted impacts are third-party effects.

The analysis is developed in the following way. The five primary economic principles are first defined and discussed. The subsequent section applies the economic principles to the design of efficient water conservation tariffs and to the evaluation of inefficient tariffs. The next section evaluates the tariff structures and tariff levels that are in use by municipalities around the world. The analysis indicates that very much remains to be done. Municipal systems contain large reservoirs of wasted water, reservoirs waiting to be tapped by efficient water conservation policies. The analysis concludes with three strategies to implement efficient water conservation incentives in residential water systems.

2. Five economic principles in water conservation

Water is a scarce resource. Economic scarcity means that there is not enough water available to meet all the wants and needs that people have for water. Economic scarcity is defined in reference to people's needs and wants rather than to physical availability. Needs and wants are defined broadly, to include the environmental and ecological services that make life possible and, so often, enjoyable. With all scarce goods, some wants and needs are unmet.

Scarcity makes water valuable. The values that people place on water make water worthy of considerable attention. When water is well-managed, water values enable the large investments necessary to ensure that essential values are protected and less essential values are supported with suitable quantities of water. When water is poorly managed, critical values are ignored and water is wasted in uses with little or no value.

Economic principles play a role in understanding and measuring water values. These principles make it possible to develop and evaluate water conservation incentives. At times, analysis of water values and incentives is highly technical and nuanced. The economic principles developed below are the basic concepts used to evaluate economic incentives and the decisions they motivate.

2.1 Opportunity cost

Using scarce water always has a cost. The scarcity of water means that there is always some other way the water may be used—some next best use. The cost is the value of the water in its next best use. The value forgone in the next best use is the opportunity cost of water. Opportunity cost is the fundamental principle of economic cost.

Opportunity cost varies across time and space. Time is important since water uses vary in quality, type and value over time. The values of water in agriculture rise and fall as seasons and growing conditions change. In winter, agricultural water values may be close to zero. Irrigation values rise substantially during the growing season, and especially during a drought. Water for outdoor recreation may show similar seasonal patterns. Water values also vary across space. Inability to transfer water across space due to lack of infrastructure or to legal barriers causes water values to diverge spatially. Divergent values are an incentive for human action to move water from a low value location to a high value location.

Divergent water values can lead to epic-scale investments in political power, litigation and infrastructure (Libecap, 2007).

Opportunity cost varies also with the quantity of water considered. The first unit of water transferred to the next best use has the highest value. Subsequent units transferred to the next best use have successively lower values. Marginal opportunity cost is the value of transferring a particular unit of water from its current use to its next best use. Marginal opportunity cost tends to fall as successive units of water are transferred from the current use to the next best opportunity.

2.2 Demand

Water demand is a relationship between water quantities and the amount users are willing to pay per-unit of water. The law of demand says that the amount a user is willing to pay per-unit declines as the amounts purchased increase. This means that there is an inverse relationship between willingness to pay and the amount of water available for use.

Household water use illustrates the law of demand. A small amount of water is highly valuable since it satisfies basic needs such as thirst and personal hygiene. Additional water for cooking and cleaning also has a high value, but not quite as high as the first few units of water used for drinking and hygiene. Household water values decline much further for values associated with gardening and lawn irrigation. Too much water may have negative values for a household—a leaky pipe may flood a basement and too much irrigation may destroy a productive agricultural field.

Water demand is represented mathematically with quantity as a function of price. Water demand for the *i*th water user is a function $w_i = f(t, \alpha)$ where w_i is a quantity of water demanded at price or volumetric charge, t, $f(\cdot)$ is the demand function and α represents other factors beside the volumetric charge that shift quantity demanded. The law of demand means that quantity demanded declines as the volumetric charge increases, so $\frac{dw_i}{dt} = \frac{df}{dt} < 0$.

Demand shifters, α, include variables such as user income, user age, seasons, weather, capital investments such as housing and acreage, water-use technology, regulatory restrictions, and information campaigns encouraging water conservation (Worthington & Hoffman, 2008). Households with greater incomes may use more water due to using more water-using appliances, larger gardens and lawns, swimming pools and other such uses. Water demand may shift seasonally since irrigation of gardens and lawns is more valuable in dry seasons than in wet seasons. Other factors that shift demand may include house and yard size, installation of water-saving technology, and knowledge of water saving strategies. Such demand shifters are the focus of non-tariff approaches to water conservation.

Water demands are estimated for a wide range of users, uses and aggregates of users and uses. Demands relevant to water conservation include household demands, crop demands, farm demands, industry demands, instream use demands and aggregates thereof, such as urban, agricultural and industrial demands. A common element is each of the latter demands is the law of demand, the inverse relationship between value as measured by willingness to pay and water quantity.

The law of demand is central to water conservation tariffs and incentives. The law of demand indicates that as volumetric tariff charges increase, the quantity of water demanded declines. Users adjust their water use downward in response to a volumetric charge increase. Users reduce their water use until the value they place on the last unit of water used or consumed is equal to the volumetric charge.

The opposite behavior happens with a reduction in a volumetric charge. A reduction in a volumetric charge means that the value that a user places on water exceeds the volumetric charge and the user responds by increasing water use. Water use increases until the user's valuation of the last unit of water is once again equal to the volumetric charge.

The responsiveness of demand to changes in a volumetric charge is summarized with a number called 'elasticity'. Elasticities are numbers that describe the percentage change in water use resulting from a one percent change in the volumetric charge. Elasticities are negative due to the law of demand. Estimated elasticities for residential water use tend to lie in a range from -0.3 to -0.6 with some reports of -0.1 or less (Dalhuisen et al., 2003; Nauges & Whittington, 2010; Worthington & Hoffman, 2008). An elasticity -.4 implies that water use declines by 4% for a 10% increase in a volumetric charge and by 40% for a 100% increase in a volumetric charge.

Elasticities are also estimated for demand shifters, α, and especially for the income levels of residential users. Income elasticities are useful in understanding how water use is likely to change with growth in incomes and with changes in the mix of income groups within service areas. An income elasticity of .4 means that annual growth in income of 4% is likely to increase water use by 1.2%. If such income growth continues over a decade, incomes rise by 34% and water use by 13.6%.

There are two important ranges of demand elasticities. Demand response is *inelastic* when a one-percent change in a volumetric charge or a shifter results in less than a one-percent change in water use. Demand response is *elastic* when a one percent change in price or a shifter results in a greater than one-percent change in water use. Residential water demands tend to be inelastic with respect to both volumetric charge and income (Dalhuisen et al., 2003).

2.3 Deadweight Loss

Deadweight loss is an economic measure of waste. Water is wasted when its value in a current use is less than its opportunity cost. Deadweight loss is the difference between current use value and opportunity cost when opportunity cost exceeds current use value.

Figure 1 illustrates deadweight loss with a simple case where a fixed amount of water is allocated between two users, person A and person B. The length of the horizontal axis represents the total amount of water available for use, 100 units. Water can be allocated to either A or B. Water allocated to A, Q_A, leaves 100 units minus Q_A, for B's use so $Q_B = 100 - Q_A$. At the left-hand corner of the diagram, A gets zero units of water and B gets 100 units. Moving from left to right along the axis, A gets more water and B gets less until A receives 100% of the water and B gets 0% at the right-hand corner of the figure.

