

Demand Management Strategies of North Carolina

Public Water Systems

by

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Abstract

The traditional approach to water resources management in the Southeastern United States does not take full advantage of economic tools for managing scarcity. It fails to prevent economically inefficient uses of water, imposes additional costs to downstream users, and degrades the natural environment. The recent drought in the Southeastern United States reveals these shortcomings and indicates that water supply planners should be aware of the role demand management can play in reducing waste and misallocation during times of water stress.

This analysis draws on data from the State of North Carolina's Local Water Supply Plan Database. In the absence of statewide standards for technical and economic efficiency in water use, it examines the decision of public water systems to voluntarily adopt demand management practices. An empirical model of water use is then estimated to determine the effectiveness of current demand management strategies, as employed by North Carolina public water systems.

Results of the analysis confirm the view held by experts: individual demand management strategies are context-specific and should be adopted with careful attention to local conditions. In North Carolina, the degree of demand management pursued by public systems reflects a policy choice of system managers, customers, and decision makers. River basin planning is also shown to positively affect the degree of demand management pursued by public systems. A model estimating overall system demand shows that conservation pricing can be effective at reducing levels of water use; however, estimating the effectiveness of demand management strategies is complicated by a lack of criteria for determining systems' program participation.

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1. Introduction

The traditional approach to water resources management in the Southeastern United States does not take full advantage of economic principles for managing scarcity. It does not properly account for the physical scarcity of water or the scarcity of capital resources required to productively employ water for human needs and economic benefits.

Traditional approaches also disregard those negative externalities of water use that serve to perpetuate this scarcity by diminishing available raw water supplies.

Scholars point out that the historical method of water supply planning is to project water “requirements,” not water demands. The requirements approach defines water demand using a trajectory of water *use*, adjusted for population growth or economic growth. Uncertainty is accounted for by conservatively estimating low, medium, or high trajectories for increased levels of water use. This approach does not consider the rising scarcity of water resources and burdens society with the costs of negative externalities and economically inefficient uses of water (Griffin, 2006).

Economic efficiency is a desirable condition in the management of water resources because it allows a scarce resource to be allocated among competing uses in a way that maximizes the value of that resource to society as whole. For most goods and services, the vehicle for this allocation is the market, yet for a number of reasons, water is considered a non-market good. In the case where market prices for water do exist, there is often a great deal of distortion in that market (Young, 1996). These distortions, e.g. subsidized water rates, conceal the true value of water for human and environmental needs and enable the costly and imprudent requirements approach to water resources management.

Water resources managers in the Southeastern United States are only beginning to recognize that successful system planning must include more than just supply-side approaches for coping with scarcity. In this region, high levels of precipitation and plentiful streams appear to have engendered the misconception that water is an inexhaustible resource. Population growth and declining water quality are just two factors that disprove this assumption. The occurrence of recent prolonged and severe droughts, in 2002 and in 2007-2008, has shown water managers the approaching horizon of water supply enhancement strategies and the need to include strong demand management strategies as a means for coping with rising water scarcity.

Public water systems have two options when levels of water use approach the physical limits of water supply sources or the limits of water infrastructure capacity. They may either increase water supply or decrease water demand (Griffin, 2006). The status quo resolution to this problem is the development of new water sources or the expansion of infrastructure. The means for doing so typically come in the form of a new well, surface water impoundment, drinking water treatment plant, or similar capital project. This option is increasingly costly from economic, political, and environmental points of view.

Experts in the field of water resource economics point to many sources of increasing costs that invalidate a pure requirements approach. In a recent textbook, Texas A&M agricultural economist Ronald Griffin identifies the following contributors: population growth and the need to provide more water to more people; economic development; declining freshwater resources due to groundwater depletion and pollution of surface water; global warming and associated uncertainty in the hydrologic cycle; high

construction costs associated with a lack of optimal dam locations and diminished capacity at existing reservoirs where sediment inputs displace available storage; depreciation of water resources infrastructure; demand for high-quality drinking water; and higher energy prices that must be paid to pump, convey, and pressurize water (Griffin, 2006).

Another option available to public water utilities is to include the other half of the equation: a requirement for economic efficiency in the allocation of scarce resources. Demand-side management represents an opportunity for society to minimize the costs of harnessing water resources by maximizing the benefits of current and future water resources investments. According to the Organization for Economic Cooperation and Development, implementing demand management represents a shift towards a more integrated approach to water resources management. Among the goals of such an approach, there are objectives that, “minimize water waste, maximize the [technical] efficiency of water use, and maximize water availability by limiting the degradation of water supplies (OECD 1998, p.21).” Available strategies for water demand management seek to minimize the demand that is placed on the natural environment to satisfy human and economic needs. Under this definition¹ of water demand, available tools for limiting the demand of public water systems include the following: water conservation education and information; effective pricing; retrofitting properties with more technically efficient, low-flow plumbing; leakage reduction; and water reuse, recycling and reclamation (Green, 2003).

¹ It is recognized that alternative definitions of water demand may lead to reconsideration of how demand management tools are classified.

2. Background

North Carolina's population is the 10th largest in the United States and the rate of growth has increased dramatically over the past 15 years. By the year 2030, the State should expect a population increase of 50% over its current 8 million. Population increases will lead to higher demands for treated, potable water from the State's public water suppliers. Public water supplies will have to cope with a future demand of 335 billion gallons per year. This figure represents an annual growth rate of 2.7% through at least 2010, with a total demand increase of 70% by the year 2030. The State's agriculture, industry, and mining needs are expected to remain constant through the year 2030 (NC Rural Center, 2005).

