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Freshwater Management in Industrialized Urban Areas: The Role of Water Conservation

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INTRODUCTION

Access to safe drinking water is a serious concern in developing countries, where 1.1 billion people lack access (WHO, 2000).[i] But access to water is also inadequate in many urban areas of industrial countries, especially during periods of drought (NDMC, 1997). The situation may worsen in industrial urban areas due to:

- Increased water demand for economic development and population growth (Wolff and Gleick, 2002);
- Impacts of changes in both global and regional climate on water

[i] Specifically important is the way in which drought impacts local societies by reducing access to safe drinking water in places that currently enjoy only marginal water quantity and quality, and endure severe seasonal shifts in precipitation. In these regions, even a slight drop off in water availability will result in severe outcomes. The impact of arid conditions and extreme poverty impedes the ability of local populations to secure consistent supplies of safe drinking water.

supply systems (Alliance to Save Energy, 2003; Blake et al. 2000; Morehouse, 2000); and

- Reduced percolation due to high levels of impervious surfaces resulting from urbanization of basins (EPA, 1997; Cahill et al. 1996; Schueler, 1994).

On a global level, annual freshwater availability per person decreased from 16,800 m^3 to 6,800 m^3 per year between 1950 and 2000 (WRI, 2000). When drought conditions persist, urban centers in many industrialized regions are prone to experience a severe freshwater supply-demand gap. A traditional method of attempting to resolve this gap is to increase supply vis-à-vis, large reservoirs, desalination plants, and inter-basin transfers. While such techniques can provide a definite source to offset water demand, costs and environmental impacts are major concerns.[ii] However, through demand-side management, the gap can be closed without large construction costs and negative environmental consequences. In fact, as will be shown, efficiency can be increased, and environmental conservation enhanced.

Prolonged periods of dry conditions in several U.S. regions over the past 25 years resulted in coordinated national and state policies and programs.[iii] California state law, for example, requires water purveyors to prepare plans to respond to cutbacks of up to 50% in their supplies in the event of drought or natural disasters (Deister, 2001). The potential of demand-side management is significant. According to Vickers (2001), system-wide demand reductions of at least 25% are possible from conservation for many North American water utilities.

This chapter explores how demand-side management can be applied to help close the expanding freshwater supply gap in industrialized urban centers, especially in drought conditions. The authors provide a U.S. case study that serves as a model for mitigating drought in such settings in which demand-side options are cost effective, environmentally benign, less energy intensive, and often more socially equitable[iv] when compared to supply options.

[ii] As a supply option, desalinization of sea or brackish water can provide virtually unlimited supplies of freshwater. But higher energy costs have limited its use to specialized applications such as military outposts on small islands, and to energy-rich, freshwater-poor coastal areas like the states of the Arabian Gulf. The substantial energy needs of desalinization mean that it has a heavy environmental impact. Another concern sometimes raised is the brine left over from the process (McCully, 2001).

[iii] The United States Congress passed the National Drought Policy Act (NDPA) of 1998, creating the National Drought Policy Commission to review strategies and solutions to successfully mitigate damages caused by drought.

[iv] The "scarce" resource may be divided in an inequitable manner as a reflection of the political and economic systems that govern it. In such cases it is likely that the poor and ecosystems will suffer the most (Smith Jr., 2003b).

The Demand-Supply Gap

At the global scale, there appears to be an under-appreciation for the manner in which droughts threaten access to adequate levels of water supply in urban areas within wealthy countries.[v] Such threats from drought are made more alarming by the fact that demand for water is rapidly expanding due to increased population growth and urban development, while supply is diminishing due to contamination[vi] and increased impervious cover.[vii] In addition, minimum stream flow requirements also reduce the volume of water available for domestic and industrial consumption.

This gap in supply and demand can significantly harm economic activities and ecological processes in urban areas, especially during periods of severe drought. Water shortages resulting from drought restrict urban activities in the commercial and industrial sectors, and also the agricultural sector in its surrounding areas, leading to unemployment and loss of tax revenue for local, state, and federal governments (CEEP, 2001).[viii] The 1996 drought in Texas alone resulted in an estimated $5 billion dollars in damage (Wilhite et al. 2000).

When drought lowers urban stream flow levels, wetlands can be impacted, multiple scales of ecosystems disturbed, and water-related environmental and recreational environmental amenities lost to residents (NDMC, 1998). Reduced quality and quantity of drinking water associated with upstream development and/or heavy withdraws during drought cause public safety and health concerns, user conflicts, reduced quality of life, and equity concerns for downstream city residents (CEEP, 2001; NDMC, 1998). In addition, reduced generation of hydro electricity

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[v] Several chapters in this volume have discussed the condition mentioned above at great length, suggesting methods and practices to overcome freshwater shortages in less-wealthy regions. While this problem is certainly a major concern for the global community, it is important to consider the impact of freshwater shortages in industrialized urban areas during droughts.

[vi] All surface water systems are considered highly vulnerable to contamination. Drinking water is at risk from surface runoff because of poor air quality, spills, wastewater discharges, sewer overflows and storm water runoff, etc. (Byrne, et al. 2003).

[vii] A one-acre parking lot can produce 16 times more storm water runoff that a one-acre meadow each year (Schueler and Holland, 2000). It is this increase in storm water runoff that negatively affects water quality, water quantity, public health, flooding, and aesthetics of waterways (Wozniak, 2004).

[viii] The growing demand for water in the cities is often satisfied by diverting irrigation water from agriculture. With every country facing irrigation water shortages, grain imports are climbing (Brown, 2000).

resulting from droughts negatively affects energy required to support urban activities.[ix]

Droughts in the western region of the U.S. provide a good example in terms of how drought affects economy, energy, environment and equity. As this region suffers through yet another year of drought, a western newspaper prints the following from drought's 'front line:'

> [Lake] Powell's water levels could sink below Glen Canyon Dam's turbines, which supply part of the West's power.... A water court ruling in 2002 shut down 800 wells and several thousand other farmers face a protracted legal battle to keep their wells pumping to irrigate corn, wheat and other grains ... Crop losses due to the drought have sapped savings, sending farmers to banks for operating loans and money for water court costs... Many of the farmers' court fights include multiple objectors, usually cities, including water-short communities in Arapahoe and Douglas counties, that want to buy the water to use in subdivisions... But there's more at stake for Colorado than just water. Revenue from the sale of electricity generated at Glen Canyon Dam at Lake Powell pays for Colorado's endangered-fish recovery programs and helps repay federal water project costs (Frazier, 2004).

The reduction of the water supply-demand gap in industrialized urban areas is therefore necessary to ensure sustainable water resource management for urban residents in industrialized countries. The primary concern is that cities secure consistent supplies of safe drinking water for all residents at reasonable rates. If supplies of freshwater are limited to the extent that residential demand cannot be met, the well-being of citizens will be sacrificed. By moving to reduce the supply-demand gap through the efficient use of freshwater, the gap can be closed, and urban health can be ensured. Other communities, including ecological ones, will also benefit from the wise use of water. Demand-side management should be at the core of this endeavor.

Demand-side Drought Management

By mitigating urban-industrial drought through the efficient use of water, the gap in supply and demand can be closed in an environmentally sustainable manner. Many ways of conserving water in an urban setting have been considered and applied as shown in Table 22.1.

[ix] Concerns regarding drought have captured the attention of many Americans in recent years. In fact, scientists at the U.S. Geological Survey have stated that the drought in the western U.S. could be the greatest in 500 years, with impact in the Colorado River Basin significantly worse that during the Dust Bowl years (Associated Press, 2004).