A's demand curve is D_A. D_A slopes downward from left to right since A's value of the last unit of water consumed declines as A uses more and more water. Conversely, B's demand curve slopes upward from left to right as B gets less and less water. B's valuation of the last unit of water increases as B gets less and less water.

Water is wasted when its value in a current use is less than its opportunity cost. This means that water is wasted when A gets all the water since A's demand curve—the values that A places on successive units of water--lies below B's demand curve when A's allocation exceeds 55 units. The triangular area between the two demand curves from 55 to 100 units of water is the value forgone by giving A all the water. The triangle area is the deadweight loss of the allocation.

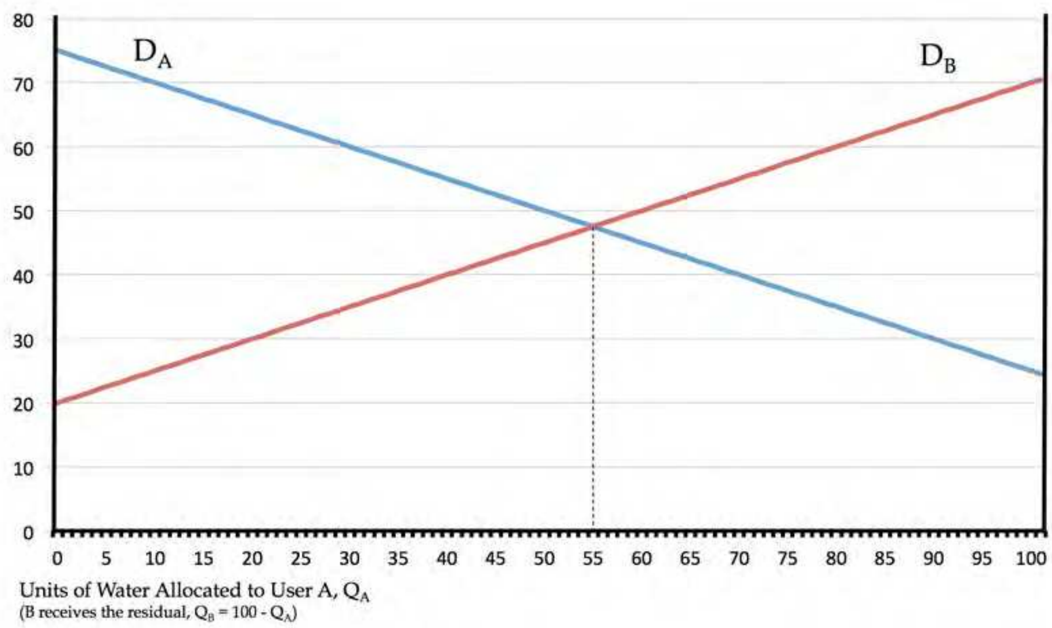

Fig. 1. Water Demand, Opportunity Cost and Allocation

Deadweight loss is the potential benefit of reducing A's use so that B can use more. For instance, by reallocating 45 units to B, the entire deadweight loss triangle from A's overuse is eliminated. When A uses 55 units and B uses 45 units, the demand values for the last unit of water used by each party are equal. Once the demand values are equal, there is no additional gain to letting B use more water. Letting B use more water than 45 units moves into the region where B's demand values are lower than A's.

Deadweight loss, wasted water, and inefficiency also result from allocating all water to B's use. At the lower left-hand corner of the the Figure 1, A gets no water and A's demand value exceeds B's demand value. Moreover, A's demand values exceed B's for all units of water up to A's use of 55 units and B's use of 45 = 100 – 55 units. When A uses 55 units and B uses 45 units demand values for the last unit of use are again equal. The deadweight loss of B using all the water is the triangular area between the demand curves from 0 to 55 units. Having A use more than 55 units would move the allocation into a region of deadweight loss, where B's values for water exceed A's values.

There is no wasted water when there is no way to reallocate water use and improve the values associated with the allocation. Economic waste of water is zero only where the demand values are equal. In Figure 1, demand values are equal where A uses 55 units and B uses 45 units. At the latter allocation, zero water is wasted since current use exceeds opportunity cost and there is no deadweight loss.

Economics defines zero economic waste as an *efficient* allocation. An allocation that is not efficient is *inefficient*. An inefficient allocation wastes water and results in a non-zero deadweight loss.

Water conservation seeks to reduce waste and improve the efficiency of water use. A reduction in wasted water creates benefits by reducing deadweight loss and improving economic efficiency. A situation is fully efficient when opportunity cost is less than or equal to the current use value for all water uses. Full efficiency with zero waste and zero deadweight loss is unlikely in practice, but research shows that there are many practicable ways to reduce waste and improve efficiency.

2.4 Water trading

Water waste and inefficiency create a powerful economic incentive to reallocate and conserve water. For all the inefficient and wasteful allocations in Figure 1, the value of the last unit of water used is less than the value of an additional unit of water in the forgone use. For instance, when an allocation favors A with 100 units of water use, the value to B for a single unit of water exceeds the loss to A of giving up that single unit. A and B have an incentive to trade water for money or water. Trading isn't strictly in terms of water and money. Any good could stand in for money as long as it is valued and can be transferred to the ownership of the party that gives up a little water.

Starting from an allocation where A uses all the water, A and B can realize mutual gains if they voluntarily transfer a portion of A's water from A to B. If A is altruistic and gains value equivalent to B's value from merely knowing that B has water, A can simply give B some water. A second possibility is for B to compensate A by paying A for the loss of water. A and B can trade water for an amount of money somewhere between B's high value and A's low value. Trading at an intermediate value creates mutual benefits for both A and B. A trade of one unit of water from A to B eliminates the deadweight loss incurred through A's low valued use of that unit of water.

A and B have an incentive to continue trading water as long as there is a deadweight loss and a potential mutual benefit. By voluntarily continuing to trade, A and B eventually arrive at the efficient allocation of water shown in Figure 1 where A uses 55 units and B uses 45 units. A and B have the same incentives to trade when they begin with B using 100 units of water. In each case they trade to the efficient allocation where the demand values are equal, A uses 55 units, and B uses 45 units. Voluntary trading away from the efficient use allocation is not possible since once at the efficient allocation, opportunity cost is less than a user's demand value.

Reduction in water waste through voluntary trading is often difficult to achieve. In many situations, water customs, water rights law and lack of physical infrastructure make trade impractical or impossible (Slaughter, 2009). Trade in water requires a form of ownership consistent with trading. A buyer expects a transfer of a legal right to hold and use the water. Defining and implementing tradable ownership rights is often a slow and difficult process (Allan, 2003).

Trade in water also requires a water resource infrastructure. Water is physically heavy and difficult to transfer from one place and time to another. Water transfers require physical transport and storage facilities. These facilities become more complicated and costly with the complexity and scale of spatial and temporal transfers.