Available raw water supplies across the State are fed by approximately 40 – 55 inches of precipitation per year. Present water supplies are able to support North Carolina's current water demands (Polk, 2007). While North Carolina is blessed with abundant water on average, seasonal variations in water availability often disguise this abundance (NC Rural Center, 2005). Water supply shortages experienced in the drought of 2007-2008 are testament to the fact that the State's available freshwater supply is subject to demographic pressure and shocks to the hydrologic system. Preliminary consumption and conservation data collected during the 2007-2008 drought only serve to highlight this vulnerability. According to news reports, it would seem that the public at large does not recognize the fact that water scarcity is a phenomenon of timing and location (Dees, 2008).

The United States Geologic Survey (USGS) found that the drought of 1998 – 2002 severely impacted public water suppliers in the Piedmont and Mountain regions.

The risk that these systems would be unable to continue providing water of adequate quantity and quality resulted in economic losses and restrictions on water use. Drought costs for the 2002 supply disruption were estimated to be \$15 to \$20 million for municipalities alone. The drought caused more than 200 municipalities and most major cities to implement voluntary, mandatory, or emergency water conservation measures (Weaver, 2005). Five short years later, North Carolina withers under the greatest water shortage it has ever experienced (NC Climate Center, 2008)².

In addition to the costs of shortfalls in available water supply, there are other factors to consider in determining water demands and the costs associated with satisfying that demand. Poor water quality increases the cost of treating water to potable standards. Water quality in North Carolina's coastal plain is increasingly saline due to over-use of groundwater supplies (Polk, 2007). Land use changes contribute to non-point source and diffuse pollution that increase water treatment costs at the local level. Conversion of land for urban use is occurring more rapidly in North Carolina than in any other State (Polk, 2007). The US EPA projects that the number of watersheds in the state with greater than 20% impervious surface will double between 2000 and 2030 (Exum, 2005).

Advocates for refining water policy in North Carolina recognize that the infrastructure needed for water treatment and delivery is decaying while the costs associated with maintaining these systems are increasing. Compounding this problem is the reality that available funds for necessary upkeep are declining (Polk, 2007). North Carolina has 535 public water systems statewide. They provide water to 67% of the State's population and the majority are owned and operated by municipalities.

² Regardless of whether the current drought is the worst hydrologic drought ever recorded, it must be recognized that it coincides with the highest level of water demand to date. As population growth continues, this trend will only amplify the severity of the next drought that occurs in the state.

Residential use accounts for 46% of the water treated by these municipalities, with the remainder being supplied to commercial and industrial users. An increase of 70% is expected in new water and wastewater connections by 2030. The North Carolina Rural Economic Development center estimates that public water suppliers within the State will require upwards of \$16 billion in infrastructure to accommodate this growth and prevent further deterioration of water supply infrastructure (NC Rural Center, 2005).

Infrastructure needs represent major challenges for public water systems. According the North Carolina Rural Economic Development Center, rural water systems have the greatest capital needs. Three out of four public water systems serve fewer than 3,300 customers. These systems have greater difficulty raising capital for infrastructure and reaching the economies of scale that allow them access to financing (NC Rural Center, 2005).

Due to poor credit ratings, rural systems often lack access to funding. According to the NC Rural Center, lack of access to loans and dwindling grant funds leave 60% of these rural suppliers in a “struggle to comply with regulations.” Furthermore, lack of capital results in water system inefficiency. Statewide, municipal water systems are estimated to lose 95.85 million gallons of water per day because of decaying infrastructure. Growth in demand and decrepit infrastructure represent the primary capital needs of public water suppliers. The Congressional budget office estimates that capital budgets should increase at a rate of 14% per year to close this financing gap (NC Rural Center, 2005).

3. Purpose and Scope

This analysis draws on data from the State of North Carolina's Local Water Supply Plan Database to examine the decision to institute demand management practices. It addresses the question of whether this decision is case-specific, or if general system characteristics can be used to identify likely participants. A model is then estimated to determine the effect of a system's propensity to participate in demand management on levels of system-wide water use.

The fundamentals of water resources economics have been developed from research focusing on the factors that influence residential water demand in the Western and Southwestern United States. In contrast, plentiful water supplies in the Eastern and Southeastern United States have hindered the development of similar investigations in this part of the country. North Carolina has formally recognized the need for comprehensive water supply planning since 1989 (NCGS 143-355). Legislation passed in that year requires the development of Local Water Supply Plans for all communities with greater than 1,000 connections or a service population greater than 3,000 citizens. Plans are required to include all information "readily available [to the water system]." This includes population projections, expected industrial development, water use information, and descriptions of present and future water supplies (NCGS 143-355). These supply-side factors are all that is needed to conduct water resources planning through application of the requirements approach.

The State of North Carolina has a policy that recognizes the need to move beyond the requirements approach. Local Water Supply Plans are also required to include,

“current and future water conservation and reuse programs.” The level of commitment to this policy goal at the local level remains a source of speculation. Some water resources stakeholders in North Carolina recognize the need to aggressively pursue water use efficiency and wastewater reuse. They point out that projections of water resources demand in North Carolina for the year 2030 are based on a constant level of per capita water use (Polk, 2007). This projection clearly indicates an application of the requirements approach and reveals that such an approach remains the status quo for water resources planning in North Carolina at the present time. The transition to demand-side management will require the development, dissemination, and implementation of effective tools for reaching technical and economic efficiency in per capita usage.

