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Conservation rates: the best 'new' source of urban water during drought

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Abstract

In the United States, water conservation-oriented rates (WCOR) are an increasingly vital tool for promoting water conservation and mitigating urban drought. Our models prove that one type of WCOR, drought demand rates (DDR), can produce with minimal regulation the quadruple objectives of conservation rates: (1) improving efficiency; (2) providing revenue neutrality; (3) assuring distributional equity and (4) guaranteeing the conservation of water. We demonstrate that such rates can also reduce days that urban streams drop below 'critical flow' levels, providing a voice for nature. Our study is situated in northern New Castle County (NCC), Delaware (DE), USA, and the lessons garnered have relevance for industrialized communities seeking a 'soft-path' to drought mitigation.

Introduction

This manuscript focuses on modelling water conservation-oriented rates (WCOR) to foster sustainability of water provision and environmental stewardship, especially during periods of drought. The research also addresses concerns regarding implementation of WCOR in terms of equity for low-income consumers, and utility revenue volatility. Our case study is based in the highly industrialized Mid-Atlantic region of the United States, and we believe that similar highly industrialized and relatively wealthy areas around the globe concerned with sustainability of ecology and supply in the face of water scarcity will benefit from our analysis. Before proceeding to our WCOR research, a review of selected geographic and regional drought literature is provided; the econometric literature is blended into the text to aid analysis.

Literature

Heathcote notes drought's place in the historical psyche of many nations (1969), providing ancient quotes to underscore his points. Nevertheless, Heathcote (1969) notes that drought has historically been under-researched, possibly because of the problems with defining it, understanding what it may do and the differences in perceptions of what it means to experience a 'drought' in different communities (see also National Drought Mitigation Center 2005). Drought is often framed as a temporary water supply 'crisis' requiring mitigation. However, some researchers, such as Richard Palmer of the Water Resources Management and Drought Planning Group at the University of Washington, evidence a more systematic and holistic approach. Geographic literature on drought and the root causes of such 'crises' is especially informative because it examines both the biophysical and socio-political dimensions of the hazard (Cutter *et al.* 2000). We add to this holistic discussion through our integration of interdisciplinary methods and emphasis on human and ecosystem sustainability.

Drought is a global phenomenon. Governments in nearly every inhabitable climate have reasons to develop drought-mitigation strategies to reduce ecological, economic and public health impacts (Berz *et al.* 2001).

Responsibility for sound drought-mitigation strategies often lies squarely upon government at multiple scales. In this regard, drought mitigation is seen less as a bottom-up process, and more as a sign of 'good governance'. As the Australian Secretary in the Attorney-General's Department noted when speaking of what he called his government's 'obligation' to mitigate impacts, 'If we think about how governments deal with crises the first examples that come to mind are natural disasters' (Cornal 2005, p. 27).

As Cutter (2004) points out, how we as societies evaluate such risks is a subjective process – and therein lies the contested nature of coping with such hazards. We assert that an important part of this process should be a critical self-examination of what humans can do on the demand side to mitigate drought, rather than solely searching for supply-side remedies that may mask over-consumptive ('unsustainable') behaviour. Dagel (1997) finds that when drought is analysed, it is too often viewed as a 'one-dimensional' hazard, and perhaps this limits the scope of our response to it. His surveys of ranchers reveal descriptive elements of drought from *their* view.

Certain authors do focus on the vulnerability of communities other than humans when examining the impact of drought (Whitford & Sobhy 1998). Indeed, while our work focuses on demand side, or 'soft-path', modelling for mitigation of supply–demand gaps during drought, we believe that our research also makes a contribution by modelling scenarios for preservation of 'critical flows'.

Political economy perspectives on drought can help contextualize management choices. Two pieces that appeared in *Antipode* in the last decade are especially worth noting, as they explore the political economy of producing 'scarcity'. Kaika's (2003) work in Greece, and Nevarez's (1996) rather insightful work in the United States, provide a glimpse of the underlying forces driving manipulation of scarcity and concern about drought for political gain. (See also Swyngedouw 1999 and his other works for insightful political economy of water analysis.) Other geographers have directly critiqued the impact of neoliberalism on vulnerability to drought, and the possible creation of 'crisis'. For example, Haughton (1998a, b) locates his critique of 'corporate constructions' of drought in the 1995–1996 crisis in West Yorkshire. He situates his work in discourse concerning the public good, regulation theory, good governance and the privatization of water supply. Bakker (1998) enters this debate as a response to Haughton's work.

Hayes *et al*. (2004) bridge drought theory and mitigation practice through the development of a drought risk analysis model that accounts for the economic, environmental and social costs of droughts. In looking forward, some researchers focus on implications of climate change models for water supply. Frei *et al*. (2002) look at the same region that our case study is based in, and they also acknowledge the important trend of growing demand that we address. They identify the same period of drought 'emergency' in 1999 that we use for our modelling. Also, Nichols (2004) highlights concerns that global warming, either through reduced precipitation or higher evapotranspiration, or both, is increasing the impacts of drought. Frederick (1997) writes on the need for adaptation to the impact of climate change on both water supply and demand. Gan (2000) performs related analysis in the context of reducing vulnerability to drought.

We found that there is a relative gap in terms of forward-looking research into demand-side management (DSM) of water in urban areas that will address gaps between supply and demand during drought, and at the same time incorporate the economic viability of purveyors and the well-being of vulnerable low-income customers. Our multidisciplinary research that follows helps address this gap, while also integrating a 'voice for nature' into our modelling by mitigating impacts on critical flows. We begin by providing a brief overview of WCOR in the United States.

Promoting WCOR in the United States

The US federal government has made water conservation a national goal, dating from the enactment of, and later amendments to, the Water Resources Planning Act (1965, amended 1975, 1978 and 1983). The US Water Resources Council has defined conservation as activities designed to reduce losses and waste of water, or improve land management practices to conserve water (Beecher & Laubach 1989). WCOR promote conservation through rate mechanisms such as excess surcharges (ES), drought demand rates (DDR), inclining block rates (IBR), seasonal rates (SR) and time-of-use rates (TOU). WCOR provide an alternative to rate structures that do not provide incentives for conservation, and WCOR are important tools for saving water in a manner that can be made sensitive to regional, physical and population/user characteristics. Figure 1 manifests the major types of rate structures our research has shown to be prevalent in our study areas, of which IBR has the most potential for supporting water conservation. The Ehemann *et al*. publication (2001) concludes that pricing (DDRs) represents the most timely and equitable approach among three common approaches to managing droughts – pricing, rationing and mandatory restrictions. Our US nation-wide survey of WCOR 'best practices' across 17 states and 43 purveyors is not included due to space constraints, but see Wang *et al*. (2005) for details.

Across the United States, water provision is becoming more economically and ecologically costly, especially in jurisdictions with high summer peak use, and where drought conditions frequently occur. To mitigate impacts, researchers such as Vickers (1991, 1993), Beecher & Stanford (1993), Beeche (1995, 1998), Schultz & Hornbogen (1997), Wang *et al.* (1999, 1996), encourage states, municipalities and private water utilities to adopt an integrated water resource planning (IWRP) approach. An important component of this strategy is the use of DSM options in conjunction with conventional supply activities to address water shortage problems.