Table 22.1. Major facets of water conservation mechanisms

Conservation mechanism	Investigator	Year published
Curtailment and ordinances	Tippett and O'Hare	1999
	Aitken, McMahon, Wearing and Finlayson	1994
	Agras, Jacob and Lebedeck	1980
	Bruvold	1979
Technological efficiency improvement	Irvine Ranch Water District	2004
	Vickers	2001
	Wang, Song, Byrne and Yun	1999
	Gleick et al.	1995
	Postel	1986
Information campaign	Irvine Ranch Water District	2004
	Peckumn	2003
	Wang, Song, Byrne and Yun	1999
	Abu-Taleb and Murad	1999
	Moore, Murphy and Watson	1994
	Nieswiadomy	1992
	Billings and Day	1989
Recycling and reuse	U.S. Environmental Protection Agency	2004
	Guendert and Jordan	2004
	Water Reuse Association	2004
	Williams and Safrit	2003
	Nolde	2000
	Jefferson, Laine, Parsons, Stephenson and Judd	2000
	Marks	2000
	Roseland	1998
Land use modifications	Wozniak	2004
	Center for Watershed Protection	2004
	Rushton and Hastings	2001
	U.S. Environmental Protection Agency	1999
	Prince George's County	1999
	Miller	1998
Conservation-oriented pricing	Wang, Smith and Byrne	2004
	Center for Energy and Environmental Policy	2002
	Wang, Song, Byrne and Yun	1999
	Renwick and Archibald	1998
	Hewitt and Henemann	1995
	Rhodes, Miller and MacDonnell	1992
	Nieswiadomy	1992

Curtailment and Ordinances

Curtailment or reasoned response is responsible for considerable success in certain water campaigns (Aitken et al. 1994). Bruvold (1979) and Agras et al. (1980) identified the tendency of people to conserve during a crisis situation like severe drought. When citizens feared a community crisis or viewed the drought as an indicator of a long-term problem, more involvement in conservation efforts was apparent. According to our interviews, another concern is how long such reductions persist – which is a reason that a long-term outreach strategy in both periods of crisis and non-crisis has been noted in places such as Corpus Christi and Tucson as being key to sustaining any necessary changes in behavior.

Municipalities use ordinances as part of demand-side management initiative. Use of ordinances that promote water conservation and efficiency include water rate, lawn watering, plumbing fixture, mandatory retrofit of water fixture, and restrictions on specific users such as golf courses (de Loe et al. 2001). Of these, water rate ordinances and lawn watering ordinances are most frequently used.

For example, the City of Santa Fe adopted the Emergency Water Regulation Ordinance in March 1996 to control water use in response to a twelve-month long drought. Commercial and residential water users were required to reduce their use by 25% as measured against the water bills during the same month of the previous year.[x] In August 1996, 91% of the residential water users used less than 12,500 gallons a month as compared with 75% in August 1995. Residential water use dropped by 28% as a result of the adoption of the ordinance, surpassing the goal of a 25% reduction (Tippett and O'Hare, 1999). Obviously this can wreck havoc with utility revenues, and this concern is addressed later in this chapter.

Efficiency Improvement

Engineering estimates (Vickers, 2001, 1993, 1991, 1989; Postel, 1986) generally indicate that efficient water appliances can significantly reduce water consumption. The Pacific Institute, a California water-research NGO, calculates that using only existing technologies, average residential water use per person in the state could be almost halved between 1995 and 2020 (Gleick et al. 1995).

In the area of the Irvine Ranch Water District in California, 51% of all residential water is used for landscape irrigation. Smart sprinkler technologies that adjust the amount of water sprayed on the daily basis of evapotranspiration rates resulted in water savings of 41 gallons per day (gpd) in typical residential settings. The observed reduction in runoff from

[x] The 25% reduction goal gave each water user a "Conservation Target." A $10 "Target Exceedance Surcharge" was assessed for each 1,000 gallons a customer used in excess of his or her target. In addition, a "High Use Surcharge" was levied on single-family residential customers that used over 12,500 gallons per month. The "High Use Surcharge" ranged from $15 to $50 per 1,000 gallons for use over 12,500 gallons.

the test area was 49% when comparing pre- and post-intervention periods, and 71% in comparison to the control group (IRWD, 2004).

Wang et al. (1999) also show that those customers who received conservation kits (including faucet aerators, low-flow shower heads, and toilet dams) as part of voluntary conservation programs had a significant reduction in water consumption compared to those who did not (16%).[xi] However, the percentage of customers using conservation devices is small.

A high penetration program could be adopted to increase participation in the delivery of water conservation devices, be it for free, or for a fee. To illustrate, the Santa Monica Energy Fitness Program used new techniques designed to increase participation in the Residential Conservation Service (RCS) program by utility customers. The technique was to complete a direct-service-home-energy audit, which included the actual on-site installation of energy saving devices in the participant's home (Egel, 1986). This type of energy program could clearly be applied to water conservation as well, especially since several of the Santa Monica measures were for hot water savings. This approach resulted in participation among the highest ever achieved by an RCS Program.[xii]

Information Campaign and Audits

Information and educational campaigns are common tools used to promote water conservation. Educational campaigns involve the use of the radio, television, and written media such as pamphlets and programs in the school systems. However, as counterintuitive as it may seem, Abu-Taleb and Murad (1999) found a very poor correlation between knowledge and action.[xiii] This study's most important observation on behavior was primary school children directly reflect their parents' views towards conservation. This is significant because it identifies an important pathway to influence younger attitudes towards conservation behavior (Peckumn, 2003).

Water utilities, in collaboration with state and local governments, could play an active role in the dissemination of quality information on the water supply situation and conservation needs. From a policy standpoint, the amount of information the residents have is not that important. The most critical matter is to get them to take the message seriously enough to change their behavior in a timely manner. The information should be clear

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xi In a typical single family home, by installing water efficient ultra low-flush toilets that use 1.6 gallons per flush, toilet use declined to 19.3% (AWWA, 1999). Low-flow showerheads are the most commonly used devices in voluntary conservation programs.

xii Since program costs and energy savings per household were comparable to those associated with most traditional RCS Programs, far more total conservation was achieved at similar cost per unit saved.

xiii Moore, Murphy and Watson (1994) observed the largest conservation came from people who had been subject to at least one water conservation campaign earlier in their life, but a follow up survey (1999) three years later found the minute correlation had disappeared and people were not conserving.

and understandable to residents and motivate them to take actual conservation measures. The information campaign should also be persistent to be most effective. Billings and Day indicate that "the effect of publicity exists only as long as the publicity continues" (1989: 63).

Using the American Water Works Association survey of 430 U.S. water utilities, Nieswiadomy (1992) estimated the impacts of public education programs on water conservation for four different regions and showed that the program, which urge people to conserve water, significantly reduce water demand only in the West region. A study of southern Arizona's campaign showed that publicity about water problems had an impact on water conservation, with an average elasticity of –0.05 (Billings and Day, 1989). A residential group which received only educational materials and a suggested irrigation schedule saw reductions in outdoor water use of 28 gpd per residence and a 36% decreased in runoff following intervention. Relative to the control group, the education program resulted in a 21% reduction in runoff (IRWD, 2004).

Water audits can be an important tool of information campaign. Many municipalities use water audits of homes and businesses to save water through retrofitting or changing practices of water use. Water audits are subsidized in several municipalities as their responsibilities have been increased, while general revenues have decreased. Water conservation is bolstered by programs that provide free leak detection via audit and which may be supported via rebate programs to promote consumer choice of low-flow toilets and other high efficiency water service technologies.

Water Recycling and Reuse

Water recycling can be an effective method of reducing urban water consumption. A gray water recycling system exclusively used for toilet flushing can save 34% to 40% of household consumption, with a payback period of 8 years in a four-person household (Jefferson, 2000; Nolde, 2000; CMHC, 2000). A more expansive system that also uses recycled water for irrigation can save between 50% and 70% (EPA, 2004; Marks, 2000).