Water trading also requires an institutional infrastructure to identify water resources, to account for their location in space and time, and to define and enforce rules and procedures. A crucial economic feature of such trading rules and procedures is the degree that they distribute or consolidate resource ownership. Mistaken efforts in 'privatization' consolidate water treatment and distribution systems in a single owner. Single owners are all too likely to exploit their position as monopolists by restricting water access, raising water prices and increasing inefficiency and waste.

The cost and difficulty of developing efficient water trading infrastructure limits the practicability of water trading in many situations. Trade seems most feasible in dry regions around the world where water is particularly scarce, the opportunity cost of waste is high and the costs of physical transfer are relatively low (Grafton et al., 2010; Ruml, 2005).

2.5 Third-party effects

Water use and conservation involves decisions about how, when and where water is used. Third-party effects arise when such decision directly affect water availability to services and people that are not directly involved in a decision. Third-party effects are also denoted as externalities and spillovers and are relatively common in water management (Slaughter, 2009)

Water withdrawals from a water body potentially affect other water users. Water withdrawn from a reservoir for municipal use and irrigation may have negative impacts on boating, fishing and valued ecosystems. If so, these are negative third-party effects on boaters, fishers and those who value the ecosystem services. Negative third-party effects can also arise from irrigation drainage, from the toxins and pathogens in municipal and industrial wastewater, and from ground and surface water depleted by overuse.

Third-party effects may also be positive and beneficial. Construction of a reservoir funded by irrigators and municipal users may have positive third-party effects on boaters, fishers and ecosystem services. Treatment of urban wastewater may result in a recyclable product for irrigation and industrial cooling.

3. Efficient water conservation tariffs

Municipal water tariffs are the rates, charges and fees that municipal water systems charge users for water provided. Municipal tariffs are different from the prices that emerge from large markets. Market prices are typically the result of many buyers and sellers negotiating trades over time. Municipal water tariffs are usually set in an administrative and political setting. Administrative tariffs may be highly durable and may reflect political pressures more than the opportunity costs of the resources, including water, that are used in water treatment and distribution. Water is wasted and financial sustainability is threatened when tariff revenues do not cover costs.

Municipal water tariffs support water conservation to the extent that they encourage efficient water use and discourage waste. At the same time, efficient tariffs do not encourage overinvestment in water conservation and hoarding. Water conserving tariffs are just high enough to recover the economic costs of water provision, including the opportunity cost of water withdrawn from other uses and wastewater returned from the water system to the hydrological cycle.

3.1 Efficient water tariffs

Efficient water conservation tariffs have three attributes. First, they are simple enough that they can be accurately communicated to and understood by water users. Water users may not know how much they are charged for water use and only a subset of those who do know can work through the details of how reduced water use may save them money (Whitcomb, 2005). Rates can be complex and confusing even for an informed user (Martins et al., 2007; Dziegielewski et al., 2004).

Water tariffs need to be simple enough so that users can see how they can save money by reduced water use, careful conservation and investment in water saving technology. Gaudin (2006) finds that less than 20% of water utilities inform water users of the tariff schedule in water bills. When tariff details are clearly communicated and explained, water use falls by an average of 30% (Gaudin, 2006).

Second, water conservation tariffs provide the revenue necessary to cover the economic costs of water provision. This means, in part, that water conservation prices bring in enough revenue to pay the full financial costs of water provision, including the capital, maintenance, operating and administrative costs.

The financial opportunity costs of municipal water provision may be broken down into two components. The first is a fixed cost component, ϕ, that equals the financial costs of establishing a water and wastewater infrastructure of a given capacity. Fixed cost includes the capital investments costs of reservoirs, diversions, pipelines and treatment plants. The scale of the latter investments tends to be relatively fixed by their design capacity and varies relatively little with water volumes within the design capacities. Fixed financial cost also includes other costs that remain fixed within broad volume intervals. The latter include the overhead cost of an administration, accounting, and billing insofar as these do not vary with volumes processed. Fixed cost may be adjusted to account for new capital investments (Griffin, 2001).

The second portion of financial opportunity cost varies with the volume of water and wastewater processed. Variable costs arise from the labor, equipment, chemicals and energy required to treat, distribute, and maintain service quality and reliability as larger volumes of water and wastewater are processed. The variable cost component is denoted, δw. Variable cost increases proportionately with total water use within the system, $w = \sum_{i=1}^{N} w_i$, where N is the number of water users, $i = 1, \ldots, N$. The factor of proportionality, δ, is the financial opportunity cost of providing an additional unit of water and wastewater services. It is the marginal financial opportunity cost of water.

The total financial cost, $f(w)$, is the sum of fixed and variable costs, $f(w) = \phi + \delta w$. Total financial opportunity cost is the market cost of capital and purchased inputs used in processing municipal water and wastewater services. They are 'financial' in a sense that they show up explicitly as expenditures in a municipal system's financial accounts. When a municipal system purchases water inputs and pays to eliminate wastewater impacts, the financial costs shows in the system's accounts. However, explicit payments for raw water and pollution impacts are often not made. In the latter case, raw water and wastewater incur an unpaid opportunity cost.

The third attribute of an efficient water conservation tariff is that it accounts the non-financial opportunity costs of raw water inputs and wastewater outputs. These non-financial costs may have a fixed component associated with the ecological and environmental services forgone due to investments such as reservoirs and pipelines. In an efficient tariff, these non-financial fixed costs are added into ϕ along with financial opportunity costs.

The greater share of opportunity cost is likely to vary with the quantity of water provided and wastewater returned to the hydrological system. Variable opportunity cost includes unpaid values of raw water when raw water would have otherwise been used in some other economic activity such as agriculture. Additional sources of potential opportunity costs are forgone instream uses, changes in ambient water quality due to wastewater effluents, and forgone future use when current use depletes future supplies. The latter opportunity cost arises in the case of reservoirs and groundwater reserves when increases in current use significantly increase future scarcity.

Opportunity costs that vary with the volume of water and wastewater are denoted λw. The factor of proportionality, λ, indicates how opportunity cost increases with an additional unit of water and wastewater services; it is the marginal opportunity cost of water and wastewater provision. The full economic cost, $e(w)$, of water and wastewater services is the sum of financial and non-financial opportunity costs, $e(w) = f(w) + \lambda w = \phi + \delta w + \lambda \mathrm{w}$. The economic cost has two components, a fixed cost, ϕ, and a variable cost, $\delta w + \lambda w = (\delta + \lambda)w$. Fixed and variable economic costs are sums of financial and non-financial opportunity cost. The sum is made explicit in the formulation because variable cost turns out to be central to water conservation incentives. The sum of the two variable cost parameters, $\delta + \lambda$, is the full economic cost of providing an additional unit of water within a municipal system of a given capacity; it is the marginal economic cost of providing processed water and wastewater.

A water conservation tariff is efficient in the sense that it encourages no wasted water. An efficient tariff communicates the full economic cost of water and wastewater services. Since economic costs have fixed and variable components, an efficient tariff reflects both components: the variable cost of water and wastewater services provided to a user and the user's share of fixed cost (Coase, 1946).

