

# Enhancement of sustainability in cities through water conservation: the case of the Wilmington Metropolitan City, Delaware

Y.-D. Wang, M. Scozzafava, J. Byrne, S. Wozniak,  
M.-S. Yoo, M. Hesson & A. Waegel

*Center for Energy and Environmental Policy, University of Delaware,  
U.S.A*

## Abstract

Water becomes a scarce resource in cities due to urban sprawl and ground-surface water contamination. This shortage, especially during drought seasons, limits economic activities, reducing the quality and quantity of drinking water, and lowering the level of stream flows passing through urban waterways and associated catchments. This paper shows, using the case of the Wilmington Metropolitan City (covering northern New Castle County), that a combined policy of water conservation-oriented rates (WCORs) and conservation technology programs (CTPs) in the residential sector can meet a sustainability goal of the city in peak water demand seasons: sufficiently meeting the short-term additional water requirement of 15 million gallons per day (mgd) in 2010 (with simultaneously achieving revenue neutrality of a water utility and equity to low-income customers) and sustaining in-stream ecology.

*Keywords: urban sustainability, water conservation, peak water demand seasons, droughts, stream flows.*

## 1 Introduction

Sustainability in a city can be enhanced through lowered resource inputs and waste outputs without lowering socio-economic conditions for current and future generations. Water is one resource for cities, and its conservation, reuse, and recycling has significant implications for urban sustainability. Water becomes a scarce resource in cities due to urban sprawl and ground-surface



water contamination. This shortage, especially during drought seasons, limits economic activities, reducing quality and quantity of drinking water, and lowering the level of stream flows passing through urban waterways and associated catchments.

This paper intends to show that well-designed water conservation programs can enhance the sustainability of a city. Sustainability is considered to be enhanced through conservation measures by sufficiently meeting the short-term additional water requirement in a cost-effective way, while simultaneously achieving revenue neutrality of a water utility and equity to low-income customers and sustaining in-stream ecology.

Our focus is peak water demand seasons in the Wilmington Metropolitan City, covering northern New Castle County, Delaware. The conservation programs considered here are only water conservation-oriented rates (WCORs) and conservation technology programs (CTPs) in the residential sector. Based upon our national surveys and extensive literature review, the conservation potential for implementing a wide array of CTPs is evaluated. For the potential impact of the conservation-oriented rates, we utilize an econometric model estimated from our panel data of 500 households (1992-1997).

As a way of proceeding in this paper, a sustainability framework for the city is first developed, followed by a discussion of the role of water conservation in the context of the framework. Using the Wilmington Metropolitan City as a case, the paper estimates the potential amount of residential water savings through WCORs and CTPs. Finally, it is demonstrated that residential water conservation leads to sustainability in the city, especially during summer droughts.

## 2 A framework of city sustainability

The city is conceived as a socio-ecosystem, a combined system composed of human and ecological dimensions. The system extends to include socio-economic aspects of human opportunity in cities, integrated with ecological aspects regarding resources consumed and wastes discharged. In a broad sense, the city is an intersection of the natural environment, the built environment, and the socio-political environment [1].

In consideration of urban sustainability, it is important to consider such aspects as hinterland, dynamics, and interdependence. Urban sustainability affects, and is affected by, a city beyond its boundary. Its hinterland can be trans-regional and even transnational. Dynamics imply a time dimension in that current urban activities do not lower the quality of life for future generations. Urban activities here are defined as the ones associated with resource uses, throughput processes, and the consequent negative or positive outputs. Interdependence is more of a static dimension in that the quality of urban life can be sustainable by balanced and integrated consideration of usage of energy (E), social-political equity (E), ecological viability (E), and economic development (E), or  $E^4$ .



As shown in Figure 1, sustainability in a city can be enhanced through activities that lower energy/resource flow (energy), enhance equitable civil/cultural flow (equity), increase environmental amenity flow (environment), and induce efficient technology/ capital flow (economy) in the development of cities without lowering socio-economic conditions for current and future generations. To be sustainable, urban development activities in a city need to consider hinterland, dynamic nature, and interdependence of  $E^4$  in its policies and programs. Sustainable urban development, in turn, makes it possible for a city to achieve efficient energy uses, improve economic efficiency, ameliorate social equity, and generate ecological efficiency for now and in the future.