Recycled water can come from homes, rainwater storage tanks and storm drains. There are many potential applications for recycled water in the home and throughout the community. Individual homes can use recycled water to flush toilets, water gardens, and wash cars, while communities can irrigate public areas and create artificial lakes or fountains. Household gray water is transported through a dual reticulation system of pipes. This system involves collecting wastewater from a residence, treating it off-site, then returning the recycled water to the community.[xiv] It is

[xiv] Although the majority of recycling projects involve entire communities, not all systems require the development of large infrastructure. There are systems available for purchase by individuals that involve the recycling of their personal gray water. Specific products

noteworthy that major metropolitan areas such as the city of Denver uses recycled water for display in its zoo and on local golf courses.[xv]

A number of different water recycling projects are currently in place in the U.S., especially in southern areas and California. In St. Petersburg, Florida, water reclamation efforts have been underway since the 1970's. 8,000 people were already being served in 1995, and the system is expected to expand to up to 17,000 residents (Water Reuse Association, 2004). There is also a dual reticulation system planned for Brunswick County, North Carolina. New developments will be constructed with the pipe infrastructure needed to make use of recycled water for lawn irrigation, while older communities will be retrofitted when economically efficient (Williams, 2003).[xvi] In Los Angeles, 500 homes rerouted gray water to their washing machines and saved approximately 4 million gallons of water per year (Roseland, 1998).

The satellite reuse plant[xvii] alleviates the need to expand old, centralized wastewater systems in an urban location, where expansion can be disruptive and costly. In Woods Valley, California the high-quality effluent produced from the satellite facility irrigates the community's golf course as well as fill the course's water features (Guendert and Jordan, 2004). This remote treatment of wastewater for reuse provides a reliable, drought-proof supply water that can benefit urban communities by reducing the reliance on overstressed existing supplies, increasing availability of potable water and improving the environment by decreasing discharges of wastewater to oceans, lakes, rivers, streams, and creeks (Guendert and Jordan, 2004).

Land Use Modification

Conventional urban development can create many problems due to traditional construction practices. Water that previously ponded in natural depressions, infiltrated into the soil and provided groundwater recharge, or evaporated and transpired into the atmosphere, is now converted into surface runoff (U.S. EPA, 1999). As groups such as the Center for Watershed

sold in the United States include the Envirosink and the Cloudy Water Recycling System. These two devices offer the choice of a low-tech option and much higher tech option.

xv The San Antonio Water System has a gold course program named "Golf Fore" that certificates four levels of environmental achievement based upon the four criteria of: 1) Water conservation; 2) Water quality; 3) Wildlife habitat and open space; and 4) Community outreach.

xvi Recycled water has been used in the service area of the Irvine Ranch Water District in California (IRWD) since 1967. Recycled water is used for landscape irrigation, agriculture, in large commercial building's toilets, and (as a pilot study) in cooling towers. The full array of recycling services can be viewed on the corresponding website.

xvii The new technology used for these types of applications is the membrane bioreactor (MBR) which allows it to be easily sited; operates reliably with minimal operator attention; contains microorganisms in the process; and provides a high-quality effluent (Guendert and Jordan, 2004).

Protection (2004) note, increases in impervious surfaces such as rooftops, roads, parking lots, and driveways reduce percolation and filtration. As a consequence, a lot of rainfall is converted into stormwater runoff, negatively affecting water quality and quantity, habitat, biological resources, and public health, and often enhancing flood hazards.

A two-year study by the Southwest Florida Water Management District (Rushton and Hastings, 2001) has shown that permeable pavement can produce both water quantity and water quality effects that far exceed that of other types of conventional pavement. Also, the implementation of a rooftop garden in Philadelphia has shown decreased stormwater runoff flows (Miller, 1998).

Low impact development (LID) is a technique brought to the forefront by the staff working for Prince George's County, Maryland. Based on eight sustainability goals, LID practices can be employed to retrofit urban communities, making them more hydrologically sustainable by increasing water quality, preventing flooding and protecting biological resources (Prince George's County, 1999). Specific examples of structural procedures include rooftop gardens, rain barrels, rain gardens, bioretention areas in parking lots and along roadsides, permeable pavement, and infiltration basins (Wozniak, 2004).

These urban practices have been shown to provide many benefits including enhanced property values and redevelopment potential, greater marketability, improved wildlife habitat, thermal pollution reduction, energy savings, smog reduction, enhanced wetlands protection, and decreased flooding (U.S. EPA: 2000, 1999). Of course, in cities where vector-borne diseases are a concern, one must be cautious in utilizing technologies such as rain barrels in order not to dramatically increase the number of potentially disease causing vectors near homes.

Water Conservation Pricing

A conservation-oriented pricing policy is essential for ensuring that water utilities and customers alike weigh efficiency alternatives properly in their water supply and demand decisions.[xviii] The most serious water supply problem faced by water utilities is peak summer demand that occurs when capacity is limited. In this case, utilities satisfy demand through such options as purchasing expensive water from other utilities, reactivating old wells currently not in use or expanding storage capacities. These supply-side actions impose high costs on the utilities (higher marginal costs). Consumers who are the principal source of peak demand should shoulder higher costs. Thus, seasonal water conservation pricing reflects these higher costs (Wang et al. 2004).

[xviii] Pricing policy is essential for a demand-side management in combination with metering to provide an incentive for customers to reduce water use. Metering is a prerequisite for conservation-oriented rate structures (De Loe et al. 2001).

Since pricing is a significant policy variable influencing water conservation, water utilities need to continue considering pricing as a water DSM alternative to conventional supply options (Wang et al., 1998). To be most effective, pricing structure should be designed in such a way that discretionary water users in the summer months are given signals to reduce consumption. Indeed, outdoor water use has been found in the literature to be particularly sensitive to price increases, especially during the high-demand summer months (Hewitt and Hanemann, 1995; Rhodes et al. 1992).

Price responsiveness varies by the income group. According to Renwick and Archibald (1998), lower income households were more price-responsive because their water bill typically constitutes a larger share of their household budgets. This implies that price policy will achieve a larger reduction in residential demand in a lower income community than in a higher income community. The Center for Energy and Environmental Policy (2002) shows, however, that during summer months the upper-income groups have a much higher price responsiveness than low-income groups because their discretionary uses are more easily altered than those corresponding to basic needs for which demand more readily 'hardens.'

Impacts of Demand-side Drought Management

The impacts of the efficient use of water on economy, environment, energy and equity ($\mathbf{E}^4$) are positive. Water conservation improves the $\mathbf{E}^4$ balance, enhancing urban sustainability, especially during droughts in urban areas. Previous responses to drought have been mostly reactive, representing a crisis management approach that has been largely ineffective (Wilhite et al. 2000), whereas conservation programs can be effective to reduce the risks associated with drought in a more systematic manner.

Economy

Customers enjoy immediate economic benefits through lowered bills, but the more important element is long-term societal benefits from lessening or eliminating needs for costly supply-side facilities or wastewater and sewage treatment facilities (Wang et al. 2004; U.S. EPA, 1998; Featherstone, 1996). In Santa Barbara, CA, a large desalination plant brought in the late 1970s due to a severe drought is in the process of being 'mothballed' because reductions in demand occurred from the high costs passed on to consumers (Gleick, 2002). The three examples below further attest proven measures of water savings.