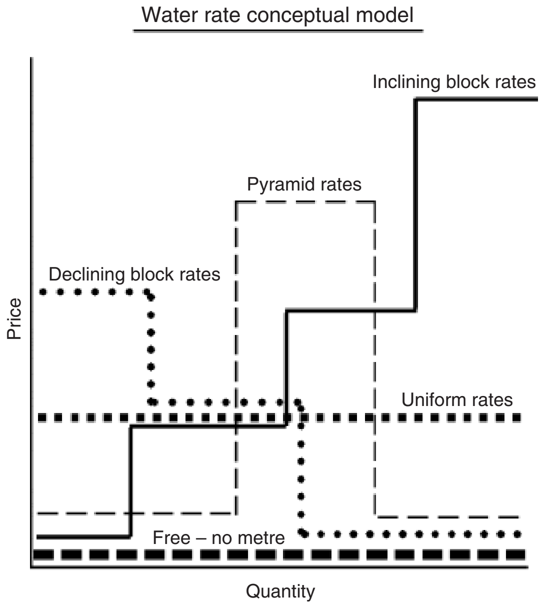

Fig. 1. Water rate conceptual model according to our 2003 survey of utilities across the United States.

WCOR are an important component of DSM efforts. Quantitative analysis of consumer responses to WCOR can provide valuable information regarding the effectiveness and persistence of their implementation. The following sections evaluate the potential impacts of a series of WCOR on utility revenues, equity as it pertains to customers and contribution to water conservation. Using prior drought conditions as a reference, the authors design a revenue-neutral and equitable WCOR option for the State of Delaware (DE) that significantly mitigates the impact of drought.

Analysis and construction of DDR: northern DE

The geographic setting for our analysis is within the Christina River Basin (CRB), which is nested within the Delaware River Basin (Fig. 2). The Delaware River Basin spans parts of the states of Delaware, Maryland, New Jersey, New York and Pennsylvania in the Mid-Atlantic region of the United States. This area includes a megalopolis stretching from the City of Boston south to Washington, DC, with the study area midway. The

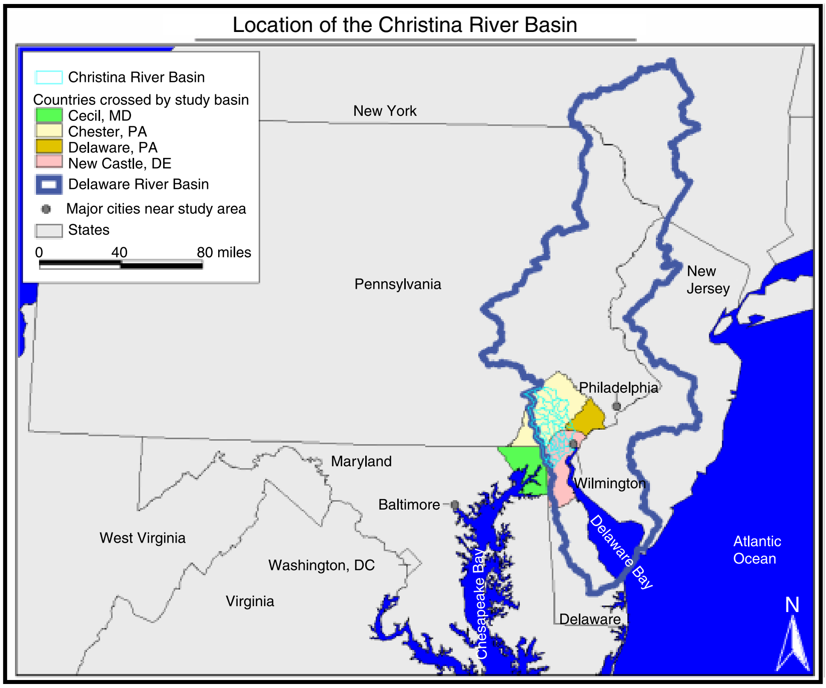

Fig. 2. Location of the Christina River Basin within the Delaware River Basin.

Table 1 Population data for counties and cities within the Christina River Basin (CRB)

City/town	County, state	1990 population	2000 population	Per cent change	2000 population within CRB
County	Chester Co., PA	376 396	433 501	15.2	226 960
County	New Castle Co., DE	441 946	500 265	13.2	159 352
County	Cecil Co., MD	71 347	85 951	20.5	1281
Wilmington	New Castle Co., DE	71 529	72 664	1.6	72 664
Newark	New Castle Co., DE	25 098	28 547	13.7	28 547
Downingtown	Chester Co., PA	7749	7589	– 2.1	7589
Coatesville	Chester Co., PA	11 038	10 838	– 1.8	10 838
Kennett Square	Chester Co., PA	5218	5273	1.0	5273
Avondale	Chester Co., PA	954	1108	16.1	1108
West Grove	Chester Co., PA	2128	2652	24.6	2652
West Chester	Chester Co., PA	18 041	17 861	– 1.0	17 861

Source: United States Environmental Protection Agency (2004).

climate is modified humid continental, and the maximum summer temperatures are normally in the upper 20 to low 30 °C (mid 80 to low 90°F) range, and during January, the coldest month, the average daily temperature is approximately 0 °C (32°F). The greatest amounts of precipitation normally occur during summer thunderstorms. Senior & Koerkle (2003d) note that about half the precipitation in the CRB is discharged to stream flow, with the rest lost to evapotranspiration. On average, nearly 65% of stream flow is composed of base flow and 35% is surface runoff. Streams have only low to moderate gradients. In areas of higher gradients, stream bottoms are characterized by exposed bedrock, gravel and sand. In lower gradient areas, stream reaches and pool channel bottoms are often covered with sediments.

The CRB has an area of approximately 1461 km^2 (564 mi^2) and is composed of the Brandywine Creek (BC) (842 km^2 or 325 mi^2), White Clay Creek (WCC) (277 km^2 or 107 mi^2), Red Clay Creek (RCC) (140 km^2 or 54 mi^2) and Christina River (CR) (202 km^2 or 78 mi^2) watersheds. Those watersheds encompass parts of Delaware County, Pennsylvania and Cecil County, Maryland. However, the main drainage areas are Chester County, Pennsylvania and New Castle County (NCC), DE. NCC is the setting for our case study. The elevation in the CRB ranges from almost sea level to nearly 317 m (1040 ft) above sea level in the BC watershed (Senior & Koerkle 2003a). Streams within these basins serve as sources of drinking water (United States Environmental Protection Agency 2004).

The population within the CRB is approximately 387 593, with the great majority of the population in New Castle and Chester Counties (Table 1). The primary population changes are a growth in Hispanic population basin-wide, and upper basin loss of farmland to residential development. Land use in the basin can be broken down according to the categories utilized in the creation of watershed loading models (Senior & Koerkle 2003 a,b,c,d) (Table 2).

Water withdrawals are unevenly spread across the basin. However, the greatest withdrawals are in DE. Water is withdrawn upstream by Philadelphians and others, but this does not normally impact water availability downstream, and in times of shortage downstream users have purchased water from Chester County. (See the report on CRB total maximum daily loads by the United States Environmental Protection Agency 2004 for details.) The City of Wilmington is the major water user in the basin, and is allowed to withdraw up to 136 274 400 litres daily (L/day) [36 million gallons daily (mgd)].