The Local Water Supply Plan database contains pertinent data for assessing public water suppliers’ commitment to demand management strategies. These may be used to indicate factors that influence North Carolina public water systems to limit the amount of water used in their system. A major piece of this analysis presents the application of statistical methods in an effort to quantify these factors.

Consideration of both the demand and supply elements of water scarcity is only beginning in the Southeastern United States; in general, public systems still respond to water shortages with plans to develop new sources. For those public water systems that have begun this transition, the lack of experience with demand-side management calls for an evaluation of its present effectiveness at reducing raw water withdrawal by the system. North Carolina policy makers and advocates can use the results of this evaluation to set future goals for economic and technical efficiency in water resources management.

4. Literature Review

The LWSP database includes data on 7 possible demand management strategies that are reported by each system that submits a plan. Each of these strategies is considered to have some effect on how well a water system manages its available water supply. This section provides an introduction to each of the following: meter replacement programs, metering of outdoor use, leak detection, plumbing retrofit, water conservation education, conservation rate structures, and reclaimed or recycled water.

Meter replacement programs are promoted on the basis of ensuring the financial viability of a water system. Inefficient and inaccurate meters can lead water systems to lose substantial amounts of revenue (van der Linden, 1998). According to literature on meter replacement programs, successful and cost effective implementation and evaluation of meter replacement programs requires a sophisticated understanding of statistical sampling techniques and thorough understanding of basic ordinary least-squares regression (Yee, 1999). Furthermore, the data and personnel requirements of an effective meter replacement program require significant amounts of time for meter inspection and data analysis. In sum, sources indicated that smaller meters should be replaced every 15 years, while larger meters for high flow volumes should be replaced on a schedule of 5 – 10 years.

Even in the water-rich Southeastern United States, outdoor watering makes a large contribution to municipal water demands. Studies on the efficiency of lawn irrigation and measures for measuring application rates point out that in some areas, outdoor watering may account for as much as 50-60% of annual residential water demand

(Lesmeister, 2007). The Town of Cary, North Carolina indicates in its Water Conservation and Peak Demand Management Plan that one of the primary foci of the plan is to reduce peak levels of summer use associated with irrigation (CARY, 2000). Importantly, the plan also notes that this seasonal demand is “driven by a large proportion of residential customers, an affluent customer base, and high community standards for the appearance of commercial properties (CARY, 2000, Executive Summary).”

Leak detection programs are reported to reduce levels of unaccounted for water loss by 50-75% in small systems. Anecdotal evidence from Southeastern water utilities indicates that even the most advanced ultrasonic devices can recoup their expense in less than one year (Leauber, 1997). Other methods for leak detection include visual assessment and monitoring of hydraulic pressure in water lines (Regnier, 1986). Leak detection remains one of the most basic and obvious methods of water demand management and conservation.

Plumbing retrofit programs encourage the installation of water conserving devices in households. Studies often indicate that households use low-flow shower devices to conserve energy, but that low-flow toilets are typically influenced by a household’s desire to conserve water (Renzetti, 2002). Studies indicate that installing one of these devices can decrease household water use by as much as 8-10% in each instance (Renwick, 1998).

Educating the public about the need to conserve water resources is a common approach to demand management during times of water stress. Renzetti (2002), Timmins (2003), and Kenney et al. (2008), all point out that water conservation education can lead to reductions in water demand, but that these programs are most effective when used in

conjunction with pricing strategies or technical measures for demand reduction. There is also some indication that long-term water conservation may be subject to declining long-run effectiveness (Howe, 2008).

Water conservation rate structures, for the purpose of this analysis, include flat rate structures and increasing block rate structures. Increasing block rate structures have varying water rates for step-wise increases in water use. Kenney et al. (2008) point to literature indicating that the mere existence of an increasing rate structure has been proven to decrease residential water demand. This effect remains a matter of some debate due to uncertainty about the level of understanding a typical customer is likely to have about their water rate structure. Flat rate structures result in a constant price for any volume of water use. These structures are included because they are a conservative alternative to a third type of rate structure, the declining block rate structure. This price structure charges a decreasing rate for water as volumetric use increases.

The use of recycled or reclaimed water is the most significant of demand management strategies. It has the largest potential for offsetting a public water system's raw water withdrawals. A number of issues remain unresolved with the implementation of reclaimed water, such as the issue of historical return flows enjoyed by downstream users. Asano (1990) points out that the viability of reclaimed water is extremely sensitive to local situations. In most cases the high infrastructure and regulatory costs associated with these systems requires a detailed analysis. The potential gains from water reclamation or reuse include regulatory cost savings of reduced wastewater discharges, and economic benefits for customers with substantial demand for reclaimed water (Asano, 1990). Reuse can also be used to significantly reduce peak demand by providing

a reliable source of water for irrigation purposes. Also, industrial users are often willing and able to benefit from water reuse projects. It should be noted that these potential reclaimed water customers expect to receive such water at a reduced cost, due to perceptions that the water is somehow less adequate for their needs than potable water (Hermanowicz, 2001).