An important reason for the suspension of the Two Forks Dam, planned to supply water to Denver, Colorado, was that installing meter and water-saving devices in Denver households could save more water than the dam would supply – and at about one-fifth of the dam's $1 billion cost. After the U.S. EPA vetoed Two Forks in 1990, the Denver Water Department actively promoted water use efficiency, helping to cut average household consumption by 9% in just two years (Haberman, 1993).

The Town of Cary, NC, has found that a carefully planned water conservation program can offer a 'new' source of water and enabled the town to delay two future plant expansions by 10 years (Platt and Delforge, 2001). Its Water Conservation Program (WCP) recommended seven programs that have a combined benefit-cost ratio of 4.44. The programs reduce retail water production of 4.6 mgd by 2028, representing a savings in retail water production of 16%.

Since the early 1990s, New York City has saved more than 250 million gallons per day in water through a conservation program that included an aggressive low-volume toilet rebate program involving more than 1 million fixture replacements. These savings allowed the city to avoid spending more than $ 1 billion to expand a wastewater treatment plant and have indefinitely postponed development of new water supply sources (Vickers, 2001).

Environment

Reduced water consumption lowers needs for withdrawal from surface and groundwater and treatment of wastewater, mitigates saltwater intrusion in certain cities near coastal areas,[xix] and mitigates or eliminates environmentally questionable water supply augmentation solutions (CEEP, 2001; U.S. EPA, 1999).

The burning of fossil fuels to generate the energy used to supply water (including treatment) affects air quality. Emissions from power plants contribute to already high levels of pollutants in the urban environment. In addition, millions of tons of carbon dioxide are emitted every year, contributing to global climate change. Global climate change has the potential to alter water tables and disrupt water supplies in many areas, making water even more costly (and energy intensive) to obtain in the future (Alliance to Save Energy, 2003).

Excessive ground and surface water withdrawals can be avoided vis-à-vis conservation. Aquifer depletion can cause the land above to subside, with serious consequences for the stability of buildings. In fact, Beijing is sinking at an annual rate of around 10 centimeters, and its water table dropping by up to 2 meters a year. The ground under Houston, Texas has subsided by more than 2 meters over the last four decades (Panel on Land Subsidence and National Research Council, 1991).

Altered flows are a concern as well. More than 20% of all freshwater fish species are now threatened or endangered because dams and water

[xix] Sinking water tables in coastal areas can cause saline water to seep into aquifers, ultimately making them useless for either drinking water or irrigation. Drinking water supplied by groundwater under a number of cities and towns along the eastern and southern coasts of the US has been contaminated by saline ingress.

withdrawals have destroyed the free-flowing river ecosystems where they thrive (Gleick, 2002).

Energy

Energy consumption is directly reduced when residents adopt water efficient appliances, and water utilities use less energy for surface and groundwater withdrawal and wastewater treatment and discharge (Cohen et al. 2004; U.S. EPA, 1998). Specially, reductions in peak water system loads reduce peak energy demands by less water pumping, treatment, and heating so that energy utilities avoid or reduce capital expenses (Gleick, 2002).

Sullivan et al. (2001) show in their Oregon study that the mean electricity savings from the new clothes washer was 0.9 kWh/cycle, for a 68% reduction in use over the baseline electric water heater, while the mean water savings was 15.2 gallons/cycle, for a 38% reduction in use over the baseline. In the case of the new dishwasher, compared with the baseline equipment, the mean water savings was 3.7 gallons/cycle, for a 39% reduction in use, whereas the mean electricity savings was 0.6 kWh/cycle, for a 39% reduction in use.[xx]

The worldwide energy consumption to pump and treat water for urban residents and industry is between 2 and 3% of total global energy consumption (Alliance to Save Energy, 2003). Unfortunately, relatively little attention has been given to reducing energy use in urban water systems. Energy costs draw precious budgetary resources from other important urban functions such as education, public transportation, and health care. In the developing world, the cost of energy to supply water may easily consume half of a municipality's total budget. Even in developed countries, energy is typically the second largest cost after labor in urban water systems (Alliance to Save Energy, 2003).

Equity

Conserving water makes it easier to optimize water allocation between competing users, this is due to increased water availability. Given the Earth's limited water budget, conservation is essential to build a 'water trust,' an endowment that generations to come can rely on for their own security and prosperity (Vickers, 2001). As we will demonstrate later, compared to supply-side options, conservation can be achieved without over-burdening under-privileged residents, and also enhances opportunities for participation by residents and localized communities in water decision processes (Newman, 1999).

[xx] Sullivan et al. also show that the energy savings from reduced water distribution and water/wastewater treatment from the water and energy-efficient devices (including clothes washers, clothes dryers, dishwashers, toilets, showerheads, and faucet aerators) were calculated to be 55 kWh per home per year. These savings are realized by the community through reduced electricity use by supply pumps and other water/wastewater treatment equipment.

Successful urban conservation efforts will reduce conflicts over in-stream flow rights and competing uses of water that are occurring with increasing frequency (Vickers, 2000). Improved efficiency of water use will result in additional water to share among competing users and with the natural environment. Getting more from each gallon of water extracted from nature is the key to meeting future human needs and at the same time protecting the environment (Postel, 2000).

A Case Study: Wilmington Metropolitan Area

Delaware has a history of periodic water 'shortages' due to droughts. The portion of the state most affected by drought has typically been the city of Wilmington and its metropolitan perimeter. Approximately 70% of metropolitan Wilmington's drinking water is drawn from the Christina River Basin – mainly composed of the White Clay Creek (WCC) and the Brandywine Creek (BC). During droughts, water supply in the area can be severely strained. Water quality has also been threatened (Wang et al. 2001; WSTF, 1999).

Withdrawals of water from the Christina River Basin is regulated by the 7Q10 Minimum Flow Standard, which is based on a statistically computed lowest flow rates occurring once every 10 years for a 7-day period. This standard prescribes the minimum flow that must be maintained in the streams so that human health, riparian ecosystems and aquatic life are not significantly impacted. According to the Second Report by WSTF submitted to the state's Governor and General Assembly, the demand in the Wilmington metropolitan area for 2010 is projected to reach 88 mgd (DWSCC, 2001). When demand for water is compared with supply availability, it becomes evident that the adequacy of the water supply system depends on the adoption of the 7Q10 system. Table 22.2 indicates the water balance for the metropolitan area in 2000 and 2010.

Expanding the 7Q10 standard to include both BC and WCC could result in a projected supply deficit of nearly 15 million gallons per day (mgd), or, 17% of the demand during droughts in 2010. The solution to meeting this

Table 22.2. Water supply and demand scenarios in the Wilmington Metropolitan Area: 2000 and 2010

Scenario	Supply (mgd)	Demand (mgd)	Balance (mgd)
No 7Q10	93	86 (for 2000)	7 (8%)
7Q10 in WCC, not in BC	85	86 (for 2000)	–1 (–1.2%)
7Q10 in both WCC and BC	73	86 (for 2000)	–13 (–15%)
7Q10 in both WCC and BC	73	88 (for 2010)	–15 (–17%)

shortfall could lie either in increasing supply or in reducing demand– or some combination of the two. Water conservation efforts can play a crucial part in achieving the goal of reducing demand by 17% in the Wilmington metropolitan area. This reduction can enhance the **E**[4] balance, helping city residents to flourish into the indefinite future without unnecessarily undermining the integrity of the hydrological cycle or ecological systems that depend on it (Malkina-Pykh and Pykh, 2003; Gleick et al. 1995).

As previously discussed, in an urban setting, many strategies for conserving water have been considered and applied (Wang et al. 1999). They include curtailment, conservation-oriented pricing, information campaign, technological efficiency improvements, recycling and reuse, and land use modifications. In our analysis, we consider conservation-oriented pricing and conservation technology programs in the residential sector to meet the gap between water supply and demand during droughts modeled for the target year of 2010, while achieving revenue neutrality for utilities and equity for low-income groups.