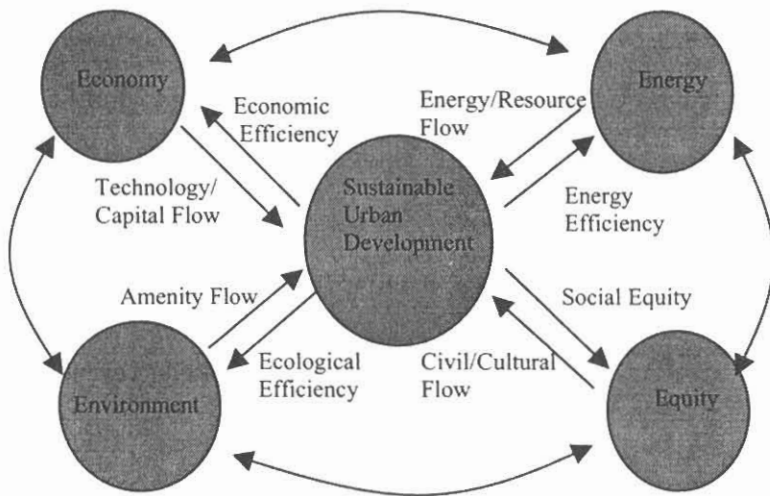


Figure 1: A framework of sustainable urban development—integration of  $E^4$ .

### 3 Water and urban sustainability

Water is one resource for cities, and its conservation, reuse (i.e., rainwater) and recycling (for various urban uses) have significant implications for urban sustainability. Water becomes a scarce resource in cities due to increased population, economic growth, urban sprawl, ground-surface water contamination, and above all poor management practices. This shortage, especially during drought seasons, restricts the  $E^4$  balance.

Water shortage during droughts restricts urban activities in the commercial and industrial sectors, and also the agricultural sector in its hinterland, leading to unemployment and loss of tax revenue for local, state, and federal government (economy). Droughts lowers the level of stream flows passing through urban creeks and wetlands, disturbing aquatic ecosystems in the stream and reducing water-related environmental and recreational values—environmental amenity—

to city residents (environment). Reduced quality and quantity of drinking water associated with upstream development and/or heavy intakes during droughts causes such burdens as public safety and health concerns, user conflicts, reduced quality of life, and distributional inequity on downstream city residents (equity). Reduced generation of hydro electricity in the hinterland resulting from droughts negatively affects energy required to support urban activities (energy).

The conservation of water improves the  $E^4$  balance, enhancing urban sustainability, especially during droughts in urban areas. Customers enjoy immediate economic benefits through lowered bills and medium and long-term benefits from lessening or eliminating needs for costly supply-side facilities or wastewater and sewage treatment facilities (economy). Reduced water consumption lowers needs for withdrawal from surface water, lessens saltwater intrusion in certain cities near coastal areas, and mitigates or eliminates environmentally questionable water supply augmentation solutions (environment). Conserved water makes it easier to optimize water allocation to competing users through increased water availability. Compared to supply-side options, conservation can be achieved without seriously raising burdens to the under-privileged residents and also enhances opportunity for participation by residents and localized communities in water decision processes (equity). Energy consumption is directly reduced when residents adopt water efficient appliances, and utilities use less energy for surface water withdrawal and wastewater treatment and discharge (energy).

#### 4 Wilmington as a case

Delaware has a history of periodic water shortages due to droughts, demonstrating just how vulnerable the northern part of the State is to the phenomenon. The portion of the State most affected by drought has typically been the Wilmington Metropolitan City where it receives approximately 70% of its drinking water from the Christina River Basin (mainly composed of the White Clay Creek (WCC) and the Brandywine Creek (BC)). During the droughts, water supplies in the city were severely strained. Water quality was also threatened.

The availability of water in WCC (and BC probably before the target year of 2010) is constrained by the 7Q10 Minimum Flow Standard that is statistically computed to occur 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. The demand in northern New Castle County covering the city for the year 2010 is projected to reach 88 mgd [2]. When demand for water is compared with supply availability, it becomes evident that the surplus or deficit of water would depend on the adoption of the 7Q10 system.

Expanding 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 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 City.

In an urban setting, many ways of conserving water have been considered and applied. They include curtailment, conservation-oriented pricing, information campaign, technological efficiency improvements, recycling and reuse, and land use modifications. In our application, we only consider conservation-oriented pricing and conservation technology programs in the residential sector.

## 5 Water Conservation-Oriented Rates (WCORs)

In the design of WCORs as a tool for drought management, it is important to account for revenue volatility and address possible distributional effects. WCORs are usually justified by linking to a marginal cost pricing that can often be at odds with consideration of revenue neutrality, causing revenue shortfall or surplus. Researchers also show that a marginal price is regressive to low-income customers when compared with high-income customers [3].

### 5.1 A model and price elasticity

A series of analyses were conducted 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 City, Delaware by the Center for Energy and Environmental Policy, University of Delaware. In the sensitivity analyses, the 500 households are assumed to represent residential customers in the Wilmington Metropolitan City.

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 we had developed for the Artesian Water Company [4]. 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.

Based on the estimated elasticity for each income group, a series of scenario analyses were conducted to examine the level of changes in utility revenue and water consumption for each income group. In these analyses, water consumption on the amount exceeding the critical cut-off level (10,000 gallons to 30,000 gallons per summer quarter) is only subjected to the higher rates (from 20% to 50%), whereas 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 3 requirements: water conservation, revenue neutrality to utility, and equity to customers. The scenarios that meet all the 3 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).