Longitudinal data

A series of scenario analyses were conducted utilizing a set of 500 households from the period 1992–1997. The households were randomly drawn from the service area of Artesian Water Company Inc., an investor-owned water utility serving northern NCC. This 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 was obtained from surveys conducted in 1992 and 1994. These surveys incorporated questions involving 87 variables relating to water consumption and conservation behaviour (Wang *et al.* 1996, 1999).

Major numerical variables from the surveys:

- Average price of water (bill divided by consumption)
- Household income
- Household size (number of people)
- Lot size for each house
- Assessed property value including house and land for tax purposes
- Number of rooms in each household

Table 2 Land use percentages in the Christina River Basin by watershed

Category	All watersheds	Brandywine Creek watershed	White Clay Creek watershed	Red Clay Creek watershed	Christina River watershed
Residential – septic	9.6	10.5	6.5	17.1	4.6
Residential – sewer	6.8	3.9	11.1	6.1	13.7
Urban	3.8	2.7	3.4	1.6	10.8
Agricultural – livestock	4.9	6.3	5.8	1.3	0.0
Agricultural – row crop	28.1	32.7	25.3	29.2	11.9
Agricultural – mushroom	1.5	0.0	4.9	– 6.3	0.0
Forested	28.3	31.8	24.8	24.0	21.6
Open	5.2	3.8	4.9	5.2	11.6
Wetland, water	1.2	1.2	0.9	1.2	1.6
Undesignated	2.5	1.4	3.0	2.1	6.6
Impervious – residential	4.0	2.9	5.5	4.5	6.4
Impervious – urban	4.1	2.8	4.0	1.7	11.4
Total	100	100	100	100	100

Source: Senior & Koerkle (2003a–d).

- Frequency of dishwasher uses per month
- Frequency of clothes washer uses per month
- Number of water-conserving fixtures installed
- Frequency of car washing at home during the summer months
- Frequency of watering lawns during the summer months
- Conservation orientation perceived by customers

Major dichotomous variables from the surveys:

- Ownership and frequency of (re)filling of pool
- Use of an indoor appliance consuming a considerable amount of water
- Awareness of the utility's summertime sprinkling regulations
- Any water conservation measures taken outdoors
- Any substantial investment in landscape plantings in the previous year
- Reported checking of water bill to see whether it is increasing
- Awareness of sewer bill's direct connection to water consumption
- Awareness of the water price increase
- Awareness of both the water conservation efforts undertaken by the utility and conservation tips through its water bill inserts or pamphlet
- Consumer perception that water shortages are likely in the near future
- Consumer opinion towards the use of rates to encourage greater water conservation
- Reception of water conservation devices from the utility
- Presence of children between ages 0 and 5 years
- Presence of children between ages 13 and 19 years

These data and information were integrated with the reference data from the 1999 drought.

Drought conditions

DE has a history of periodic water shortages caused by drought (State of Delaware Governor's Office, 1999). The state experienced major droughts in 1995 and 1999, which created great concern regarding how vulnerable the northern part of the State is to the phenomenon. The portion of the state most affected by drought is typically northern NCC, which receives approximately 70% of its drinking water from the CRB.

According to the DE Water Resources Agency and the National Oceanic and Atmospheric Administration (NOAA), the period between April and July 1999 was the driest period for DE in the 105 years since records were kept (Kauffman 2005). According to precipitation departure records that begin in 1993, using 30 years of averaged data, by July 1999 the cumulative precipitation departure from the mean in the study area was – 30.40 cm (– 11.97 in.).

The CRB experienced all-time low-flow levels in 1999. The BC reached record low stream flow levels for 18 days in July and August. WCC reached record low stream flow levels for 14 days during the same period. Indeed, low stream flow levels reduced drinking water quality. Saltwater migrated up the WCC to the point that the chloride concentration levels of DE's drinking water exceeded the US EPA standard of 250 mg/L on several occasions. Also, low stream flow levels adversely impacted surface water ecosystems and the surrounding environment, causing stress to ecological communities [governor's Water Supply Task Force (WSTF) 1999].

On 23 July 1999, Governor Carper, under advice from the Drought Advisory Committee (DAC), signed Executive Order No. 61, declaring a 'drought warning' for northern NCC. As conditions in the state continued to worsen, on 5 August the governor signed Executive Order

No. 62, declaring a 'drought emergency' and issuing mandatory water restrictions for all industrial, commercial, residential, as well as governmental water users in northern NCC. As the length and the severity of the drought of 1999 continued to intensify, on 26 August, Governor Carper signed Executive Order No. 65, which created the WSTF. The main objective of the WSTF was to develop a long-term water supply strategy.

The WSTF report includes a detailed analysis of 16 *supply-side* options. The WSFT report, however, does not give equal consideration to DSM and options for conservation. The report only generally mentioned DSM by noting that water providers should be encouraged to adopt inclining or SR structures. Some utilities had tested such rates.

Gap in supply and demand

As noted, the WSTF was given a mandate to examine the current and future scenarios for water supply in DE, especially in northern NCC (where the bulk of the state's population and industry is located). The WSTF examined both water supply availability and water demand patterns. This included the availability of water in the WCC and the BC, which are the primary sources of water for the cities of Newark and Wilmington, respectively.

The availability of water in WCC (and perhaps in the future BC as well) is constrained by the 7Q10 Minimum Flow Standard. This is the low-flow level statistically computed to occur once every 10 years for 7 consecutive days. 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. These in-stream flow scenarios were developed by WSTF (1999):

- No 7Q10 – in this scenario, minimum in-stream flow standards are suspended along the BC and WCC due to a 'Drought Emergency'. The resultant water availability is 352 042 200 L/day (93 mgd) (no concern for nature).
- No 7Q10 on BC, but 7Q10 on WCC – this represents the current condition where a minimum in-stream flow standard exists only on WCC. Water availability becomes 321 759 000 L/day (85 mgd).
- 7Q10 for both BC and WCC – this represents a future condition where in-stream flow will be established on both the BC and WCC. The resultant water availability amounts to 276 334 200 L/day (73 mgd).

According to the Second Report (March 2001) submitted by the WSTF to the governor and general assembly, the demand in northern NCC for year 2010 is projected to reach 333 115 200 L/day (88 mgd) (WRA *et al.* 2001). When demand for water is compared with supply availability according to these three scenarios, it is evident that the surplus or deficit of water depends upon the adoption of the 7Q10 system. Table 3 indicates the water balance for 2000. Expanding the 7Q10 standard to include both BC and WCC could result in a supply deficit of nearly 49 210 200 L/day (13 mgd), or 15% of the demand in 2010. The solution to meeting this shortfall could be to either increase supply or reduce demand, or a combination of both. Water conservation, including WCOR, can play a vital part in achieving the goal of reducing demand by 15% in northern NCC to 'meet peak demands during droughts' [Delaware Water Supply Coordinating Council (DWSCC) 2001, p. 4].

Table 3 Water supply and demand scenarios in northern New Castle County: 2000 and 2010

Scenario	Supply	Demand	Balance
No 7Q10	352 042 200 L/day 93 mgd	*For 2000*: 325 544 400 L/day 86 mgd	7 (8%)
7Q10 in WCC, not in BC	321 759 000 L/day 85 mgd	325 544 400 L/day 86 mgd	− 1 (− 1.2%)
7Q10 in both WCC and BC	276 334 200 L/day 73 mgd	325 544 400 L/day 86 mgd	− 13 (− 15%)
7Q10 in both WCC and BC	276 334 200 L/day 73 mgd	*For 2010*: 333 115 200 L/day 88 mgd	− 15 (− 17%)

WCC, White Clay Creek; BC, Brandywine Creek.