Water Conservation-oriented Rates (WCORs)

In the design of WCORs, it is important to account for revenue volatility and address possible distributional effects (Chesnutt and Beecher, 1998 and Chesnutt et al. 1996). WCORs are usually justified as a form of marginal cost pricing that can often be at odds with a goal of revenue neutrality (Pint et al. 1999). Results suggest that if pricing is the primary conservation instrument, lower income households could bear a larger share of the conservation burden (Renwick and Archibald, 1998). Researchers have also found that marginal pricing can be regressive to low-income customers when compared with high-income customers (Pint et al. 1999; Agthe and Billings, 1997). These concerns are addressed below.

Water Conservation and Price Elasticity

A series of analyses were conducted by the Center for Energy and Environmental Policy at the University of Delaware utilizing a panel of 500 households for the period 1992-1997. The panel households were randomly drawn from the service area of Artesian Water Company, Inc., an investor-owned water utility serving a portion of the Wilmington metropolitan area. The dataset contains not only water consumption and bill information for the sample households during the summer quarters, but also information on their socio-economic characteristics that were obtained from surveys conducted in 1992 and 1994 (Wang et al. 1998). In the sensitivity analyses, the 500 households are assumed to represent residential customers in the Wilmington metropolitan area.

As a means of evaluating conservation, revenue, and equity implications of WCORs, we first classified the sample households into four income groups. The price elasticity of each income group was next estimated based on the model CEEP had developed for the Artesian Water Company. This is based on a regression model that is built using a proportional change measure of price and consumption between 1992 and 1997, instead of a single-year cross-sectional model. Before estimating the proportional change regression model, preliminary analyses were first conducted using the t-test (for dichotomous independent variables) and Pearson's correlation (for numerical independent variables) to identify variables that were significantly influence change in water consumption. The general form of the equation (1) used here is as follows (Wang et al. 1999):

$$[(Q_1 - Q_0) / Q_0] = ß_0 + ß_1 [(P_1 - P_0) / P_0] + ß_2 \text{ INFORM} + ß_3 \text{ DEVICE} + e \quad (1)$$

where, $[(Q_1 - Q_0) / Q_0]$: Proportional changes in day- and weather-adjusted water consumption during the summer months between two periods

$[(P_1 - P_0) / P_0]$: Proportional changes in inflation-adjusted average prices of water during the summer months between two periods

INFORM : Consumers with higher levels of water conservation information provided by Artesian = 1 and consumers with lower levels of information = 0

DEVICE : Customer who used water conservation devices provided by Artesian = 1 and customers who did not = 0

e : Error term

The overall price elasticity of water demand for residential customers in this utility derived from the above equation is –0.82, which is comparable with other studies. According to a study for the eastern U.S., winter elasticity is relatively low at –0.15, and summer elasticity is at –0.57, but the elasticity of outdoor sprinkling is quite elastic at –1.57 (Billings and Jones, 1996). A 5-year panel study for 121 households in Texas shows elastic price elasticity during summer, ranging from –1.57 to –1.63 (Hewitt and Hanemann, 1995). Using the income classification, separate regression analyses for households in each income bracket were performed to estimate elasticity for each income group (Table 22.3).

A series of scenario analyses were conducted to examine the level of changes in utility revenue and water consumption for each income group. As a reference case, both 15% and 20% price hikes were applied to all residential customers irrespective of their consumption levels and different elasticities as shown in Table 22.4. As expected, they lead to violation of

Table 22.3. Price elasticity for different income groups

Income group	Price elasticity
Group 1: Low-Income	–0.688 (–7.15)
Group 2: Low-Middle Income	–0.738 (–8.53)
Group 3: High-Income	–1.028 (–4.87)
Group 4: Upper-Income	–1.686 (–8.47)
Total residential customers	–0.816 (–13.56)

Note : The values in the parentheses denote t statistics. The estimated price elasticities are statistically significant because the observed t values are greater than the critical t values of –1.96 with significant level of 5%.

Table 22.4. Summary of the sensitivity analysis

Sensitivity scenarios	Equity to the low-income group	Revenue neutrality to utility	Utility-wide water conservation
Reference Scenario			
• Rate 15%↑ Entire Consumption	No	No	S (17% ↓)
• Rate 20%↑ Entire Consumption	No	No	S (23% ↓)
Marginal Consumption Scenarios			
• Rate 20%↑ Consumption>12,000 gals	Yes	Yes	S (10% ↓)
• Rate 20%↑ Consumption>13,000 gals	Yes	Yes	S (9% ↓)
• Rate 35%↑ Consumption>15,000 gals	Yes	Yes	S (13% ↓)
• Rate 25%↑ Consumption>10,000 gals	Yes	No	S (14% ↓)
• Rate 20%↑ Consumption>20,000 gals	Yes	Yes	NS (4% ↓)
• Rate 20%↑ Consumption>30,000 gals	Yes	Yes	NS (2% ↓)

the equity principle to the low-income group. The low-income group is expected to pay more, even with their lowered consumption. The reference cases meet a conservation criterion (significant reductions by 17% and 23%, respectively), but falls short of meeting the other two criteria: revenue neutrality to utility and equity to low-income customers.

In our alternative scenario analyses, water consumption on the amount exceeding the critical cut-off level from 10,000 gallons to 30,000 gallons (Pint et al. 1999; Tippett and O'Hare, 1999) per a summer quarter is only subjected to the higher rates from 20% to 50% (Wang et al. 2001). No rate change is assumed in the consumption below the level. Based on a series of scenario analyses, we identified a sound WCOR option that meets all the three requirements: 1) Water conservation; 2) Revenue neutrality to utility; and 3) Equity to customers.

The scenarios that meet all the three requirements are the cases where water rates were assumed to increase by 20%-35% on consumption above 12,000-15,000 gallons during the summer quarter. The most significant water savings come from the 35% rate hike and the 15,000 gallons cut-off level. In the case of a 35%-15,000 gallon scenario, statistically, no significant changes before and after the implementation are incurred in utility's revenue and low-income customers' bills. Overall conservation impact is statistically significant, reducing 13% of utility-wide residential water consumption (a 20%-12,000 gallon scenario is estimated to achieve a 10% reduction).

Table 22.5 shows in detail the results of the most significant water savings scenario (35% -15,000 gallons) that meets all the requirements of a sound WCOR option. Statistically, no significant changes before and after the implementation of a WCOR are incurred in utility's revenue (reduction in average bills from $68.9 to $65.9) and low-income customers' bills (from $51.3 to $50.7 in the low-income group and $63.0 to $61.9 in the low-middle income group). Overall conservation impact is statistically significant, reducing 13% of utility-wide residential water consumption (from 17.2 thousand gallons to 15.0 thousand gallons per quarter).

Table 22.5. Mean changes in revenue and consumption in various income groups: 35% marginal price increase on consumption above 15,000 gallons

Income groups	Revenue per customer (cutoff 15,000 gallons)			Consumption per customer (cutoff 15,000 gallons)		
	Before ($)	After ($)	Statistical significance*	Before (1,000 Gal.)	After (1,000 Gal.)	Statistical significance*
Group 1	51.27	50.68	NS	10.69	10.23	NS
Group 2	63.04	61.91	NS	15.08	14.17	NS
Group 3	77.19	71.96	S	19.67	17.57	NS
Group 4	83.41	70.21	S	22.38	17.18	S
Utility	68.85	65.91	NS	17.18	14.96	S (13% ↓)

* Note: 'S' denotes statistically significant difference in the before and after values, while 'NS' denotes statistically no significant difference based on one-tailed test with the 95% confidence level.