Other researchers point out that the economic benefits of water reuse depend on the costs of alternative water supplies. This consideration is particularly applicable in the Western United States where potential customers for reclaimed water may realize substantial saving from acquiring rights to a cheaper, lower quality water source that is still able to meet their needs (Wong, 2000). The consideration of the effects of water rights regimes on demand management strategies is beyond scope of this analysis, but it is worth mentioning that at present, systems operating under common law riparian rights are less likely to experience regulatory or infrastructure costs high enough to make use of reclaimed water an economically viable alternative to developing new raw water supplies. This situation results from the fact that water rights are not transferable under the riparian doctrine. Several exceptions to this supposition can be identified in North Carolina, such as in Orange County Water and Sewer Authority. OWASA benefits from a single, high-volume user of reclaimed water: The University of North Carolina (OWASA, 2005). Similarly, the Town of Cary, North Carolina experiences a strong yearly peak demand for residential lawn irrigation during summer months. This demand is easily satisfied by using reclaimed water (CARY, 2000).

5. Data and Methods

Data

The North Carolina Department of Environment and Natural Resources, Division of Water Resources (DWR), collects and maintains data specific to each public water system in the state. As mentioned previously, the Local Water Supply Plan (LWSP) database is the result of an act of the state legislature. The database contains data from the formal planning process that requires public water systems to account for the current and projected water use of its customer base. The plans are updated every five years to “reflect relevant data and projections,” and contain information to support a requirements approach to water supply planning (NCGS 143-355).

According to the authorizing statutes, the LWSP database exists to “assure the availability of adequate supplies of good quality water to protect the public health and support desirable economic growth.” The plans provide cross-sectional data on North Carolina public water systems. The State Division of Water Resources is directed to use these data as a basis for creating a statewide water supply plan. In doing so, the DWR is also able to identify compatibility and conflict between the local plans of public systems (NCGS 143-344).

Since passage of the statute in 1989, there have been three cycles of LWSP submissions that contain data for the years 1992, 1997, and 2002³. The DWR LWSP website reports that North Carolina public water systems submitted 520 Local Water Supply Plans for the 2002 planning cycle. The North Carolina Division of Water

³ The 2007 LWSP data collection cycle is concurrent with the development of this analysis and is presently unavailable. The 1992 cycle is widely recognized as flawed and incomplete. Similarly, some data used in this analysis is not available for the 1997 cycle.

Resources provided the complete 2002 dataset for use in this analysis. The cross-sectional dataset provided contains 527 observations⁴. The data provided by public water systems provide a comprehensive description of attributes that are specific to each system. The attributes are classified into five categories: system information, water use information, water supply sources, wastewater information, and planning.

The system information category includes physical descriptions of infrastructure, programs, and water conservation. These variables contain information particularly applicable to the operation and maintenance of the system. Miles of distribution lines, feet of new water mains, meters replaced, finished water storage capacity, information about water pressure, valve flush, cross-connections programs, meter replacement programs, and leak detection programs are all factors that describe the day-to-day operation and management of the water system. Water conservation measures are of particular interest to this study and the water supply plans contain information about the existence of plumbing retrofit programs, water conservation education programs, use of reclaimed water, metering of outdoor use, leak detection, as well as the type of water rate structure employed by the system.

Water use information describes the geographic and demographic composition of the system customers. Rather than simply reporting the number of customers served, the database contains data on how the service population is further divided by percentage of the population in each source watershed. Water use is broken down by customer types to describe residential, commercial, industrial, and institutional uses.

⁴ It is likely that the dataset provided by DWR was generated using a master list of public water systems where historical database records must be maintained to track system mergers or systems that cease operation. Military installations are excluded from the dataset.

The section on water supply sources presents crucial data for this analysis. Systems report average and maximum daily use, by month. These figures are likely compiled from monthly system reports, as required by drinking water regulations (15A NCAC 18C). Each water supply source is listed separately and includes average and maximum daily use from that source.

The remaining LWSP section that is applicable to measuring the effects of demand management strategies is the planning section. Descriptions of population projections extend to the year 2030. Current levels of water use are described as a percentage of currently available raw water supplies. Total available supply is defined as the sum of surface water supply, ground water supply, purchases, and future supplies through 2030. Demand is based on service area demand, sales, and future sales through the year 2030.

Methods

The conceptual framework of this analysis employs a two-stage least squares technique that has been used to measure the effectiveness of voluntary programs for pollution control and energy conservation (see Hartman, 1988; Khanna and Damon, 1999; Welch et al., 2000; and Vidovic and Khanna, 2007). In the application of this method to measure the effectiveness of voluntary programs for reducing the pollutant emissions of individual private firms, Khanna and Damon (1999) hypothesize that the level of emissions produced by each firm is chosen in such a way as to maximize profits over time. To the extent that a voluntary program for emissions reduction enables a firm to avoid the costs of regulation, firms can be expected to volunteer for participation. The

researchers point out a selection bias⁵ is generated by the fact that the same observable and unobservable characteristics influencing the participation decision also lead the firm to choose its level of emissions.

In the context of North Carolina public water supply systems, levels of aggregate water use are chosen to satisfy the specific demands of the systems' individual customers. From a system standpoint, the same characteristics that influence individual customer demand are hypothesized to influence the aggregate water demand of the public water supply system that serves these individual customers. Factors hypothesized to contribute to variation in North Carolina public water system use include observable system-specific characteristics and the systems' decision to employ demand management strategies.

The decision of a water systems to use demand management strategies is characterized as a binary variable equal to 1 if the system participates and 0 otherwise. To follow the process used in previous studies by Hartman (1988) and Khanna and Damon (1999), the decision to participate in demand management is modeled as a discrete choice equation, dependent on observable public water system characteristics (see: Table 1).