DDR and policy issues

DDR are a type of WCOR utilized during periods of water scarcity; this involves increasing the water rates during drought emergency (recall the IBR example) to prompt consumers to save water. Researchers have provided different examples of DDR structures that support conservation during drought (Duke & Montoya 1993; Beecher *et al.* 1994; Lemoine & Cuthbert 1995). In the design of DDRs as a tool for drought management, it is important to account for revenue volatility and address possible distributional effects (Bishop & Weber 1996; Chesnutt & Beecher 1998). Revenue instability caused by DDRs is a result of the multiple degrees of uncertainty. Unlike flat rates that have a single degree of uncertainty, namely the number of future customers, DDRs contain uncertainty about the number of customers and the amount of use (Chesnutt *et al.* 1996). DDRs (and WCOR in general) are usually justified by linking to a marginal cost pricing that is often at odds with the consideration of revenue neutrality (Pint 1999). Depending on the magnitude of the price elasticity, increases in water rates can cause revenue shortfall or surplus.

The concept of 'elasticity' is important to understand. If demand is elastic, a given rise in price of water results in a relatively larger decrease in its consumption, causing a utility to receive smaller revenues. If demand is inelastic, a rise in price causes consumers to spend more money on water, raising revenues for the utility. And if demand has unit elasticity, a rise in price causes no change in revenues to the utility because a fall in consumption is proportional to a rise in price.

DDRs can also have significant and highly variable distribution effects on residential customers due to the differing responsiveness to price changes. Results suggest that if pricing is the primary conservation instrument, lower income households could bear a larger share of the conservation burden (Renwick & Archibald 1998). Agthe & Billings also note that marginal price is regressive to low-income customers when compared with high-income customers (1997; Pint 1999). We took care to address this equity concern in our model.

Scenario analysis

As a means of evaluating revenue, equity and conservation implications of DDRs, the sample households were classified into four income groups. The 500 sample households represent a sample from 1992 to 1997. During this time, the authors launched two surveys to obtain information regarding household and housing characteristics. Information was also collected on their summer month water consumption and bill amounts for each year from the Artesian Water Company Inc. (a local investor-owned utility serving the northern part of NCC, DE). Table 4 shows the household income classification and the number of households in each bracket. The low-income group is under \$25 000 in annual income, and the upper-income group is over \$65 000.

To evaluate the impact of price on income groups, the price elasticity of each income group was estimated based on the model that the researchers developed for the Artesian Water Company Inc. It is based on a regression model that is built using a proportional change measure of price and consumption between 1992 and 1997 (Wang *et al*. 1999), instead of a single-year cross-sectional model, as shown below

$$[(Q_1 - Q_0)/Q_0] = \beta_0 + \beta_1[(P_1 - P_0)/P_0] + \beta_2 \text{ Inform} + \beta_3 \text{ Device} + e,$$

where β_0 denotes a constant, and β_1 through β_3 present the coefficient of each independent variable; $[(Q_1 - Q_0)/Q_0]$ the proportional changes in day- and weather-adjusted water consumption during the summer months between two periods; $[(P_1 - P_0)/P_0]$ the proportional changes in inflation-adjusted average prices of water during the summer months between two periods; Inform the consumers with higher levels of water conservation information provided by Artesian = 1 and consumers with lower levels of information = 0; Device the customer who used water conservation devices provided by Artesian = 1 and customers who did not = 0; and e an error term.

For our model, the independent variables that were conceptually and statistically significant in the preliminary t-tests and correlation analyses are included in this proportional change equation. Correlations of the growth rate of water consumption with water consumption-inducing factors (e.g. income, household size, lot size, housing value, number of rooms, lawn, appliances, etc.) turn out to be statistically insignificant due to no changes (or minor changes) in these variables during the two periods. The statistically significant independent variables included in the equation are: $[(P_1 - P_0)/P_0]$; Inform and Device (Wang *et al*. 1999). The estimated result shows an F-value (43.8) far greater than the critical F-values of 2.965, indicating that the model is statistically significant at the 0.05 level. The R^2 is 0.206, relatively strong considering the fact that a proportional change model usually has a lower R^2. All the signs of the estimated coefficients conform with prior expectations. No problem with heteroscedasticity (the residual variance is not dependent on the value of the explanatory variable) or multicollinearity (the explanatory variables are not very highly correlated with each other) exists. Inform and Device are also significant at the 0.05 level.

The coefficient of β_1 in the preceding model becomes the price elasticity of water demand (Wang *et al*. 1999). Proportional changes in water consumption $([Q_1 - Q_0]/Q_0)$ and price $[(P_1 - P_0)/P_0]$ were constructed in such a way that the estimated coefficient of $[(P_1 - P_0)/P_0]$ is equivalent to the price elasticity. Using differential calculus, it can be shown that $d([Q_1 - Q_0]/Q_0)/d([P_1 - P_0]/P_0)$ is equal to $([dQ_1/dP_1] \times [P_0/Q_0])$, the elasticity of water demand (Q_1) with respect to P_0.

The overall price elasticity of water demand (the coefficient of β_1) for residential customers in this utility derived from the above equation is -0.82, meaning that a 10% increase in real water price would reduce water

Table 4 Household income classification

Household classification in US\$	Number of households
1. Low-income group \$0–\$25 000	88
2. Low-middle income group \$25 001–\$45 000	179
3. High-middle income group \$45 001–\$65 000	98
4. Upper-income group \$65 001 and above	135
Total	500

consumption by 8.2% during the summer months. Using the income classification shown in Table 4, separate regression analyses for households in each income bracket were performed with the same model.

Information from utilities or municipalities consists of individual customer's water consumption and bill amounts, only allowing for calculation of average prices. Average prices (*P*) adjusted for inflation are used in our case, reflecting the assertion that the consumer responds to his/her bill (Wilder & Willenborg 1975; Foster & Beattie 1981), or average prices (Nieswiadomy & Cobb 1993), and rarely knows what his/her marginal rate is. Average water prices, however, may lead to a simultaneous bias in the estimation of price elasticity because consumption is determined by prices, and prices, in turn, are determined by consumption. Our analysis is based on proportional changes in average prices $[(P_1 - P_0)/P_0]$ so that the simultaneity bias is insignificant. This also has marginal implications because changes in water consumption depend on changes in average prices between 2 years.

As shown in Table 5, for the lowest-income group, the lowest value of price elasticity indicates the demand for water is mostly inelastic, changing very little with an increase in price. On the other hand, the upper-income group, with its highest value of price elasticity of -1.69, indicates an elastic demand for water, showing a change in demand greater than price change. This indicates that the use of water in this income bracket has a lower utility than in the lower income groups. Or, to simplify, the water uses of the low-income customer are more basic and essential in nature (i.e. drinking and bathing), and therefore cannot be reduced as easily as the discressionary uses of the high-income consumer (i.e. potentially pools, fountains, etc.).