Our scenario results also show that a DDR option could enhance efficiency of water resource allocation among customers. Upper-income customers usually use much more water vis-a-vis discretionary uses than low-income customers, as reflected in their high price elasticity (–1.686 compared to –0.688 of the low-income group). As shown in Table 22.6, with the cut-off consumption level of 15,000 gallons, the marginal prices for the low-income and low-middle income groups are not changed, but in cases of high income (assumed consumption of 25,000 gallons per a summer

Table 22.6. Efficiency implications of a WCOR implementation: based on artesian's WCOR residential tariff (1997)

Inclining rates	Income group	Before*	After*
1st Block	Low Income (Consumption 10,000 gals)	$ 2.45	$ 2.45
2nd Block	Low-Middle Income (Consumption 15,000 gals)	$ 2.61	$ 2.61
2nd Block	High Income (Consumption 25,000 gals)	$ 2.61	$ 3.22
3rd Block	Upper Income (Consumption 35,000 gals)	$ 3.04	$ 4.47

Note: * Inclining block rates per 1,000 gallons.

quarter) and upper income customers (assumed summer quarter consumption of 35,000 gallons), their marginal prices are increased by 23% (from $2.61 to $3.22) and 47 percent (from $3.04 to $4.47), respectively. The price hikes target discretionary water uses by large consumers.

Conservation Implications of WCORs

Assuming all the utilities in the metropolitan area adopt a WCOR option as suggested above, residential water consumption is expected to reduce by 13% during drought events. The proportion of residential water consumption to the total consumption during the summer months is expected to be 48.8% in 2010 (WSTF, 1999), which is equivalent to a 6.3% reduction in total water consumption in 2010. As around 12% of water produced is unaccounted in the city (Song, 2001), total water savings from the case scenario would amount to 7.1%, equivalent to 6.3 mgd (in a 20% -12,000 gallon scenario, it would be 5.5%, equivalent to 4.8 mgd).

In 2010, water demand in northern New Castle County is projected to reach 88 mgd, but its supply is expected to be 85 mgd, based on the current condition where a 7Q10 exists only on WCC (but not on BC), meaning a negative balance of 3 mgd. But due to a WCOR option, water demand could be reduced to 81.7 mgd, and no water shortage problem would surface. In the case where 7Q10 is applied to both WCC and BC, the area is projected to need 88 mgd in 2010, but its supply is only 73 mgd, a deficit of nearly 15 mgd or 17%. Residential water savings through the above WCOR option would reduce 6.3 mgd, leaving 8.7 mgd short.

Conservation Technology Programs (CTPs)

The state, in collaboration with water utilities, can encourage adoption of more efficient water-consuming appliances by residential customers. On January 13, 1988, the Delaware River Basin Commission (DRBC) passed Resolution 88-2, setting standards for toilets, showerheads, faucets and urinals. It applied to all fixtures and fittings in new or renovated homes throughout the Delaware valley.[xxi] This resolution went into effect July 1, 1991. By January 1, 1992, three of the four states—Delaware, New Jersey, New York—had adapted statewide standards that met the DRBC standards (Featherstone, 1996).

In this study we have only considered five indoor appliances and one outdoor lawn sprinkler. The indoor appliances include clothes washers, dishwashers, faucets, toilets, and showerheads. Assuming that the homes built after 1991 will adopt the state plumbing code, our estimation of conservation potentials for faucets, toilets and showerheads are applied only to the housing units already existed in 1992. For clothes washers and dishwashers, both new and existing housing units are applied in the estimation of water savings potentials. Water savings potential for lawn sprinklers is estimated on the basis of the size of lawn areas regardless of the age of housing units.[xxii]

Data, Assumptions and Procedures

As part of estimating water savings potential, we used the census data regarding number of households in the Wilmington metropolitan area in 1990 and in 2000, and a forecasted number of households in 2010 by the Delaware Population Consortium. For the participation rate of CTPs by residential customers, we take after those commonly used in the evaluation analysis of energy efficiency programs (IWG, 2000), assuming to be 65% in 2010. For the automatic energy efficiency improvements (AEEI) in water-consuming appliances, even without any policy interventions they are assumed to be 2% for those fixtures subject to the plumbing code and 1% for regular appliances such as clothes washers and dishwashers due to their slow turnover rates compared to toilets, showerheads or faucets.

For each indoor appliance, we first estimate the percentage of households that had inefficient appliances in 1992 based on our survey result. The percentage figure is adjusted to estimate those in 2010 by applying its automatic annual efficiency improvement rate. Once the number of households who would participate in CTP in 2010 is identified, potential water savings are estimated through multiplying it by an engineering and/or empirical savings figure (identified through literature review). The savings figure is usually expressed as gallon per capita per day (gpcd).

For outdoor water savings from lawn sprinklers, our target is total acreage of lawn areas in 2010, rather than total number of households or housing units. To produce the total lawn acres, remote sensing with a tie-in to a geographic information system (GIS) can be utilized by overlaying

[xxi] It required a maximum flow of 1.6 gallons per flush (gpf) for toilets and 1.5 (gpf) for urinals.

[xxii] Although it should be noted, however, that new houses need more water for gardens and lawns because of higher evapotranspiration rates due to lack of mature trees, but data do not allow for the distinction.

the parcel layers to residential properties. Using the percentage of lawn areas out of residential acres and potential reduced water consumption per acre, we estimated water savings from sprinkling per acre per day under a certain percentage of program participation assumption.

Estimation of Water Savings

Clothes washers and dishwashers are not subject to the State Plumbing Code regulation. Based on the CEEP survey, it was identified that 99% of households have clothes washers, and among them only 20% have efficient clothes washers. Potential water savings from efficient clothes washers range from 4.0 to 6.5 gallons per capita per day (gpcd) (FEMP, 2002; PNNL, 2002). Seventy-seven percent of households owned dishwashers, and only 20% of them have efficient dishwashers. Potential water savings from efficient dishwashers range from 0.4 to 1.0 gpcd (DRBC, 2002; Vickers, 2001). As an example, Table 22.7 summarizes procedures and estimates of potential water savings from CTP with respect to clothes washers.

Table 22.7. Potential water savings from clothes washers program (2010)

Estimation procedures	Estimates
Number of households in 2000: 2000 Census	189,017
Number of households in 2010: Delaware Population Consortium	207,988
Number of persons in a household in 2010: Delaware Population Consortium	2.65
Number of households with CW in 2000 (eligible households): 99%	187,127
Percentage of households with efficient CWs in 1992: CEEP survey	20.0%
Percentage of households with efficient CWs in 2010: a 1% annual improvement	24.2%
Number of households with inefficient CWs in 2010 (target households)	141,842
Number of households with potential program participation: 65% in 2010	92,197
Potential water savings (mg/yr.): 5.6 gpcd (DeOreo, 2001)	499.4
Potential water savings (mg/yr.): 4.0 gpcd (FEMP, 2002)	354.9
Potential water savings (mg/yr.): 6.5 gpcd (PNNL, 2002)	577.9
Potential water savings (mg/yr.): 5.9 gpcd (Vickers, 2001)	526.1
Potential water savings (million gallons per day)	0.97~1.58

Since faucets, toilets and showerheads are all subject to the State Plumbing Code regulation, their estimation procedures of water savings are different from those of clothes washers and dishwashers. New residential housing units built or renovated after 1991 are supposed to have efficient plumbing facilities because of the regulation. Our target units in 2010 are based on the 1992 housing stocks (with inefficient faucets, toilets and showerheads) minus those housing units to install efficient plumbing fixtures according to an annual 2% AEEI. In case of faucets, those households with efficient faucets were only 23% in 1991 (based on the CEEP survey) and are expected to increase to 27.8% in 2010 due to a 2% automatic annual efficiency improvement. Potential water savings from efficient faucets range from 1.2 to 2.7 gpcd (DeOreo, 2001 and Vickers, 2001). Using the same approach, water savings from low-consumption toilets and low-flow showerheads are estimated.