The first component of an efficient tariff is a volumetric charge. An efficient tariff levees a volumetric charge, τ, equal to the economic cost of an additional unit of water and wastewater services. The efficient volumetric charge per unit of water is $\tau = \delta + \lambda$. For the delivery of w_i, the ith user pays $\tau w_i = (\delta + \lambda)w_i$. By charging τ per-unit to each user, a municipal system recovers the full variable economic cost, $(\delta + \lambda)w$, of providing N users with water and wastewater services, $w = \sum_{i=1}^{N} w_i$.

Empirical analysis indicates that users respond to volumetric charges by reducing water use as the charge per unit increases (Nataraj & Hanemann, 2011). An efficient volumetric charge, $\tau = \delta + \lambda$, presents water users with the full incremental economic cost of their water use decisions. As the law of demand indicates, a user's own valuation of water is initially large for the first few units of water. When a user's own valuation is greater than the efficient per-unit charge, τ, the user increases water use.

As water use increases, demand values decline by the law of demand. Through error or neglect, use may increase to the point where the user's own valuation is less than τ. When this shows up in a billing cycle, the user finds it worthwhile to cut back on water use to the point where the demand value is equal to the per-unit charge. This is an efficient level of water use where the demand value is equal to the marginal opportunity cost of water. An efficient volumetric charge eliminates wasted water.

An efficient volumetric charge also gives users an incentive to find and install water-saving technologies. When a technology saves water at a per-unit cost less than τ, the user benefits by installing the technology. Volumetric charges different from τ leads users to make wasteful decisions. A volumetric charge less than τ results in too much water use and too little investment in water-saving technologies. A charge greater than τ makes the opposite error: too little water is used and too much is invested in uneconomic water-saving technology.

The second component of an efficient tariff is a fixed charge. The fixed tariff component recovers the portion of the economic fixed cost, δ that is not covered by volumetric revenue, τw. A portion of the latter revenue covers the variable financial cost, δw that is paid to acquire labor and other resources necessary for operating the system. The second portion of volumetric revenue is the opportunity cost, λw, of resources used but not paid in a financial transaction.

Opportunity cost revenue, λw, reduces the economic fixed cost that needs to be supported by additional revenue. The amount of the net fixed cost, $\eta = \delta - \lambda w$, is positive when $\delta > \lambda w$ and zero, negative when $\delta < \lambda w$ and zero when $\delta = \lambda w$ (Hall 2009). When the net fixed cost is positive, the system requires an additional fixed charge to cover the remaining cost. When net fixed cost is negative, the system receives revenues in excess of its financial costs and may return a fixed rebate to water users. When the net fixed cost is zero, there is no need for a fixed charge.

Economic principles allow considerable leeway in determining how net fixed costs are allocated across users, though two constraints apply. Let η_i be the fixed charge to the ith water user. The first constraint is that users' fixed charges add up to the total net fixed cost, $\eta = \sum_{i=1}^{N} \eta_i$, where η_i is the fixed charge paid or fixed charge rebate received by the ith water user. The second constraint is that the η_i is unrelated to the volume of water used. When η_i is correlated with w_i then the fixed payment alters the way a user views the volumetric charge. Rather than viewing the volumetric charge solely in terms of τ, the user views the volumetric charge as higher or lower consistent with the degree of correlation with η_i and whether η_i is a payment or a rebate.

The fixed charge allows municipalities to address fairness and equity without altering the water conservation properties of an efficient volumetric charge. Fixed charge schedules might address fairness and equity with a variety of measures that are correlated with equity considerations such as income, but not directly correlated with adjustments in water use. Baberan and Arbues (2009) suggest household size as a factor. Other possible measures include η_i differentiated by class of user such as industrial, commercial and residential; by zoning and land use categories; by interior areas of homes; or by neighborhood development vintage.

An efficient water conservation tariff is composed of a fixed and volumetric charge, $\eta_i + \tau w_i$. The fixed component provides the revenues required to (a) cover net fixed cost and (b) address fairness and equity. The volumetric charge, τ, is set to equal the marginal financial and non-financial opportunity costs of water and wastewater provision. The volumetric charge communicates efficient water conservation incentives to all water users.

3.2 Inefficient water tariffs

Municipal water systems adopt and maintain rate structures for a variety of reasons unrelated to water conservation. Common tariff structures include uniform volumetric rates without fixed charges, flat rates, decreasing block rates, increasing block rates and different combinations of volumetric, flat, decreasing block and increasing block rates. Except for combined flat and volumetric rates, each of these alternative tariffs have a *structure* that discourages efficient water conservation and encourages inefficiency and waste.

A *uniform rate* without a fixed charge is a charge per-unit of service received by a water user. A uniform rate is a volumetric charge since the total amount paid by a user is the product of the per-unit charge and the volume of water used. With positive fixed costs, a uniform rate set to cover the full economic costs of water and wastewater use is greater than the efficient volumetric charge. Such a rate is too high for efficient water conservation. An excessive uniform rate causes users to forego water uses that are beneficial and wastes time, money and resources in inefficient water saving. A uniform rate equal to an efficient volumetric charge presents users with efficient incentives for water conservation, but fails to cover net fixed costs. Ignoring positive net fixed costs makes the system financially unsustainable, an all too common problem in municipal systems (Banerjee et al., 2008; Hoehn and Krieger, 2000; Organization for Economic Cooperation and Development [OECD], 2009).

A *flat rate* is a fixed charge per connection without a volumetric charge. Flat rates may be set to cover the economic cost of municipal water and wastewater. In systems without user metering, a flat rate is the only feasible alternative (OECD, 2009). The water conservation flaw in flat rates is that they place no cost on an additional unit of water. The user's cost of an additional unit of water is zero, so water is treated accordingly. Users make decisions accordingly, using water as if it is free rather than scarce and valuable.

Flat rates result in significant water waste and large economic costs. Users not only use water inefficiently, they also find it financially unwise to prevent 'unintentional' waste. Leaky valves go unrepaired and outdoor irrigation is left unmonitored—wastewater merits no attention when more can be obtained without cost. Moreover, much of the wasted water flows through the sewer and wastewater system, unnecessarily increasing wastewater treatment costs and the third-party costs of pollution and pollution-caused disease.

A *decreasing block rate* is a set of volumetric charges that decrease in a staircase fashion as water use increases. Levels of water use are divided into intervals called blocks that are the lengths of the steps. The height of a step is the volumetric charge. The highest volumetric charge is at the top of the staircase and volumetric charges decrease with each step or block as water use increases. A water user using enough water to cover two blocks pays two different rates for water use; one for the first block of water use and a lower rate for the second block. A user whose water quantity covers three blocks pays three different rates for water. The latter user pays the highest rate for the first block, an intermediate rate for the second, and the lowest rate for the third.

A decreasing block rate can cover economic costs, but it is does not encourage efficient water use and conservation. At most, no more than one of the blocks can have a volumetric rate consistent with efficient water conservation. The other blocks encourage too little or too much conservation. Oddly, the decreasing block structure gives individuals using the least amount of water the largest incentives for water conservation. Those using the most water face the weakest incentive for cutting back.

An *increasing block rate* is a set of volumetric charges that increase in a staircase fashion. The lowest charge occurs at the first block and the largest charge occurs at the last block. Like the decreasing block rate, an increasing block rate covering economic or financial cost is unlikely to send efficient water conservation signals to any block. Users at the first block face too small an incentive for water conservation and those at the last block invest too much in water conservation.