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 by each group. In these analyses, water rate hikes were assumed to range from 20 to 50% at the margin, and on average under the critical levels of water consumption from 37 854 L (10 000 g) to 113 562 L (30 000 g) per a summer quarter. For the marginal scenario analysis, water consumption on the amount exceeding the critical cut-off level (per a summer quarter) is only subjected to the higher rates, whereas no rate change is assumed in the consumption below the level. For the average scenario application, those households who consume water greater than the critical cut-off level are subjected to a price increase on their entire quantity of water consumed.

Table 5 Price elasticity for different income groups

Income group	Price elasticity
1. Low-income group	-0.688 (-7.15)
2. Low-middle income group	-0.738 (-8.53)
3. High-middle income group	-1.028 (-4.87)
4. Upper-income group	-1.686 (-8.47)
Total residential customers	-0.816 (-13.56)

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 a significance level of 5%.

To meet our core goals of revenue neutrality, equity and conservation, it is necessary to determine the critical cut-off amount of water in scenarios. Depending on the socio-economic and physical characteristics of the area involved, the cut-off amount will differ. Usually, the cut-off amount can be referred to as a 'lifeline rate' that denotes minimum amounts of water required for human needs; this 'basic needs' level of water is designated as a human right by the UN (Smith 2003, 2007). Water shortfall, especially during droughts, is mostly caused by discretionary use of water, not by minimum usage of water. It is, therefore, strongly recommended to use the marginal consumption approach, so that only water consumption exceeding the critical cut-off level is targeted.

As a way to evaluate DDR impacts on utilities and customers, the before and after values (bills and consumption) of the DDR implementation were estimated per customer by income group (and utility wide) and tested to see whether their mean values were significantly different. For this significance test, the confidence interval of the mean was calculated with the significance level of 95% in a one-tailed test. If the observed mean value of a specific income group lies within the interval, the two means are not statistically different – meaning that the DDR implementation does not affect the income group in terms of bills or water consumption.

Revenue-neutral and equitable DDR

In our scenario analyses, the 500 households are assumed to represent residential customers in a hypothetical water utility in our setting. Scenarios were developed in order to identify a sound DDR option that meets all the three core requirements using the marginal applications. The scenario results are summarized in Table 6. Out of six scenarios reported in the table, three scenarios meet all the three requirements of a sound DDR option. They are the cases where water rates were assumed to increase by 20–35% on consumption above 45 425–56 781 L (12 000–15 000) g during the summer quarter. The most significant savings come from the 35% rate hike and the 56 781 L (15 000 g) cut-off level (13%). Table 7 shows in detail the results of the most significant water savings scenario (35% – 56 781 L or 15 000 g) that meets all the requirements of a sound DDR option. Statistically, no

Table 6 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 > 45 424 L (12 000 g)	Yes	Yes	S (10% ↓)
Rate 20% ↑ Consumption > 49 210 L (13 000 g)	Yes	Yes	S (9% ↓)
Rate 35% ↑ Consumption > 56 781 L (15 000 g)	Yes	Yes	S (13% ↓)
Rate 25% ↑ Consumption > 37 854 L (10 000 g)	Yes	No	S (14% ↓)
Rate 20% ↑ Consumption > 75 708 L (20 000 g)	Yes	Yes	NS (4% ↓)
Rate 20% ↑ Consumption > 113 562 L (30 000 g)	Yes	Yes	NS (2% ↓)

S, significant; NS, not significant.

Table 7 Mean changes in revenue and consumption in various income groups: 35% marginal price increase on consumption above 15 000 gallons

	Revenue per customer cut-off 56 781 L (15 000 g)			Consumption per customer cut-off 56 781 L (15 000 g)		
Income groups	Before (US$)	After (US$)	Statistical significance	Before 3785 L (1000 g)	After 3785 L (1000 g)	Statistical significance
1. Low-income group	51.27	50.68	NS	10.69	10.23	NS
2. Low-middle income group	63.04	61.91	NS	15.08	14.17	NS
3. High-middle income group	77.19	71.96	NS	19.67	17.57	NS
4. Upper-income group	83.41	70.21	S	22.38	17.18	S
Utility	68.85	65.91	NS	17.18	14.96	S (13% ↓)

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

Table 8 Efficiency implications of a DDR implementation: based on Artesian's WCOR residential tariff (1997)

Inclining rates	Income group	Before* US$	After* US$
1st block	Low income (consumption 37 854 L or 10 000 g)	$ 2.45	$ 2.45
2nd block	Low-middle income (consumption 56 781 L or 15 000 g)	$ 2.61	$ 2.61
2nd block	High income (consumption 94 635 L or 25 000 g)	$ 2.61	$ 3.22
3rd block	Upper income (consumption 132 489 L or 35 000 g)	$ 3.04	$ 4.47

*Inclining block rates per 3785 L (1000 g).
DDR, drought demand rates; WCOR, water conservation-oriented rates.

significant changes before and after the implementation are incurred in the utility's revenue (reduction in average bills from $68.85 to $65.91) and low-income customers' bills (from $51.27 to $50.68 in the low-income group and $63.04 to $61.91 in the low-middle income group). Overall conservation is significant, reducing 13% of utility-wide residential water consumption (from 65 109 L or 17 200 g to 56 781 L or 15 000 g). This is noteworthy because it results in mitigating the gap between supply and demand, without revenue volatility or inequitable burdens on low-income consumers.

Our scenario results also show that a DDR option could enhance the efficiency of water resource allocation among customers. Upper-income customers usually use much more water through discretionary uses than low-income customers, as reflected in their high price elasticity. As shown in Table 8, with the cut-off consumption level of 56 781 L (15 000 g), the marginal prices for the low-income and low-middle income groups are not changed but in cases of high-income (assumed consumption of 94 635 L, or 25 000 g, per summer quarter) and upper-income customers (assumed summer quarter consumption of 132 489 L or 35 000 g), marginal prices are increased 23% (from $2.61 to $3.22) and 47% (from $3.04 to $4.47), respectively.

DDRs as a drought management tool

From our scenario analysis, it is inferred that some case scenarios meet all three criteria to be a sound DDR option in a hypothetical utility. That is, they do not negatively affect water bills of the low-income group, are revenue neutral for the utility, and bring about significant water savings. These are the cases where increases in marginal price are applied to residential customers whose consumption is $>45\,425$ or 56 781 L (12 000 or 15 000 g) during the summer quarter. If a 35% scenario is adopted, residential water savings would be 13%.

In northern NCC, 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% eduction in the total water consumption in 2010. Because around 12% of water produced in the area is unaccounted for, total water savings from the case scenario would be equivalent to 7.1%. 'Unaccounted for water' is represented by the gap between the water supplied and what is metred. In 2010, water demand for northern NCC is projected to reach 333 115 200 L/day (88 mgd), but its supply is expected to be 85 mgd, resulting in a negative balance of 11 356 200 L/day (3 mgd). (Based on the present condition where 7Q10 applies on WCC, but not on BC.) However, through a DDR option, water demand could be reduced to 310 402 800 L/day (82 mgd), which is less than the supply. Under the current condition (7Q10 only applied to WCC), no water shortage problem would surface in 2010 with our DDR option. Given the potentially powerful effects of DDRs, care should be taken in implementing them. Owing to space constraints, for discussion of structural barriers to implementation, see Wang *et al.* (2005).

An underappreciated, but significant advantage of a DDR option is its positive environmental impact. The reduction in the consumption of water allows for an increased amount of water to remain in the natural environment, thus, buoying ecological systems and multistakeholder user rights in a manner championed in integrated water resources management literature.