In the case of lawn sprinklers, a completely different approach was used. Instead of housing units as a basic unit of analysis, outdoor water savings are estimated on the basis of lawn acreage and potential water savings per acre (McCann, 1994). According to Robbins et al. 2002, lawn area is usually 60% of residentially-zoned land area. This figure was adjusted by both the CEEP survey result and a 2% automatic efficiency improvement. The survey shows that one-quarter of those households who have a lawn and/or gardens did not water at all during the summer. Using this adjusted figure, potential water savings from sprinkling management are estimated to be 1.63 mgd (Table 22.8).

Table 22.8. Potential water savings from sprinkling management during peak seasons

Estimation procedures	Estimates
Residentially-zoned land area in 2000 (acres)	200,732
Proportion of lawn area in 2000 (acres): Robbins	60.0%
Estimated size of lawn area in 2000	120,439
Estimated size of lawn area in 2010: Assuming the same proportion of lawn acre to household size as the 2000 case	132,527
Program participation rate	3%
Participating lawn acreage	3,976
Potential water savings from sprinkling management (mg/yr.): 450 g/acre (McCann, 1994)	595.0
Potential water savings (million gallons per day)	1.63

Potential water savings from the above selected indoor and outdoor conservation technologies are shown in Table 22.9. Due to the significant variations in estimated savings, the median estimate of each technology is also used in the analysis. The following summary table shows both range and median. The effective water savings become in the range from 6 to 11 mgd with median of 8 mgd by reducing 12% water losses.

Major Barriers to WCOR and CTP

Given the potentially powerful effects of WCOR and CTP in the Wilmington metropolitan area as discussed above, care should be taken in implementing them. Successful implementation of these programs is contingent upon a

Table 22.9. Summary of potential water savings from CTPs (mgd)

Conservation technologies	Water savings Range	Median
Clothes Washers	0.97~1.58	1.37
Dishwashers	0.08~0.19	0.13
Faucet Restrictors	0.23~0.51	0.26
Ultra Low-Consumption Toilets	1.89~2.92	2.36
Low-Flow Showerheads	0.04~0.72	0.24
Sprinkling Management	2.16~3.60	2.88
Indoor and Outdoor Water Savings	5.37~9.52	7.24
Effective Water Savings (Including unaccounted for water rate of 12%)	6.01~10.66	8.11

utility's current rate structure, conservation programs, awareness of consumers, system operating characteristics, potentially adverse impacts on customers, billing and implementation issues, the state's current regulatory supports, etc. The following are some implementation strategies to address major barriers to the WCOR and/or the CTP adoption.

- WCOR can be implemented during the drought emergency period declared by state or local government;
- Price hikes need to be significant enough to affect their water consumption behavior;
- Public awareness of WCOR and CTP is critically important. Changes need to be publicized in advance via media and also bill inserts to customers. These programs are only effective if they are known to customers in an appropriate time frame and are also simple enough to be broadly understood;
- Potential adverse impacts on customers need to be considered. Price hikes usually generate revenue surplus for a given utility because water demand is relatively inelastic, but they are regressive to the low-income group. A minimal amount of necessary water needs to be designated in order to address negative impacts on the low-income group and provide for equity in basic water needs;
- CTP may raise prices for customers due to reduced revenue from its implementation. CTP may discriminate low-income customers because they are less likely to take advantage of CTP, but pay higher prices. Revenue surplus possibly from WCOR is less of a concern in comparison to shortfalls. The excess utility revenues can be captured by several adjustment mechanisms, including taxes to improve low-income equity issue (Merrifield and Collinge, 1999);

- A close review of the rate structures and conservation programs of the unregulated utilities should be undertaken to determine if WCOR and CTP would help reduce significant water consumption in their systems during the summer droughts;
- Revenue volatility always exists in the implementation of WCOR and CTP. Implementing WCOR and CTP programs are learning experiences, requiring certain mechanisms to address volatility. They include the creation of a contingency fund, inclusion of a risk margin in calculation of revenue requirements, an automatic rate adjustment, and frequent rate adjustments (Chesnutt et al. 1996);
- The state needs to coordinate water utilities regarding implementation of WCOR and CTP programs. Monitoring, data collection, and evaluation of these programs also need to be also coordinated by the state. Governor Gary Locke of the state of Washington has signed into law a water reform measure that offers, among other benefits, a tax incentive for water utilities to conserve and reuse water. Under this measure, the tax rate would be reduced to about 1.25% from about 5% in cases where the water is conserved or reused;
- The State Public Service or Utility Commissions are one vehicle to advance implementation of WCOR and CTP programs, since sometimes they are asked to look at a number of types of WCOR and/or CTP programs and select appropriate alternative(s) for those under their jurisdiction by their State General Assembly. Currently, most municipal water systems are not regulated by Public Service Commission; and
- Unless there is the legislative resolution or governor's 'executive order' to adopt a WCOR and CTP option county- or state-wide, WCOR and CTP will be limited if adopted only by PSC. Otherwise, it may appear that some customers of investor-owned water utilities are subject to paying penalties for excess water usage, whereas customers of municipal water systems are not. WCOR and CTP programs need to be applied on a non-discriminatory basis.

Water Savings: Reduced Withdrawal

Water savings potential from both residential WCOR and CTP programs in the Wilmington metropolitan area are estimated to be in the range of 11~17 mgd (4.8~6.3 mgd from WCOR and 6.0~10.7 mgd from CTP).[xxiii] The estimated minimum savings are less than what is forecasted to be needed during drought seasons in 2010 (15 mgd), but the maximum savings

[xxiii] It can be argued that water savings may be underestimated because synergic effects of both programs are not considered. Utility revenue issues associated with CTP is not fully considered due to limited information on program costs and additional investment costs incurred during summer peak.

exceed the target. Considering the fact that these savings are only from the residential sector, any gap between supply and demand can be easily resolved through water conservation programs if they include the other sectors. Some studies show that the commercial and industrial sectors may have higher potentials for water savings than the residential sector (Vista et al. 1997).

Reduced Intakes from Stream Flows

As a means of exploring impacts of WCORs and CTPs on stream flows in the Christina River Basin, a scenario approach is adopted to estimate potential reduction in water intakes from three utilities that withdraw water from BC or WCC.[xxiv] Stream flows are also affected by heavy use of groundwater sources because a lot of groundwater comes from shallower aquifers that draw from the same runoff that feeds freshwater ecosystems – but that is not in this model.[xxv] In order to estimate potential reduction in water intake from the streams, water savings from WCORs and CTPs by each utility were first estimated.

For Scenarios I and II, we used two saving figures (10% and 13%) that are revenue neutral and equitable WCORs for use during drought summer months. These saving percentages are derived from the cases where the 20% marginal price increase is applied to consumption above 12,000 gallons and the 35% marginal price increase above 15,000 gallons during the summer quarter. A 20% -12,000 gallon scenario is estimated to achieve a 10% reduction in residential water consumption, whereas a 35%-15,000 gallon scenario represents a 13% reduction. Daily water savings per utility were estimated by the following formula:

$$DDR = RPD * SR * (1 + UR)$$

where,	DDR	:	Residential daily peak water savings from the WCOR
	RPD	:	Residential daily peak water demand
	SR	:	Water savings rate from the WCOR
	UR	:	Unaccounted-for-water rates

The results of the estimate are shown in Table 22.10. The city of Wilmington is expected to reduce water intake from the Brandywine Creek

[xxiv] Scenarios I and II are solely based on WCOR in the residential sector, and another two Scenarios (III and IV) are derived from residential CTP. Scenarios V and VI include both WCOR and CTP.