Increasing blocks are often adopted based on claims of fairness and equity. The claim rests on the idea that the poorest and most disadvantaged groups are likely to use the least water, so the initial low rate lowers the cost sustained by these users (OECD, 2009). Research indicates that the fairness and equity claim is not valid. Poor and disadvantaged users fail to benefit, even in cities where fairness and equity appear most needed. Increasing rates tend to be regressive for two reasons. First, the initial block rate is paid by all users, rich, poor and middle-income, so there is no relative gain to the poor. Second, poorly financed municipal systems often exclude the poor from water service, so the benefit of low rates goes entirely to the middle-income class and rich (Komives et al., 2005). The poor are all too often left outside the municipal system where water costs can be 2 to 60 times greater than municipal rates (Saleth & Dinar 2001).

The final category includes a wide-range of tariff structures that combine uniform, flat, decreasing and increasing rates in different ways for different user types. Tariffs can also be adjusted by seasons of the year such as summer or during droughts. The essential problem with these combined structures is that, like their component parts, they fail to present users with simple, understandable and correct incentives for efficient water conservation. The result of such mixed signals is wasted water with all its costs of unnecessary water and wastewater treatment, foregone beneficial uses, and ecological damages.

4. Tariff incentives for residential water conservation

Residential water tariffs are well recognized as a water conservation tool (State of California, 2008; Beecher et al., 2005). This section examines whether existing tariffs encourage water conservation. The section begins with a brief comparison of experience with tariff and non-tariff approaches to water conservation. Tariff structures and volumetric charges used by water systems around the world are then reviewed to determine the extent that existing tariffs are efficient. Most tariffs appear too low to incorporate non-financial opportunity costs.

4.1 Non-tariff tools for water conservation

Water managers often favor non-tariff tools for water conservation. Non-tariff approaches include informational campaigns, technology rebates, voluntary restrictions and mandatory restrictions accompanied by legal penalties. Research indicates that most informational campaigns and voluntary restrictions are unreliable as conservation tools (Olmstead & Stavins, 2009), though some well-structured informational campaigns may reduce water use by up to 8% (Renwick & Green, 2000). Rebates on efficiency toilets show no effect on water use (Renwick & Green, 2000).

Mandatory restrictions enforced with strong penalties can be effective where penalties are strictly enforced and violators are made to pay. In Aurora, Colorado, restrictions with penalties reduced summer water use by up to 26% (Kenny et al., 2008). Renwick and Green (2000) study California water systems serving 8 million people and find that restrictions with penalties reduce water use by 19 to 29%. However, a portion of the public vocally resists restrictions and fines. Imperfect monitoring, uneven enforcement and criminalization of civil behavior—such as caring for one's property—can result in public controversy (Atwood et al., 2007). Also, restrictions may reduce a targeted behavior, but they do nothing to encourage waste reduction in unrestricted uses.

Water conservation tariffs may also generate public resistance. No one likes a cost increase. Worse yet, however, is going without water service as millions do when inadequate tariffs fail to cover even financial costs (Nauges & Whittington 2009) or when excessive water withdrawals threaten instream recreational and environmental resources (Hickey & Diaz 1999).

The structure of efficient conservation tariffs allows costs to be distributed in ways that increase the degree of public acceptance. First, an efficient volumetric rate is fair since it addresses the full economic cost of using an additional unit of water. With an efficient rate, no one gets away by not paying the incremental cost of water. Second, the fixed charge can be adjusted to address equity concerns across users and to avoid putting excess burdens on those unable to pay.

4.2 Water tariff structures used by municipal systems

Efficient water conservation tariffs have both an efficient structure and an efficient level. The efficient structure has two parts, a volumetric charge and a fixed charge. The analysis examines data on tariffs to determine the extent that water tariffs in use diverge from an efficient structure.

A 2010 water tariff survey by Global Water Intelligence [GWI] describes water tariff structures and levels for 276 water systems worldwide. Table 1 lists the number of survey responses by region and the percentage distribution of five tariffs. Responses from Asian water systems comprise about one-third of the sample. European systems provide an additional third of responses. The remaining third of responses were obtained from water systems in Africa, the Middle East and North Africa (MENA), North America and South America, with North American systems providing about 12% of the responses.

Region[a]	Water Systems (#)	Regional Rate Structure Distribution (%)[a]					
		Vol.	Flat	I Block	D Block	Efficient	No Data
All	276	23	3	50	2	20	2
Africa	18	0	0	94	0	6	0
Asia	94	41	3	50	0	5	0
Europe	87	22	1	24	1	48	3
MENA	19	5	0	89	0	5	0
N. America	32	6	9	44	16	22	3
S. America	26	8	0	88	0	0	4

[a]"MENA" is the Middle East and North Africa, "N." is North and "S. is South. "Vol." means a volumetric rate, "Flat" means a fixed charge, "I Block" means an increasing block structure, and "D Block" means a decreasing rate structure.

Table 1. Municipal Tariff Structures

The most common tariff structure is the increasing block structure reported by 50% of the systems. The increasing block structure gives water users divergent and inefficient signals for water conservation. Ninety-four percent of systems in Africa use increasing block structures and more than 88% use these structures in the MENA and South America. The high incidence in less developed regions is unfortunate both for efficiency and equity. Wasted water erodes already low incomes and increasing block tariffs have the most regressive consequences for the poor (Komives et al., 2005). Notably, the increasing block structure is much less common in Europe and North America.

Efficient tariffs structures with volumetric and fixed charges are used in 20% of the systems surveyed. Almost half of the systems surveyed in Europe use efficient tariff structures. The high European incidence of efficient tariffs may reflect recent reforms reported by industry organizations (Beecher et al., 2005). Twenty-two percent of North American systems use an efficient structure. Efficient tariffs are least common in South America, MENA, Asia and Africa.

Volumetric charges alone are common in Asia and Europe, with 41% of Asian systems reporting volumetric rates. Volumetric rates can offer efficient incentives for water conservation, but to do so, tariff revenues are not likely to equal financial costs. A tariff based on an efficient volumetric rate alone risks financial insolvency. Flat and decreasing block structures are uncommon in the GWI data. The low incidence may reflect the nature of the sample. The sample is targeted to the largest systems worldwide and systems that are functioning adequately enough to respond to survey inquiries. Flat tariffs are the only alternative in the absence of water use metering and many water systems operate without such metering (Banerjee, 2008; World Health Organization & United Nations Children's Fund, 2000).

The incidence of tariff structures in smaller North American systems and towns also cautions extending the global survey results to all water systems. Beecher (2011) surveys 80 water systems in the north central area of the United States and finds that 44% use decreasing block tariffs, 18% use increasing block tariffs, and no systems use efficient structures. Dziegielewski et al., (2004) finds that 35% of 426 water systems in Illinois use decreasing block structures, 4% use increasing block structures and only 1% use an efficient structure. In 12 larger water systems in Colorado, 44% use either a volumetric charge or an increasing block tariff, 12% use decreasing block tariffs and none use an efficient tariff structure (Western Resource Advocates, 2004).