Mitigating the impacts of drought on stream flow and ecology

Traditional perspectives do not capture the importance of connecting source water's simultaneous out and in-stream value to a need to manage demand. But DDRs represent an opportunity to preserve stream flow and ecology through keeping more water in-stream, rather than in pipes and under chemical treatment. Normally, the focus is on water only as a source for human consumption, with ignorance concerning impacts on stream flows unless they impact 'nature's services'. A more progressive view recognizes the importance of managing demand to enhance resource sustainability and minimize capital costs for water provision and wastewater treatment, while minimizing treated flows (i.e. thermal pollution) to streams. However, a more promising third perspective offered here recognizes the aforementioned considerations, and also links to the importance of keeping nontreated, or 'natural' water in-stream in the first place in order to support ecology and capture 'unaccounted for' benefits to ecology from residential water conservation. In this sense, the flow of water is reversed through managing demand, and ecology is acknowledged more fully as a stakeholder in terms of source water withdrawals.

Our research extends the results of our DDR model to show the simultaneous impact of the previously analysed DDRs on reducing withdrawals (again, the purveyors use surface water). Maximizing the 'natural' water kept in-stream is especially important during periods of drought, for at such times streams can reach or fall below 'critical' levels such as the 7Q10 standard DE uses, or the New England Median Flow (NEMF) standard used in several northeastern states.

Stream flow and needs assessment

Three major water purveyors that utilize surface water in northern NCC are the City of Newark (WCC), United Water DE (WCC at Stanton and CR) and the City of Wilmington (BC). This section explores the demand experienced by these purveyors in July 1999 to examine whether or not critical low-flow levels reached or surpassed in some tributaries could have been avoided at times utilizing DDRs. The methods utilized included three major sources of data:

- in-stream flow needs analysis;
- data related to demand during the drought that spanned July 1999; and
- elasticity-based forecasts utilized to estimate the amount of water that could be left in-stream.

In 1997, David C. Yaeck, Consulting Services, the Delaware Department of Natural Resources and Environmental Control and the Delaware Water Resources Agency prepared a report concerning ecological in-stream needs in the surface water sources for the study area. These data were converted into a form compatible for our study. In addition, NEMF standards were computed and added to the analysis. The bottom-line of our review is that 7Q10 is indeed the *absolute lowest* minimum flow appropriate for setting as an ecological threshold in the analysis that follows, thus, our choice to incorporate the NEMF method, because it offers a more conservative environmental measuring stick, due to the fact that it assumes that more water should be left in streams than does the 7Q10 standard. It should be noted, however, that the NEMF method is not appropriate for small basins, and thus is not utilized in all models.

Data collected for the month spanning the drought and streams modelled include:

- daily stream flow data from Delaware's Water Resources Agency;
- daily stream flow data from the United States Geological Survey (USGS) Water-Data Report MD-DE-99-1 'Water Resources Data Maryland and DE Water Year 1999' (some data recalculated due to the distance between the stream gages and water intakes);
- 7Q10 levels for study areas; and
- calculations of an NEMF standard for appropriate (relatively large) study areas.

Daily (actual) stream flow, daily demand, the 'natural' level of stream flow without local withdraws, 7Q10, and NEMF data and standards were collected or calculated and converted to cubic metres per second (cms) [cubic feet per second (cfs)] to provide a common unit of measurement. This made it possible to discover which days stream flow was above, at or below critical minimum flows. The study examines scenarios on a day-by-day basis and by mean values.

Analysis is provided in the following section through tables, graphs and charts that make day-by-day and mean monthly comparisons of the various effects of DDRs during drought easy to comprehend for policy makers. Owing to space constraints, tables noting daily flows for each river on a day-by-by day basis could not be included in this manuscript.

Scenario analysis revisited: water savings and reduced withdrawal

As a means of exploring the impacts of DDRs on stream flows in the BC, CR and the WCC, four scenarios were built. Two scenarios (Scenarios I and III) are solely based on the residential sector, and another two scenarios (Scenarios II and IV) include the commercial and industrial sectors, as well as the residential sector. In order to estimate potential reduction in water intake from the streams, water savings from DDRs by each utility were first estimated.

For Scenarios I and III (the residential cases), two saving figures (10 and 13%) that are revenue-neutral and equitable DDRs for use during drought summer months were used. These saving percentages are derived from the cases where the 20% marginal price increase is applied to consumption above 45 425 L (12 000 g) and the 35% marginal price increase above 56 781 L (15 000 g) during the summer quarter. A 20% 45 425 L (12 000 g) scenario is estimated to achieve a 10% reduction in residential water consumption, whereas a 35% 56 781 L (15 000 g) scenario creates a 13% reduction. Daily water savings per utility were estimated by the following formula:

$$\mathrm{RS} = \mathrm{RPD} \times \mathrm{SR} \times (1 + \mathrm{UR}),$$

where RS is the residential daily peak water savings; RPD the residential daily peak water demand; SR the water savings rate from the DDR; and UR the unaccounted-for-water rates (percentage proportion of unaccounted-for-water).

The results of the estimate are shown in Table 9. Daily savings are presented under Scenarios I and III conditions during summer droughts.

Elasticities for northern NCC are not available for the commercial and industrial sectors. Through review of refereed journals, we identified elasticity with wide variations, ranging from −0.14 to −0.98 in the industrial sector and from −0.18 to −0.92 in the commercial sector (Amatetti *et al.* 1997). Although an argument can be made that in comparison with residential customers, industrial and most types of commercial applications of water have a higher elasticity (Amatetti *et al.* 1997), the lowest price elasticity was utilized for our analysis in the estimation of water savings from the industrial (−0.14) and the commercial sectors (−0.18).

Unlike the case of the residential sector, wherein consumption cut-off rates were used, a 15% rate hike during

Table 9 Daily savings of residential peak water consumption

Utility	Peak daily	Savings rate (%)	Unaccounted-for-water rates (%)	Daily savings
City of Wilmington	31 456 674 L/day (8.31 mgd)	10	13.0	3 558 276 L/day (0.94 mgd)
		13		4 618 188 L/day (1.22 mgd)
United Water Delaware	26 800 632 L/day (7.08 mgd)	10	9.05	2 952 612 L/day (0.78 mgd)
		13		3 785 400 L/day (1.00 mgd)
City of Newark	1 741 284 L/day (0.46 mgd)	10	13.0	189 270 L/day (0.05 mgd)
		13		264 978 L/day (0.07 mgd)
Total/average	59 998 590 L/day (15.85 mgd)	10	11.2	6 662 304 L/day (1.76 mgd)
		13		8 668 566 L/day (2.29 mgd)