As discussed previously, the requirements approach represents the status quo methodology for water supply planning in North Carolina; therefore, public water systems that have implemented demand management represent a voluntary departure from historical practices. Furthermore, in projections of future water demands for North Carolina, the water supply planning methodologies employed by state-funded agencies

⁵ According to Hartman (1988), in determining the success of a voluntary program, it is inappropriate to simply compare variables of interest between program participants and non-participants. He states, "This comparison is appropriate *only* if participants and [sic] nonparticipants are identical in all respects except program participation."

project constant levels of per capita water demand. Effectively, this represents tacit evidence that the requirements approach to water supply planning is the accepted norm⁶.

TABLE 1. Factors for NC Public Water System Demand Management.

Variable	Description	Units	Source
Demographic			
log_income	Log of median income for systems' primary county	N/A	NC Rural Center
rc_pctbachhigh	Percent of residents in systems' primary county with a baccalaureate degree or higher	Percentage	NC Rural Center
Financial			
efc_rev_exp	Ratio of system's operating revenue to expenditure	Ratio	UNC Environmental Finance Center
System Characteristics			
must_purch	Indicator variable for whether a system lacks facilities for water withdrawal or extraction	Binary	NC DENR LWSP
perc_resid	Percentage of system composed of residential connections	Percentage	NC DENR LWSP
perc_loss		Percentage	NC DENR LWSP
fut_cur_ratio	Percentage of unaccounted for water Ratio of systems' projected future water use to current estimated use	Ratio	NC DENR LWSP
pipemiles_percap	Miles of distribution line per customer, based on reported service population	Miles	NC DENR LWSP
basin	Indicator variable for whether the system has participated in basin-wide planning initiatives	Binary	NC DENR LWSP

Self-selection bias is introduced into the present analysis by the voluntary nature of public water suppliers' demand management strategies. Measuring the effect of voluntary measures for reducing raw water withdrawals is difficult because systems implementing demand management strategies are likely to differ in observable, system-specific characteristics from those systems that do not participate in voluntary demand management strategies. These observable differences will be reflected in the unobservable preferences of program participants (Hartman, 1988). For the case of public water suppliers in North Carolina, this self-selection bias means that the

⁶ The recognition of this fact is in no way intended to belittle or undermine the crucial role these studies have played in bringing attention to the challenges North Carolina faces for ensuring adequate future water supplies for population growth and economic development.

characteristics of systems that implement demand management strategies should be different from the characteristics of systems that continue to operate under the requirements approach. The fact that some systems have decided to voluntarily implement demand management may be the result of unobservable preferences for water conservation on the part of the systems' customers or managers.

After conducting a literature review of factors contributing to demand management systems, it is hypothesized that the factors listed in Table 1 are likely to influence a public water system in North Carolina to choose to undertake some measure of demand management.

2nd Stage

It is assumed that public water system demand in North Carolina is determined by the aggregate demand of each system's customer base. Previous studies indicate that domestic water use can be regressed against independent variables that describe income, marginal price of delivered water, and a measure of climatic conditions (Griffin, 2006). According to Robert Young, of Colorado State University,

“Empirical domestic water demand studies typically postulate that the quantity of domestic water demanded per connection varies with the ‘appropriate’ price of domestic water, prices of related goods, income of domestic water consumers, climate, and conservation policies (Young, 1996, p. 90).”

For the purposes of this cross-sectional analysis of North Carolina public water systems, it is assumed that variables describing domestic water demand at the individual customer level also appropriately describe system-wide aggregate water demands. Researchers point out that it is often difficult to separate domestic water accounts from other types of connections within the water system, thus total municipal consumption is often used as a

focus for econometric estimation of water demands (Young, 1996). In the present analysis, the dependent variable is system-wide water use, as reported by the LWSP Database.

In accordance with economic theory related to water demands, the marginal price of water per gallon is expected to have a negative effect on the amount of water demanded by the utilities' customers and the utility itself. Median income is expected to have a positive effect on water withdrawals because higher income customers, on average, are more likely to use more water, i.e. for appliances or lawn irrigation. Climate conditions are likely to have a strong effect on quantity demanded due to changes in rainfall or evapotranspiration (Young, 1996). Lastly, predicted values of system's propensity to conserve, from the probit model specified in the first stage of the analysis, are used as an independent variable.

6. Results

The NCDENR Local Water Supply Plan Database contains information on six possible demand management strategies. The implementation of these strategies represents public water systems' efforts to reduce the total amount of water used by their system. Table 2 presents summary data for each separate demand management measure. The strategy most commonly employed by water systems is meter replacement. The use of reclaimed water is the least commonly used strategy.

Table 2 serves to indicate that specific, individual demand management strategies may be employed in a variety of circumstances. For this reason, a separate model of the decision to adopt each individual demand management strategy is performed using the

same independent variables thought to influence overall voluntary participation in demand management (as a formal, composite program).

TABLE 2: Summary of Demand Management Measures

Variable	Description	Units	% Use
meter_rep_prog	Water meter replacement program	Binary	66%
outdoor_use	Metering of outdoor use	Binary	38%
leak_detect	Leak detection program	Binary	31%
wc_education	Water conservation education program	Binary	37%
plumb_retro	Plumbing retrofit program	Binary	24%
Rates	Increasing block or flat rate structure	Binary	56%
Reclaimed	Use of reclaimed water	Binary	7%

The results presented in Table 3 indicate factors that may be considered important determinants for the selection of any individual demand management strategy⁷. Results indicate that meter replacement programs are negatively affected by whether the system must purchase water from another system and positively affected by participation in basin wide planning initiatives. Education may also be a positive contributing factor to the decision to implement a meter replacement program. Metering of outdoor water use is directly related to levels of education amongst water customers and the system's projected future demands, but inversely related to the percentage of residential customers in a system. Customer income levels may also negatively affect the decision to implement metering of outdoor use. Leak detection programs are positively influenced

⁷ From this point forward, the reader should be aware that any discussion of model results proceeds under the assumption that statistical significance at the 10% level is sufficient evidence to conclude that the effect of the corresponding variable on model outcome is not random. This means that the effect of any independent variable discussed from this point forward has a 90% or greater chance of having a non-random effect on model outcomes.

by customers' level of education, number of miles of water distribution lines per capita, and participation in basin wide planning efforts. Leak detection may also be negatively influenced by the ratio of future to current demand.