4.3 Water tariff levels set by municipal water systems

Efficient tariff levels are set so that the volumetric charge is equal to the financial and non-financial opportunity costs of providing an additional unit of water. Table 2 lists monthly average water rates based on the 2010 GWI survey. The second column in Table 2 lists income per capita within the systems responding to the survey. Overall, average income per capita is $20,595, but regional levels range from a low of $1,645 in Africa to a high of $48,119 in North America. The average monthly charge per 1,000 gallons is $4.53 for water and $3.32 for sewerage and wastewater. Sixty-four systems or almost 25% report no wastewater charge billed to water uses. The average combined water and wastewater charge is $7.08 per 1,000 gallons of water use.

Region[a]	Water Systems (#)	Income per Capita[b] ($)	Water and Wastewater Charge[d] ($ per 1,000 gallons)		
			Water	Wastewater	Water and Wastewater
All	276	20,595	4.53	3.32	7.08
Africa	18	1,645	2.09	0.70	2.79
Asia	94	12,736	2.63	1.50	4.13
Europe	87	35,722	7.82	3.83	11.65
MENA	19	14,292	2.79	0.34	3.13
S. America	32	8,513	3.01	0.90	3.91
N. America	26	48,199	4.79	5.86	10.65

[a]"MENA" is the Middle East and North Africa, "N." is North and "S. is South.
[b]Income per capita is annual gross domestic product per capita for 2005.
[c]Increasing and decreasing block structures result in different charges for different use levels. The 2010 GWI data lists average charges for a use level of 15 cubic meters or 3,963 gallons per month.

Table 2. Level of Municipal Water System Tariffs

Water and wastewater rates vary noticeably over the listed regions. Water rates are highest in Europe and North America and lowest in Africa and Asia. The average water rate in Europe is more than three times the water rate in Africa. Wastewater rates are highest again in Europe and North America and lowest in Africa and MENA. Combined rates are less than average in Africa, MENA, South America and Asia.

A standardized cost index allows a comparison of water rates relative to the revenue needed to cover operating, maintenance and capital costs (Komives et al., 2005). The index divides rates into the four categories shown in Table 3: insufficient or sufficient to cover operating and maintenance costs (O&M), sufficient to cover operating, maintenance and capital costs (O&M&C) and sufficient to cover costs in addition to minimum operating, maintenance and capital costs.

Costs vary depending on local and regional differences in wages and other prices, so the index sets different rates for less and more developed countries. The index does not include a fourth category of "Sufficient for Additional Costs" for more developed countries, so this threshold was set at $9.00 in these countries, double the rate needed to cover standard operating, maintenance and capital costs. The analysis applies the four less developed country cost categories to systems where mean income per capita is less than $10,000 per year in the 2010 GWI survey. It applies the more developed cost categories to systems with income per capita more than $10,000 per year.

Table 3 categorizes tariffs for the 121 systems in lower income regions, the 155 systems in higher income regions and all systems. Almost one-third of the tariffs in low-income regions and 8% of the tariffs in higher income areas are insufficient to cover only operating and maintenance costs. Fifty-seven percent of tariffs in developing countries are insufficient to cover the additional costs of capital. The data indicate that over all systems, only 14% recover revenue sufficient to cover more than standard operating, maintenance and capital costs with their current tariffs. This means that as many as 86% of the systems provide inadequate incentives for water conservation by failing to include non-financial opportunity costs.

Context	Insufficient for O & M [a]	Sufficient for O & M [a]	Sufficient for O & M & C [a]	Sufficient for Additional Costs
Less Developed	Less than $0.9	$0.9 to $1.8	$1.8 to $4.5	Greater than $4.5
More Developed	Less than $1.8	$1.8 to $4.5	$4.5 to $9.0	Greater than $9.0
Global Water Systems:				
Income < $10,000 (%)	31	26	36	7
Income > $10,000 (%)	8	28	45	19
All (%)	18	27	41	14

[a] "O & M" is operating and maintenance cost and "O & M & C" is operating, maintenance and capital cost.

Table 3. Cost Sufficiency of Municipal Water Rates

Figures 2 and 3 show that there is considerable variation in the adequacy of tariff levels within regions and countries as well. Much of the MENA is arid and the water opportunity costs are likely to be high. Figure 2 indicates that tariffs in 7 MENA systems are inadequate to cover operating and maintenance expenses, let alone encourage water conservation consistent with both financial and non-financial opportunity costs. Eleven MENA tariffs appear to cover financial costs to some degree. Six tariffs exceed standard financial costs. The rates in Jerusalem, Tel Aviv and Dubai appear high enough to include some portion of opportunity costs in addition to the immediate financial requirements of operation, maintenance and capital costs.

Figure 3 shows that tariffs in the United States tend to recover operating and maintenance costs, but at least 11 of the 19 systems shown set tariffs that are insufficient to cover capital costs. Four low tariff systems—Dallas, Las Vegas, Denver and San Antonio--are in arid regions where the opportunity cost of water is high, yet their tariffs fail to match the standard index for normal financial costs. Six of the 19 systems set rates adequate for revenues in excess of standard financial costs. The tariff for one city, San Diego—also in an arid region—exceeds the $9 level where tariff revenue may include a portion of non-financial water opportunity costs.

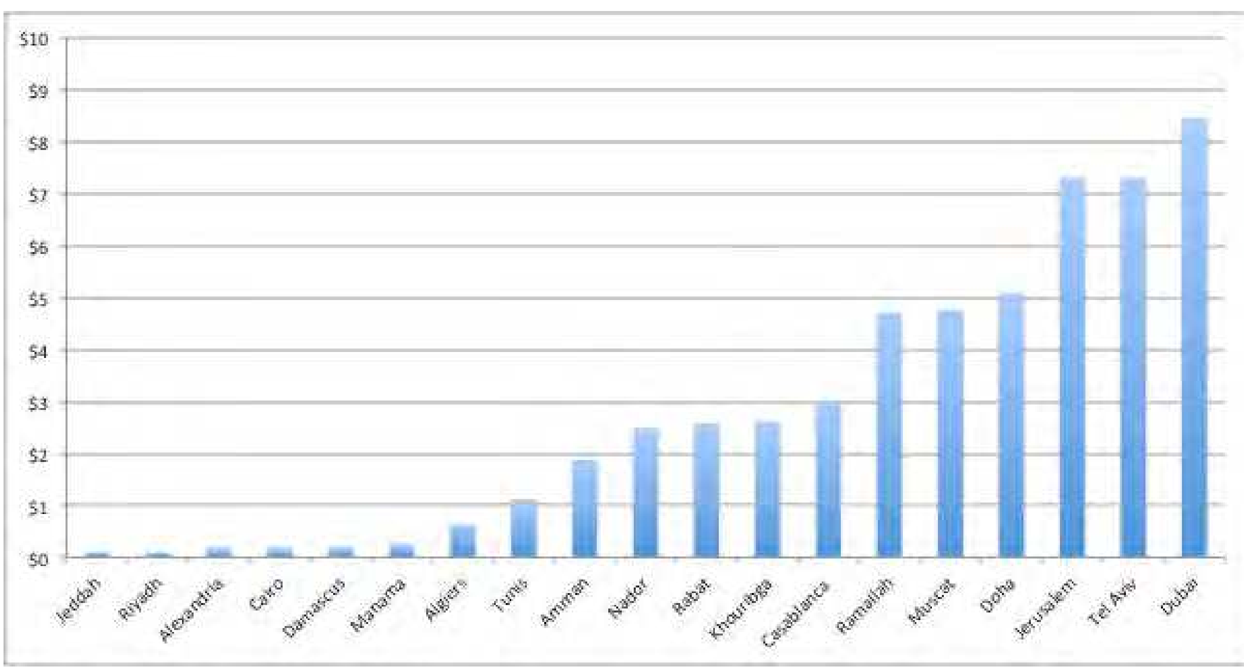

Fig. 2. Municipal Water Rates, Middle East and North Africa ($ per 1000 gallons)