Table 10 Commercial and industrial daily peak water savings

Utility	Peak daily	Price elasticity	Price hike (%)	Unaccounted-for-water (%)	Daily savings
Commercial					
City of Wilmington	19 343 394 L/day (5.11 mgd)	– 0.18	15.0	13.0	605 664 L/day (0.16 mgd)
United Water Delaware	44 667 720 L/day (11.80 mgd)	– 0.18	15.0	9.05	1 324 890 L/day (0.35 mgd)
City of Newark	2 081 970 L/day (0.55 mgd)	– 0.18	15.0	13.0	75 708 L/day (0.02 mgd)
Total/average commercial	66 093 084 L/day (17.46 mgd)	– 0.18	15.0	10.3	1 968 408 L/day (0.52 mgd)
Industrial					
City of Wilmington	75 405 168 L/day (19.92 mgd)	– 0.14	15.0	13.0	1 779 138 L/day (0.47 mgd)
United Water Delaware	33 652 206 L/day (8.89 mgd)	– 0.14	15.0	9.05	757 080 L/day (0.20 mgd)
Total/average Industrial	109 057 374 L/day (28.81 mgd)	– 0.14	15.0	11.8	2 574 072 L/day (0.68 mgd)
Total commercial and industrial	175 150 458 L/day (46.27 mgd)		15.0		4 542 480 L/day (1.20 mgd)

Table 11 Expected daily peak water savings by utilities

	City of Wilmington	United Water Delaware	City of Newark	Estimated impact
Residential				
Scenario I: a 20% – 45 424 L (12 000 g)	3 558 276 L/day (0.94 mgd)	2 952 612 L/day (0.78 mgd)	189 270 L/day (0.05 mgd)	6 700 158 L/day (1.77 mgd)
Scenario III: a 35% – 56 781 L (15 000 g)	4 618 188 L/day (1.22 mgd)	3 785 400 L/day (1.00 mgd)	264 978 L/day (0.07 mgd)	8 668 566 L/day (2.29 mgd)
Residential/commercial (C)/industrial (I)				
Scenario II: Scenario I+C&I	5 943 078 L/day (1.57 mgd)	5 034 582 L/day (1.33 mgd)	264 978 L/day (0.07 mgd)	11 242 638 L/day (2.97 mgd)
Scenario IV: Scenario III+C&I	7 002 990 L/day (1.85 mgd)	5 867 370 L/day (1.55 mgd)	340 686 L/day (0.09 mgd)	13 211 046 L/day (3.49 mgd)

droughts was assumed to apply to the whole consumption of industrial and commercial water. In this case, revenue issues are not considered because of limited information and also the assumed lower elasticities. Based on the following formula, potential water savings from the DDR by both sectors are estimated and shown in Table 10.

$$\mathrm{CIS} = \mathrm{CIPD} \times (\mathrm{CIE} \times \mathrm{RH}) \times (1 + \mathrm{UR}),$$

where CIS is the commercial or industrial daily peak water savings; CIPD the commercial or industrial daily peak water demand; CIE the commercial or industrial price elasticity; RH the rate hike (by 15%); and UR the unaccounted-for-water rates (percentage proportion of unaccounted for water).

Table 11 summarizes expected daily peak water savings for three utilities by each scenario. The City of Wilmington shows the largest savings, ranging from 3 558 276 to 7 002 990 L/day (0.94–1.85 mgd), whereas the City of Newark is expected to reduce withdrawals of water during the summer months, ranging from 189 270 to 340 686 L/day (0.05–0.09 mgd). Overall, Scenario IV, which combines high residential peak savings (Scenario III) with commercial and industrial minimum peak savings, conserves the most at 13 211 046 L/day (3.49 mgd) during the drought summer.

Effects of DDRs on stream flow: the drought spanning July 1999

We set up a day-by-day comparison of July 1999 flow data by surface water source. This includes day-by-day analysis of the natural state of stream flow (no withdraws, as local demand is eliminated), the actual state of the stream (local demand included) and analysis that includes implementation of 'DDR Scenarios I, II, III and IV'. These data are juxtaposed with 7Q10 and NEMF (for larger basins) standards of low-flow critical levels for each body of water. In addition, similar analysis is provided utilizing the mean monthly stream flow values. Owing to space constraints, to learn in a highly detailed way how to process data to support this methodology see Wang *et al.* (2005).

Figures 3–6 allow the reader to visualize graphically how modelled flows and ecological standards interact in our scenarios. For the graphs, all data were converted from units used to measure demand to their streamflow equivalents. Where the actual flow for Scenario I, II, III or

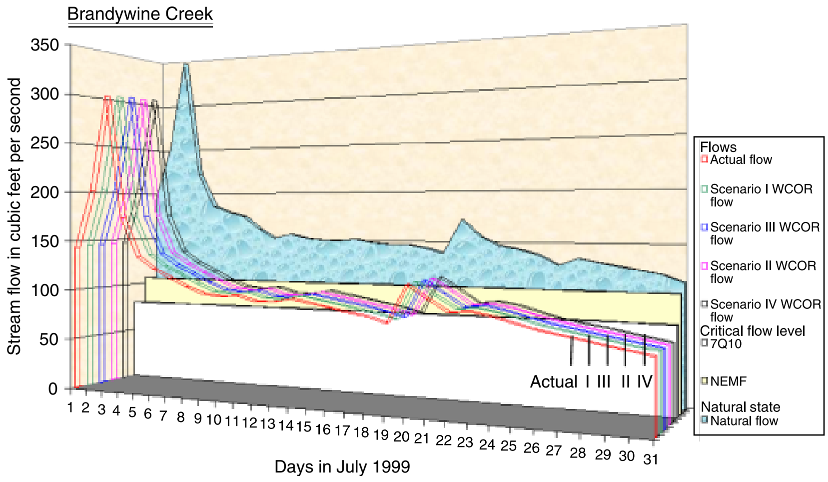

Fig. 3. Brandywine Creek scenarios. WCOR, water conservation-oriented rates; NEMF, New England Median Flow.

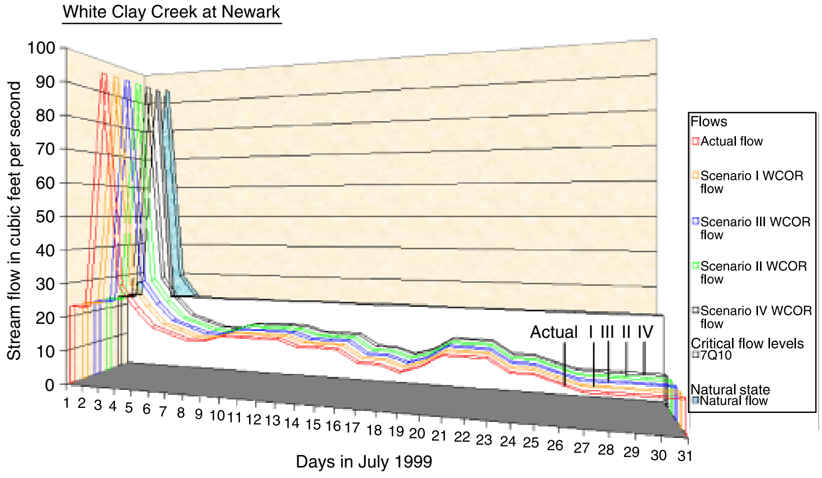

Fig. 4. White Clay Creek at Newark scenarios. WCOR, water conservation-oriented rates.