TABLE 3: Modeling of Factors for Individual DMS

Variable	Individual Demand Management Strategies						
	meter_rep_prog	outdoor_use	leak_detect	wc_education	plumb_retro	rates	reclaimed
Demographic							
log_income	-0.6 <i>0.122</i>	-0.65 <i>0.091*</i>	0.032 <i>0.935</i>	-0.28 <i>0.464</i>	-0.28 <i>0.489</i>	0.38 <i>0.308</i>	-0.91 <i>0.165</i>
rc_pctbachhigh	1.58 <i>0.084*</i>	2.44 <i>0.003***</i>	2.44 <i>0.003***</i>	0.64 <i>0.427</i>	1.83 <i>0.031**</i>	1.34 <i>0.094*</i>	3.91 <i>0.000***</i>
Financial							
efc_rev_exp	-0.26 <i>0.3</i>	-0.32 <i>0.21</i>	-0.21 <i>0.431</i>	-0.39 <i>0.136</i>	0.21 <i>0.437</i>	-0.28 <i>0.257</i>	-0.5 <i>0.263</i>
System Characteristics							
must_purch	-0.36 <i>0.009***</i>	-0.0014 <i>0.992</i>	-0.0006 <i>0.996</i>	-0.21 <i>0.137</i>	0.02 <i>0.919</i>	-0.14 <i>0.278</i>	-0.47 <i>0.078*</i>
perc_resid	-0.17 <i>0.511</i>	-0.78 <i>0.001***</i>	0.025 <i>0.927</i>	-0.12 <i>0.64</i>	-0.15 <i>0.599</i>	0.04 <i>0.858</i>	-0.87 <i>0.042**</i>
perc_loss	-0.61 <i>0.193</i>	-0.81 <i>0.089</i>	-0.18 <i>0.72</i>	-0.31 <i>0.504</i>	0.23 <i>0.646</i>	0.72 <i>0.11</i>	-1.04 <i>0.214</i>
fut_cur_ratio	-0.06 <i>0.433</i>	0.19 <i>0.000***</i>	-0.2 <i>0.027**</i>	-0.031 <i>0.646</i>	-0.21 <i>0.031**</i>	-0.004 <i>0.94</i>	0.04 <i>0.68</i>
pipemiles_percap	1.52 <i>0.356</i>	-1.06 <i>0.439</i>	4.5 <i>0.026**</i>	-0.09 <i>0.947</i>	0.87 <i>0.578</i>	-0.51 <i>0.707</i>	2.1 <i>0.184</i>
basin	0.51 <i>0.000***</i>	0.16 <i>0.223</i>	0.33 <i>0.014**</i>	0.65 <i>0.000***</i>	0.58 <i>0.000***</i>	0.05 <i>0.708</i>	0.35 <i>0.085*</i>

Note: Sample size is 463 observations.

*** Statistically significant at the 1% level.

** Statistically significant at the 5% level.

* Statistically significant at the 10% level.

A system's decision to conduct water conservation education programs is directly influenced by participation in basin wide planning efforts. Plumbing retrofit programs are positively related to basin wide planning participation, but are also negatively affected by the ratio of a system's future demand to current levels of use and levels of customers' education. The adoption of water conservation rates may also be positively attributable to the level of education possessed by system customers. The decision to use reclaimed water is directly determined by the education levels of the system's customers

and, perhaps, participation in basin wide planning efforts. Reclaimed water use is also inversely determined by the percentage of residential customers and whether system must purchase water.

Many North Carolina public water systems have already adopted demand management strategies; although, not all demand management strategies produce uniform levels of demand reduction (Renzetti, 2002). Thus, the consideration of demand management as a voluntary alternative to status quo methods for water supply planning requires some accounting for the degree of participation. Table 4 presents the construction of variables that measure this degree by counting the number of demand management strategies a system uses or by manually classifying systems that use demand management strategies about which there is some for debate⁸.

TABLE 4: Summary Statistics for Systems' DMS Count (& Poisson Dependent Variable Specifications)

Variable	Description	Mean #DMS	Std. Dev.
pois8_basin	Variable "basin" included as DMS	2.93	1.7047
pois7	Variable "basin" <i>not</i> included as DMS	2.58	1.5051
pois6_no_met	Variable "meter_rep_prog" <i>not</i> included as DMS	1.92	1.3084
pois6_no_out	Variable "outdoor_use" <i>not</i> included as DMS	2.21	1.334
pois5	Variables "meter_rep_prog" and "outdoor_use" <i>not</i> included as DMS	1.54	1.1348

Note: Sample size is 463 observations.

To estimate probabilistic models of a water system's decision to pursue demand management as a policy goal, binomial dependent variables were constructed using a range of criteria. These criteria represent possible thresholds for classifying systems as voluntary participants in demand management. Table 5 lists summaries for each of these dependent variable specifications.