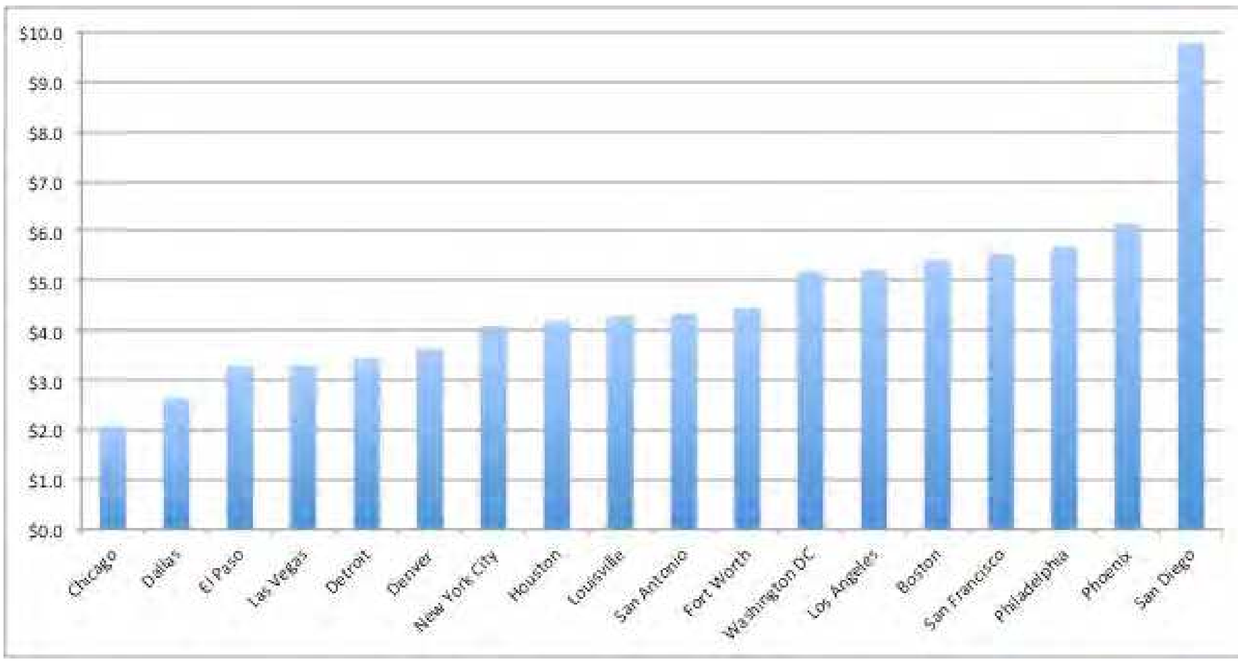

Fig. 3. Municipal Water Rates, United States ($ per 1000 gallons)

5. Implementing efficient residential tariffs

In many cities, large increases in water tariffs are likely to be required in order to encourage efficient water conservation. The amount of an increase in a particular water system depends on the current volumetric charge and the demand elasticities of water users. Dalhuisen et al. (2003) reports an average water demand elasticity of -0.4 in a review of 314 elasticity estimates obtained in 64 different research studies. However, elasticities varied significantly across studies and cities, so water use in a particular city may be less or more responsive to price increases than indicated by the average elasticity (Dalhuisen et al., 2003). For example, the average elasticity of -.4 means that reducing water use by 10% requires a 25% increase in a tariff volumetric charge. With a demand elasticity of -.1, reducing water use by 10% requires a 100% increase in a volumetric charge.

Water users are likely to resist large and unexplained tariff increases. Client acceptance of efficient water tariffs requires explanation and public education regarding the real economic costs of water. In some cases, there may be advantages to implementing efficient tariffs on a delayed schedule in order to give water users time to adjust and adopt water-saving habits and technologies before sustaining higher prices.

Three approaches to tariff reduce the financial impact of efficient water conservation incentives. The first approach is to use the efficient fixed charge to redistribute revenues in excess of financial costs. Tariffs based on unpaid, non-financial opportunity cost are certain to bring in surplus revenue above the revenue required to meet financial costs. Surplus revenue may be redistributed to water users through the fixed charge portion of the efficient tariff in a way that is consistent with fairness and equity concerns. As long as fixed charge rebates are not correlated with users' volumetric payment, fixed charge rebates do not distort the tariff incentive for efficient water conservation.

A second approach to increasing public acceptance of efficient water conservation incentives is to implement efficient tariffs for higher levels of water use and an inefficiently low tariff with volumetric water conservation rebate for low volume users (Collinge, 1994). Water conservation rebates for low volume users communicate the efficient incentive for water use *without* changes in volumetric charges below a certain threshold of water use. The volumetric rebate need only be set to pay users the volumetric opportunity cost for reduced water use. The threshold that distinguishes low and high water use may be set for individual users based on some percentage of historical use or it may be set at the same level for all water users based on some other criteria, such as using all surplus revenue encourage water conservation.

A two-tariff program combined conservation rebates may be structured in the following way. First, the volumetric charge is raised to an efficient level, λ^*, for water use in excess of the selected threshold for high water use. Second, for water use less than the threshold, the volumetric charge is set to λ^0, an amount less than λ^*. The lesser charge, λ^0, may leave unchanged an existing volumetric charge or it may be adjusted to some other level higher or lower than an existing volumetric charge. The only requirement is that $\lambda^0 \leq \lambda^*$. The third step is to set a volumetric conservation rebate. The conservation rebate is equal to the difference between the efficient volumetric charge and the lower volumetric charge, $\lambda^* - \lambda^0$.

With the described charges and rebate in place, all water users face an efficient incentive for water conservation. Water users above the threshold pay the full opportunity cost, λ^*, on each unit of water used. When water users below the threshold use an additional unit of water, they give up the opportunity to earn the rebate, $\lambda^* - \lambda^0$, on that unit of water and they pay the volumetric charge, λ^0. The net payment for an additional unit of water use below the threshold is composed of two parts, (i) the sacrifice of the rebate, $\lambda^* - \lambda^0$, and (ii) the payment of the volumetric charge, λ^0. The sum of the sacrifice and volumetric charge is the opportunity cost of water use, the efficient incentive $\lambda^* = (\lambda^* - \lambda^0) + \lambda^0$.