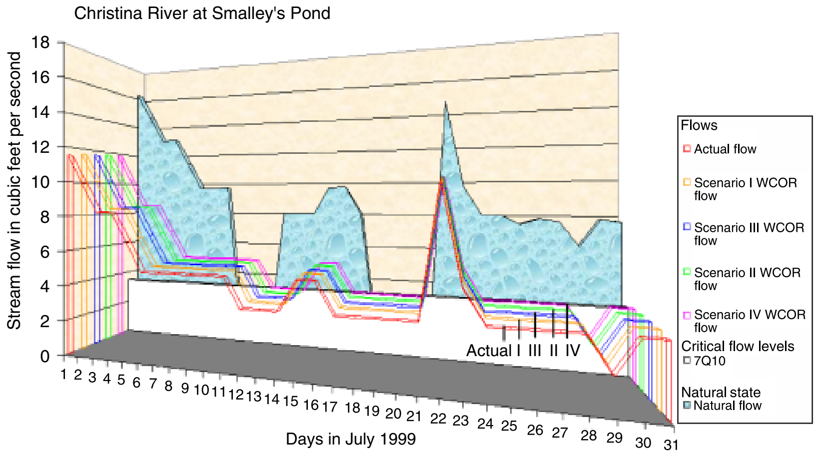

Fig. 5. Christina River at Smalley's Pond scenarios. WCOR, water conservation-oriented rates.

IV flows dip below the white 7Q10 or yellow NEMF standards in the graph, the critical flow level has been violated. The water savings kept in the streams progressively from Scenarios I to IV mitigate the number of days spent in violation, and consequently, damage to ecological systems.

In Fig. 3, the BC, use of DDRs resulted in 26 (very nearly 27) straight days above 7Q10 ecologically critical

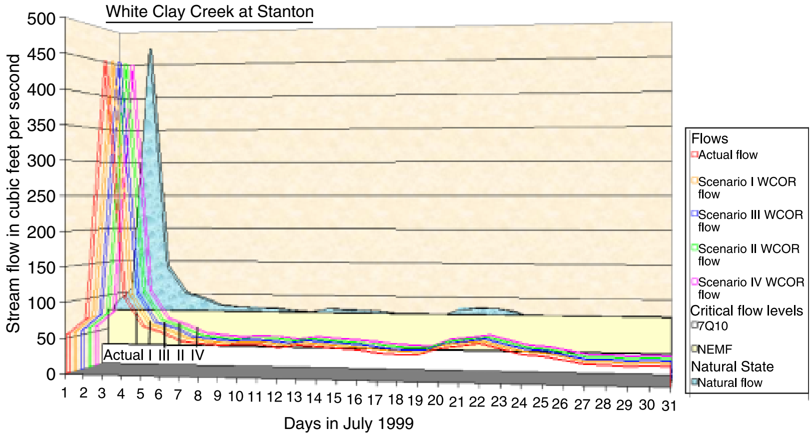

Fig. 6. White Clay Creek at Stanton scenarios. WCOR, water conservation-oriented rates; NEMF, New England Median Flow.

Table 12 Days spent at or below 'critical levels' for ecology under July 1999: DDR Scenarios I, II, III and IV

Surface source water	7Q10	New England Median Flow method	Notes
Brandywine Creek			
City of Wilmington			
July 1999	7	22	
Scenario I	5	22	
Scenario III	5	22	
Scenario II	5	22	
Scenario IV	5	21	Day 27 – break point of 7Q10 nearly reached using Scenario IV WCOR
Christina (Smalley's Pond)		Not applicable	
United			
July 1999	16		
Scenario I	1		
Scenario III	1		
Scenario II	1		
Scenario IV	1		
White Clay Creek (Newark)		Not applicable	Only five full sets of data, as combination of 'passby' (for downstream users) and 7Q10 requirements forced Newark to rely solely on wells on many days due to low flow. Results are still important though, as WCOR potential to stretch supplies and preserve ecology is evident when savings are projected longer
City of Newark			
July 1999	29		
Scenario I	27		
Scenario III	27		
Scenario II	27		
Scenario IV	27		
White Clay Creek (Stanton)			
United			
July 1999	5	29	
Scenario I	5	28	
Scenario III	5		
Scenario II	5	28	Days 27, 28, 30 and 31 – break point of 7Q10 standard nearly reached using Scenario II WCOR
Scenario IV	1		Day 29 – break point of 7Q10 nearly reached using Scenario IV WCOR (this would negate all days)
Total for entire basin			
All utilities			
July 1999	57	51	
Scenario I	38	50	
Scenario III	38	50	
Scenario II	38	50	
Scenario IV	34	49	

DDR, drought demand rates; WCOR, water conservation-oriented rates.

flow levels to start the month. This can be juxtaposed against the 18-, 6- and 5-day stretches that actually occurred. On the 19th and 26th (almost on the 27th), both DDR Scenarios I and III raise flow levels above 7Q10. Also, on the 21st, DDR Scenario IV raises stream flow above the NEMF standard. Figure 4 shows a limited implementation of the DDR scenarios for the WCC at Newark for July 1999. Newark savings reflect only 5 days of DDRs applied, as the City of Newark alternately pumped ground water and ceased surface water withdrawals. Nevertheless, a contribution to stream flow is illustrated. Impressively, for the CR at Smalley's Pond (Fig. 5), utilization of merely a DDR Scenario I drops the number of days spent below 7Q10 from 16 to 1. Even greater benefits are realized under Scenarios II, III and IV. DDRs nearly pick up a final day, which would mean the entire month would be saved from reaching 'critical levels' for ecology. In the case of the WCC at Stanton (Fig. 6), all DDR scenarios are able to lift stream flows above the NEMF standard on the second. In addition, nearly the entire last week of July was spent below 7Q10, but DDR Scenario IV intervention raises levels above the 7Q10 standard for all but 1 day on the 29th.

Table 12 provides a useful quick reference of days spent at or below critical levels in July 1999 under the four DDR modelling scenarios. It also illustrates the total basin benefits in northern NCC. Across all basins in total, DDR Scenario IV implementation results in a decline in days spent at or below 7Q10 from 57 to 34 days. This represents a 40% decrease in days spent below the 7Q10 critical flow level. These results manifest a significant reduction in time during which streams failed to satisfy ecological requirements. Even given our cautious calculations, the linkages between environment–demand–supply–environment are quite clear.

Another way to interpret water conserved as shown in Scenario IV is by per cent increase in average monthly flow. Again, Newark's savings reflect only 5 days of DDRs, as the City of Newark started to use ground water, and this dramatically impacts overall basin savings. Yet, significant savings are realized across the the subbasins. The per cent increases in average flows are:

- WCC at Newark 0.14%;
- BC at Wilmington 2.83%;
- WCC at Stanton 3.89%; and
- CR at Smalley's Pond 6.87%.

Conclusions

(1) We have conducted previous studies regarding water conservation in the United States (Wang *et al*. 2005). Research including 17 states and 43 purveyors has revealed that only long-term outreach efforts to raise conservation consciousness, demonstrating a vested interest and fostering an environmental ethic, will make it possible for WCOR to alter consumer demand over the *long run*.

(2) This research, nevertheless, has demonstrated that DDR implementation *can* make an immediate and powerful *short-term positive impact* both in terms of supply and ecology. Understanding this concept and making the connections between stream flow, demand, supply and ecology will be of highly increasing importance as cities and their level of demand continue to grow.

(3) We believe that the lessons garnered and models constructed in this research hold significant implications for governments and purveyors at multiple scales in the United States and abroad who struggle to find a 'soft-path' to sustain water for both people and nature during drought.

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Note: All grey literature is available as public reports and lithographs from the Delaware State Water Coordinator at http://www.ipa.udel.edu/directory/homepages/kauffman.html.

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