⁸ It is a matter of subjectivity as to whether one classifies river basin planning initiatives as demand management. The same is true, as discussed to earlier, of reclaimed water.

TABLE 5: Summary Statistics for Probit Dependent Variable Specifications

Variable	Description	Mean	Std. Dev.
saver_basin	Equals 1 for systems where "pois8_basin>2"; 0 otherwise	0.55	0.4984
saver	Equals 1 for systems where "pois7>2"; 0 otherwise	0.48	0.5000
saver_no_met	Equals 1 for systems where "pois6_no_met>1"; 0 otherwise	0.56	0.4967
saver_no_out	Equals 1 for systems where "pois6_no_out>2"; 0 otherwise	0.4	0.4899
saver_five	Equals 1 for systems where "pois5>1"; 0 otherwise	0.46	0.4988
clear_saver	Equals 1 for systems where "wc_education=1" and "plumb_retro "=1; 0 otherwise	0.17	0.3785

Note: Sample size is 463 observations.

Table 6 presents the results of the probabilistic choice equation describing factors that influence the decision to pursue demand management strategies. Customers' level of education and participation in river basin planning initiatives both have a consistent, positive, and statistically significant effect on the decision to participate in demand management. The accuracy of model predictions is presented in Table 7. Only one of the specified probit models provides an acceptable level of overall accuracy. The model using the dependent variable "SAVER" accurately classifies more than 50% of systems. Likewise, given the system characteristics specified in the model, it has a greater than 50% chance of accurately predicting a system's classification. Table 8 presents the results of a poisson regression that was performed to confirm the consistency of independent variables affecting the probability choice equation.

TABLE 6: Comparison of Probit Results by Model Specification

Variable	Dependent Variable Specification					
	saver_basin	Saver	saver_no_met	saver_no_out	saver_five	clear_saver
log_income	0.23 <i>0.544</i>	-0.14 <i>0.715</i>	-0.18 <i>0.619</i>	0.13 <i>0.733</i>	-0.12 <i>0.757</i>	-0.47 <i>0.292</i>
rc_pctbachigh	3.61 <i>0.000***</i>	3.24 <i>0.000***</i>	2.17 <i>0.014**</i>	3.22 <i>0.000***</i>	2.21 <i>0.009***</i>	2.26 <i>0.011**</i>
efc_rev_exp	-0.46 <i>0.065*</i>	-0.31 <i>0.204</i>	-0.4 <i>0.104</i>	-0.26 <i>0.310</i>	-0.23 <i>0.361</i>	-0.11 <i>0.713</i>
must_purchase	-0.12 <i>0.368</i>	-0.15 <i>0.278</i>	-0.079 <i>0.556</i>	-0.24 <i>0.084</i>	-0.17 <i>0.225</i>	0.085 <i>0.599</i>
perc_resid	-0.403 <i>0.079*</i>	-0.33 <i>0.200</i>	-0.21 <i>0.410</i>	-0.22 <i>0.385</i>	-0.17 <i>0.505</i>	-0.09 <i>0.767</i>
perc_loss	-0.84 <i>0.066*</i>	-0.58 <i>0.220</i>	-0.084 <i>0.855</i>	-0.52 <i>0.285</i>	-0.23 <i>0.627</i>	0.25 <i>0.641</i>
fut_cur_ratio	0.05 <i>0.382</i>	-0.038 <i>0.607</i>	-0.039 <i>0.582</i>	-0.13 <i>0.111</i>	-0.079 <i>0.292</i>	-0.16 <i>0.102</i>
pipemiles_percap	1.94 <i>0.228</i>	1.63 <i>0.282</i>	2.19 <i>0.207</i>	1.33 <i>0.330</i>	2.03 <i>0.179</i>	-0.57 <i>0.727</i>
basin	N/A	0.6 <i>0.000***</i>	0.477 <i>0.000***</i>	0.67 <i>0.000***</i>	0.63 <i>0.000***</i>	0.7 <i>0.000***</i>

Note: Sample size is 463 observations.

*** Statistically significant at the 1% level.

** Statistically significant at the 5% level.

* Statistically significant at the 10% level.

TABLE 7: Accuracy Assessment of Probit Classification

Dependent Variable	Accurately Assigned			Predictive Value	
	Mean	Pr(+ D)	Pr(- ~D)	Pr(D +)	Pr(~D -)
saver_basin	0.55	68.38%	46.19%	60.49%	54.80%
saver*	0.48	52.94%	70.25%	61.90%	62.04%
saver_no_met	0.56	69.23%	48.28%	63.16%	55.06%
saver_no_out	0.4	45.11%	81%	61.03%	69.11%
saver_five	0.46	49.06%	75.70%	63.03%	63.76%
clear_saver	0.17	5%	98.96%	50%	83.30%

Dependent Variable	Inaccurately Assigned			Inaccurate Predictions	
	Mean	Pr(+ ~D)	Pr(- D)	Pr(~D +)	Pr(D -)
saver_basin	0.55	53.81%	31.62%	39.51%	45.20%
saver*	0.48	29.75%	47.06%	38.10%	37.96%
saver_no_met	0.56	51.72%	30.77%	36.84%	44.94%
saver_no_out	0.4	19%	54.89%	38.97%	30.89%
saver_five	0.46	24.30%	50.94%	36.97%	36.24%
clear_saver	0.17	1.04%	95%	50%	16.70%

* Indicates probit model with highest classification accuracy.