The two-tariff-and-rebate program gives all water users an efficient incentive for water conservation. Water users below the threshold have an additional incentive to accept the program since they may pay the current volumetric charge and have an opportunity to earn rebate income. Setting thresholds at the individual level based on historical water use gives *all* users the prospect of earning rebates. Hence, it may be possible to make almost all users better off by including unpaid opportunity costs in an efficient water conservation tariff program.

A third approach requires no change in tariffs below a selected threshold of water use, but does require a physical infrastructure to transfer water between the residential water network and the next best alternative use. This is possible in regions such as the Rio Grande basin where both urban and agricultural water is stored and withdrawn from the same network of canals and storage reservoirs.

The third approach is based on resale of water between residential water users and agricultural water users (Haddad, 2000). Similar to the tariff and rebate program, a water use threshold is set either for residential users as a group or for each user based on historical water use. In addition, a water savings account is set up for each user within the water networks billing and accounting system.

Water users make deposits into the savings account by reducing their *planned* water use below the threshold selected by the water authority. The amount deposited is the difference between the selected threshold and the amount of water that an individual plans to use. Deposits can be made by telephone, by mail-in card or on the internet. The municipal system then acts as an agent for individual savers and sells the aggregate amount of planned savings to agricultural users or in-situ agents. Sales revenues are returned to savers in proportion to their *actual* savings.

Residential users pay the full opportunity cost of water in two situations. The first is when their water use exceeds the threshold selected by the water authority. The second, is when actual water saving is less than planned saving. Users that save less than they planned, pay the full opportunity cost of water on the difference between planned and actual savings. Apart from these two cases, users pay a volumetric rate that the water authority sets for water use that is below the threshold minus planned savings. Tariff charges for water use less than the threshold minus planned savings may remain at current inefficient rates.

The third approach communicates efficient water conservation incentives to all residential water users. Users using more than the threshold amount of water face the full opportunity cost for an additional unit of water. Users below the threshold amount forego the opportunity to sell water at its opportunity cost to agricultural users when they fail to 'save' water. Each type of user has an incentive to invest in water conservation consistent with its value in the next best use.

Like the two-tariff-and-rebate program, water savings accounts and resale give residential water users an opportunity to earn income from the true economic value of water. By setting appropriate thresholds at the level of an individual user, the income earning potential can be extended to all waters users. By saving water, users have the opportunity to converts financial pain into financial gain. Users thereby share the benefit of efficient water conservation.

6. Conclusions

Economic principles help identify the consequences of wasting scarce water. The opportunity cost concept shows wasting water is not just misguided. Wasting scarce water destroys real economic opportunities and leads to losses for other water users. The concept of water demand guides the measurement of water values, helps evaluate users' responses to conservation policies, and shows how to measure the deadweight loss of inefficient water use as well as the benefits of water conservation. Analysis of water trading shows how trade gives water users strong incentives to find the highest value uses of water and to eliminate waste by moving water into those uses. Third-party effects remind us that water use has potential consequences elsewhere in the hydrological cycle, such as on *in-situ* and downstream users.

The analysis used these economic principles to evaluate whether municipal water tariffs may be designed to encourage efficient water conservation. The analysis found that efficient water conservation tariffs have two parts, a volumetric charge that communicates the opportunity cost of an additional unit of water and a fixed charge that is adjusted at the user level to address equity and fairness and at the aggregate level to address revenue requirements not covered by the volumetric charge.

Empirical analysis showed that municipal water systems across the globe are large reservoirs of wasted water. More than 80% of 276 large water systems worldwide use tariffs that encourage water waste. There is some evidence of tariff reform in Europe, but, even there, the majority of water systems use inefficient tariffs that encourage wasted water. More than 85% of the 276 systems set tariffs so low that they appear unlikely to recover capital costs. Forty-five percent of tariffs fail to cover likely operating and maintenance costs. Systems in low-income cities appear most likely to use tariffs that disadvantage the poor, threaten financial viability and waste scarce and highly valued water.

Overall, the tariffs used by cities around world suggest rather solemn prospects for many water systems: possible financial insolvency, reduced service quality and service areas, and abundant water waste. Efficient water conservation tariffs can contribute to financial solvency and unlock the reservoirs of wasted water. Water is scarce and highly valued. An efficient water tariff communicates the high value of water.

Water users are likely to resist such communication in the form of unexplained increases in their water bills. Explanation and education campaigns are standard approaches to achieving clients' acceptance of water conservation policies. There are also two ways to modify tariff programs so that users can share the gains obtained from efficient water conservation. The first approach is a two-tariff program with a water conservation rebate. This two-tariff program sets a high tariff charge for water use beyond a certain threshold and a low tariff for water use below the threshold. The threshold may be set for an individual user based on historical use or it may be a single threshold for all users in the system. The volumetric charge in the high tariff is equal to the marginal opportunity cost of water. The low tariff can be set at any lower volumetric charge, including being left unchanged from an existing rate.

The conservation rebate equals the marginal opportunity cost of water. The rebate is paid to users based on water savings relative to the threshold—on the positive difference between threshold and the water a user actually uses. The two-tariff-and-rebate program presents all users with the full economic cost of using an additional unit of water. In contrast to an across-the-board tariff increase, users actually pay the full cost of water only on water use above the threshold. Water use below the threshold has a lower out-of-pocket cost, but the same opportunity cost. A user that fails to conserve below the threshold gives up both the rebate and volumetric charge on each additional unit of water use. Users above and below the threshold have a full and efficient incentive to invest in water conservation.

The second approach is similar to the two-tariff-and-rebate program. Instead of a rebate, the second approach offers users water conservation savings accounts. The savings accounts is an electronic entry maintained by the water systems billing and account system. Users make savings deposits by cutting back on water use. As savings accumulate, the water system sells saved water at its full opportunity cost to users outside the system, such as agricultural irrigators or trustees for environmental interests. Sales revenues are returned to savers in proportion to their water deposits. As in the two-tariff-and-rebate program, all water users face the full opportunity cost of an additional unit of water and each has an opportunity to earn income from water conservation.

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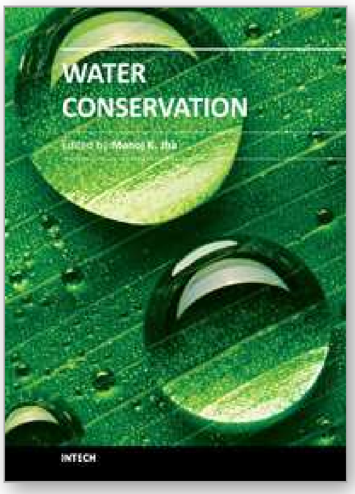

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Water is an essential and basic human need for urban, industrial and agricultural use. While an abundance of fresh water resources is available, its uneven distribution around the globe creates challenges for sustainable use of this resource. Water conservation refers to an efficient and optimal use as well as protection of valuable water resources and this book focuses on some commonly used tools and techniques such as rainwater harvesting, water reuse and recycling, cooling water recycling, irrigation techniques such as drip irrigation, agricultural management practices, groundwater management, and water conservation incentives.