[xxv] Over-drafting of groundwater can rob streams and rivers of a significant fraction of their flow, whereas pollution can render aquifers unfit for human use and degrade water quality in adjacent freshwater ecosystems (Johnson et al. 2001). In a study of 54 streams in different parts of the country, the U.S. Geological Survey (USGS) found that groundwater is the source for more than half the flow (on average). While providing surface bodies with enough water to keep them stable, aquifers also help prevent them from flooding (Sampat, 2000).

Table 22.10. Daily water savings of residential peak consumption: WCORs

Utility	Peak daily (mgd)	Savings rate (%)	Unaccounted-for-water rates (%)	Daily savings (mgd)
		10		0.94
City of Wilmington	8.31	13	13.0	1.22
		10		0.78
United Water Delaware	7.08	13	9.05	1.00
		10		0.05
City of Newark	0.46	13	13.0	0.07
		10		1.77
Total/Average	15.85	13	11.2	2.29

by 0.94 mgd in Scenario I and 1.22 mgd in Scenario II. United Water Delaware and the city of Newark are expected to withdraw less water from the White Clay Creek by 0.78 mgd (1.00 mgd in Scenario II) and 0.05 mgd (0.07 mgd in Scenario II), respectively, during summer droughts. Total daily peak savings in the residential sector are expected to range from 1.77 mgd to 2.29 mgd.

CTPs are estimated to contribute to effective water savings in the residential sector by 6.0 to 10.7 mgd with a median of 8.1 mgd as shown in Table 22.9. As the residential peak water demand is estimated at 42.9 mgd in 2010, this leads to water savings ranging from 14 to 25%, with median savings of 16%. Based on the following formula, potential water savings from the CTP are estimated and shown in Table 22.11. Water savings from CTPs for all three utility areas that withdraw water from both streams are expected to range from 2.47 mgd to 4.41 mgd. The city of Newark has the smallest impact among three utilities because of a small population.

Table 22.11. Daily water savings of residential peak consumption: CTPs

Utility	Peak daily (mgd)	Savings rate (%)	Unaccounted-for-water rates (%)	Daily savings (mgd)
		14		1.31
City of Wilmington	8.31	25	13.0	2.35
		14		1.08
United Water Delaware	7.08	25	9.05	1.93
		14		0.07
City of Newark	0.46	25	13.0	0.13
		14		2.47
Total/Average	15.85	25	11.2	4.41

$$CTP = RPD * (1 + UR)$$

where, CTP : Residential daily peak water savings from the CTP
RPD : Residential daily peak water demand
UR : Unaccounted-for-water rates

Table 22.12 summarizes expected daily peak water savings for three utilities by each scenario. The city of Wilmington shows the largest savings, ranging from 0.94 mgd to 3.57 mgd, whereas the city of Newark is expected to reduce withdraws of water during the summer months, ranging from 0.05 mgd to 0.20 mgd. Overall, Scenario IV, which combines high residential peak savings from the WCOR (Scenario II) with CTP peak savings (Scenario IV), conserves the most at 6.70 mgd during the drought summer.

Table 22.12. Expected daily peak water savings by utilities

(Unit: mgd)

Scenario	City of wilmington	United water delaware	City of newark	Total impact
• Scenario I: 35%-12,000 gal	0.94	0.78	0.05	1.77
• Scenario II: 35%-15,000 gal	1.22	1.00	0.07	2.29
• Scenario III: min. CTP	1.31	1.08	0.07	2.47
• Scenario IV: max. CTP	2.35	1.93	0.13	4.41
• Scenario V: Scn. I + Scn. III	2.25	1.86	0.12	4.24
• Scenario VI: Scn.II +Scn.IV	3.57	2.93	0.20	6.70

Impacts on Stream Flows

During July of 1999, the Wilmington metropolitan area experienced a record drought. Using the month of July as a baseline, our analysis explores how conservation can reduce water intakes by the utilities to reduce the number of days spent below 7Q10 low-flow standards.

The results of our Scenarios IV, V and VI are displayed in Table 22.13. The savings figures are added to July 1999 stream flow records (provided by Delaware's Water Resources Agency) at each utility intake site to calculate the additional daily stream flow achieved under each conservation scenario. The augmented daily stream flows are then juxtaposed against 7Q10 levels to determine the number of days spent below critical levels. Especially significant is the case of the United Water Delaware intake at Smalley's Pond, where applying any conservation scenario would reduce the number of days below 7Q10 from 16 to 1. The United Water intake on WCC also achieved significant savings, where Scenarios IV and V result in 1 day below 7Q10, and no days are below in Scenario VI. For the basin as a whole, we see that by implementing the scenarios, the number of days below 7Q10 can be reduced by 26 days from the basin total of 57 days.

Table 22.13. Number of days spent below critical 7Q10 levels, July 1999

Scenario	BC Wilmington	WCC Newark	WCC UWD	Christina UWD	Basin totals
Observed	7	29	5	16	57
Scenario IV	4	26	1	1	32
Scenario V	4	26	1	1	32
Scenario VI	4	23	0	1	31

CONCLUSIONS

A few general conclusions can be reached as a result of the analysis considered above. It is evident that WCOR and CTP programs that promote water conservation can produce an effective reduction in water consumption in urban areas during drought. This analysis shows conclusively that future water demand for the Wilmington metropolitan area can be met through the introduction of a WCOR option. The analysis also shows that the combined WCOR and CTP programs could meet the 15 mgd gap in 2010 – even with the condition of 7Q10 applied to both WCC and BC. Furthermore, the lower income group need not be subjected to an inequitable fiscal burden.

An indirect, but significant advantage of the combined conservation option is its positive **E**^{4} consequence. The reduction in the consumption of water allows for an increased amount of water to remain in the natural environment, thus supporting ecology, potentially mitigating saltwater intrusion in coastal cities, and perhaps even eliminating need for environmentally and socially questionable water supply augmentation options. Water conservation also leads to energy and economic savings. Energy consumption is reduced vis-à-vis utilization of water efficient appliances, and lowered energy needs associated with withdrawal from surface and groundwater and discharge of wastewater. Customers also enjoy immediate economic benefits through lowered bills. Compared to supply-side options, conservation can be achieved without seriously burdening under-privileged residents or downstream residents, and also enhances opportunity for participation by residents and localized communities in water management processes (Smith Jr., 2003a, b). The efficient use of water improves the **E**^{4} balance, enhancing urban sustainability, especially during the course of droughts in urban areas.

Overall, adopting the combined conservation program is a viable option. It has been established in this chapter that by employing the conservation options, and it is possible to achieve an efficient outcome without sacrificing equity requirements. The advantages of this program are that it satisfies with minimal regulation the quadruple objectives of water conservation, namely:

- Improving efficiency;
- Providing revenue neutrality;
- Assuring distributional equity; and
- Enhancing stream ecology.

Even though there are stellar examples of benefits of water conservation as indicated above, most utilities in urban areas have only scratched the surface of what is possible in their service areas. Even where some of the best funded and most promising water conservation programs exist, the majority of urban water agencies rely on voluntary practices and programs that are not comprehensive are incompletely implemented, and are inadequately monitored (Gleick, 2001). As Vickers (2001) indicates, to achieve impressive water savings, we need a combination of elements: leadership; political will; commitment to more sustainable water supply and wastewater systems; and concern about long-term costs to consumers. Most important is an understanding of, and strategic investment in, large-scale, innovative, yet dependable, water-efficiency technologies and pricing policies.

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