## 5.2 Conservation implication of WCOR

Assuming all the utilities in the metropolitan city 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 [5], which is equivalent to a 6.3% reduction in total water consumption in 2010. Because around 12% of water produced is unaccounted in the city, effective 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 of the city 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 city 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.

## 6 Conservation Technology Programs (CTPs)

The state, in collaboration with water utilities in the city, can encourage adoption of more efficient water-consuming appliances by residential customers. In this study we have considered 5 indoor appliances and 1 outdoor lawn sprinkler. The indoor appliances include clothes washers, dishwashers, faucets, toilets, and showerheads.

### 6.1 Data, assumptions and procedures

As part of estimating water savings potential, we used the census data regarding number of households in the Wilmington Metropolitan City 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 [6], assuming to be 65% in 2010. For the automatic annual efficiency improvements 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 with inefficient appliances 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 acreages of lawn areas in 2010, instead of total number of households or housing units. 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 (identified from the CEEP survey).

## 6.2 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) [7]. 77% 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 [8].

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 should have efficient plumbing facilities because of regulation. Our target units in 2010 are based on the 1992 housing stocks (with inefficient faucets, toilets and showerheads) minus those housing units to be installed with efficient plumbing fixtures according to a 2% annual automatic efficiency improvement.

In case of faucets, those households with efficient faucets were only 23% in 1992 (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 [9]. 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. Lawn area is usually 60% of residentially-zoned land area [9]. 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.

Potential water savings from the above selected indoor and outdoor conservation technologies are in the range of 5.4–9.5 mgd: clothes washers (1.0–1.6); dishwashers (0.1–0.2); faucet restrictors (0.2–0.5); ultra low-consumption toilets (1.9–2.9); low-flow showerheads (0.1–0.7); and sprinkling management (2.2–3.6). The effective water savings become in the range from 6 to 11 mgd with median of 8 mgd by reducing 12% water losses.

## 7 Water savings: reduced withdrawal

Water savings potential from both WCOR and CTP in the Wilmington Metropolitan City 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). The estimated minimum savings (11 mgd) are less than what forecasted to be needed during drought seasons in 2010 (15 mgd), but the maximum savings (17 mgd) exceeds the target. Viewed in terms of 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 other water-consuming sectors.

### 7.1 Reduced intakes from stream flows

As a means of exploring impacts of WCORs and CTPs on stream flows in the Christina River Basin, a scenarios approach is adopted to estimate potential reduction in water intakes from the utilities within the Wilmington Metropolitan City that withdraw water from BC or WCC. Two scenarios (Scenario I: a 20%–12,000 gallon scenario and Scenario II: a 35%–15,000 scenario) are solely based on WCOR in the residential sector, and another two scenarios are derived from residential CTPs (Scenario III: a minimum CTP savings and Scenario IV: a maximum CTP savings). Scenarios V and VI include both WCORs and CTPs.

Table 1 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 3.6 mgd, whereas the City of Newark is expected to reduce withdrawals of water during the summer months, ranging from 0.05 mgd to 0.2 mgd. Overall, the Scenario VI, which combines high residential peak savings from the WCOR (Scenario II) with CTP peak savings (Scenario IV), conserves the most at 6.7 mgd during the drought summer.

### 7.2 Impacts on stream flows

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

The savings figures are added to July 1999 stream flow records (provided by the Delaware 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 1: 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
7.2.1.1.1 WCOR + CTP	2.25	1.86	0.12	4.24
• Scenario V: Scn. I + Scn. III	3.57	2.93	0.20	6.70
7.2.1.1.2 • Scenario VI: Scn.II + Scn.IV				

## 8 Conclusions

A few general conclusions can be reached as a result of the analysis considered above. It is evident that WCOR and CTP that promote water conservation can produce an effective reduction in water consumption during drought seasons. This analysis shows conclusively that future water demands for the Wilmington Metropolitan City can be met through the introduction of a WCOR option under the current condition (7Q10 only applied to WCC). In addition, the analysis 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 disproportionately large revenue burden, and water utilities also may not be subject to revenue volatility.

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, lessening saltwater intrusion in coastal cities, and eliminating need for environmentally questionable water supply augmentation options. Water conservation also leads to energy and economic savings. Energy consumption is reduced from utilization of water efficient appliances and lowered energy needs associated with withdrawal from surface water and



discharge of wastewater. Customers also enjoy immediate economic benefits through lowered bills. Compared to supply-side options, conservation can be achieved without seriously raising burdens to the under-privileged residents or downstream residents and also enhances opportunity for participation by residents and localized communities in water decision processes. The efficient use of water improves the  $E^4$  balance, enhancing urban sustainability, especially during droughts in urban areas.

Overall, adopting the combined conservation program is a viable option. It has been established in this paper that by employing the conservation option, 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.

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