TABLE 8: Comparison of Poisson Models for Degree of DMS

Variable	Model Specification				
	pois8_basin	pois7	pois6_no_met	pois6_no_out	pois5
log_income	0.03 <i>0.853</i>	-0.22 <i>0.241</i>	-0.19 <i>0.384</i>	-0.15 <i>0.464</i>	-0.08 <i>0.744</i>
rc_pctbachhigh	1.74 <i>0.000***</i>	1.29 <i>0.000***</i>	1.54 <i>0.000***</i>	1.13 <i>0.002***</i>	1.38 <i>0.001***</i>
efc_rev_exp	-0.17 <i>0.13</i>	-0.2 <i>0.108</i>	-0.22 <i>0.125</i>	-0.18 <i>0.171</i>	-0.2 <i>0.206</i>
must_purch	-0.1 <i>0.097*</i>	-0.13 <i>0.058*</i>	-0.1 <i>0.194</i>	-0.15 <i>0.04**</i>	-0.13 <i>0.146</i>
perc_resid	-0.18 <i>0.068*</i>	-0.14 <i>0.218</i>	0.12 <i>0.282</i>	-0.13 <i>0.188</i>	-0.11 <i>0.366</i>
perc_loss	-0.27 <i>0.209</i>	-0.14 <i>0.547</i>	-0.05 <i>0.843</i>	-0.09 <i>0.716</i>	0.04 <i>0.895</i>
fut_cur_ratio	0.034 <i>0.132</i>	0.0009 <i>0.972</i>	-0.003 <i>0.759</i>	-0.0008 <i>0.915</i>	-0.006 <i>0.635</i>
pipemiles_percap	0.76 <i>0.153</i>	0.55 <i>0.35</i>	0.51 <i>0.455</i>	0.77 <i>0.206</i>	0.82 <i>0.258</i>
Basin	N/A	0.3 <i>0.000***</i>	0.32 <i>0.000***</i>	0.31 <i>0.000***</i>	0.35 <i>0.000***</i>

Note: Sample size is 463 observations.

*** Statistically significant at the 1% level.

** Statistically significant at the 5% level.

* Statistically significant at the 10% level.

The SAVER model presented in Table 7 is the best candidate for the second stage analysis that measures the effect of a system’s propensity to conserve on the per capita levels of water demand. Table 9 presents results from two different model specifications of system-wide per capita use, using the predicted values from the SAVER probit model.

Table 9: Results of OLS Estimation of System-wide Water Use

Dependent Variable: Log of average daily summer use (gal)		
Independent Variable	(1)	(2)
ln(income)	0.23	0.08
ln(price)	-18.01**	-14.33**
ln(rainfall)	0.066	0.19*
residential	NA	-1.38***
Demand Management	0.72**	0.41*
<i>F-statistic</i>	<i>0.0048***</i>	<i>0.0000***</i>
<i>R</i> ²	<i>0.0519</i>	<i>0.2915</i>

Note: Sample size is 298 observations.

*** Statistically significant at the 1% level.

** Statistically significant at the 5% level.

* Statistically significant at the 10% level.

7. Discussion

The literature of water resources economics identifies demand management as a promising approach for improving the economic efficiency of water use by enhancing decision-making. Demand management uses economic signals of scarcity to improve allocation of the resources required to employ water for human needs. The literature suggests that water demand management strategies provide benefits that include the following: maximizing the benefits gained from water use; reducing or delaying capital costs associated with water supply infrastructure development and upkeep; and enhancing water supplies that are available to freshwater ecosystems (Dziegielewski, 2003). Under this theoretical framework, North Carolina public water systems are hypothesized to undertake voluntary water demand management if either the system prefers demand management as a policy goal, or if demand management is less costly than developing new supplies.

As suggested in the Literature Review section and as supported by the results presented in Table 2, the individual demand management strategies employed by North Carolina systems are context-specific. It must be noted that NCDENR Division of Water Resources does not provide specific guidelines for how a system should determine its participation in any of these individual programs. This lack of consistency is a possible source of inaccurate measurement and may undermine statistical estimation of the decision to participate in individual demand management programs. Two major examples are worth mentioning. In the case of meter replacement programs, data from the LWSP database indicates that only 66% of North Carolina systems have such a program, yet closer inspection reveals that many systems reported *not* having a meter

replacement program while subsequently replacing water meters in their system. Likewise, systems that report participating in meter replacement programs indicate that no meters were replaced. An even clearer example of the need for guidelines to determine participation is evident when considering leak detection programs. The LWSP database allows systems to report whether they have such a program and provides a data field where they can further elaborate on the type of leak detection program used. Comments show that these programs vary in range from “a visual method,” to built-in leak detectors, outside contractors, or even sonar. Such inconsistencies reduce the explanatory power of the independent variables used in the probit model by increasing the overall residual error of the model.

7.1 Factors Influencing the Adoption of Individual Demand Management Strategies

The set of independent variables chosen to model the decision to adopt individual demand management strategies is based on available data in the LWSP database, case studies of water reuse and reclamation, and anecdotal evidence (see Table 1). Table 3 of the Results section presents the model output for each individual demand management strategy. These results confirm the need to systematically ensure that demand management strategies appropriately conform to the system in which they are to be employed. The following discussion attempts to explain the factors that are found to contribute to the decision to adopt any single demand management strategy.

Meter replacement programs are found to be negatively influenced by whether the system must purchase water from another system. These systems lack access to raw

surface and groundwater sources, and likely do not have water treatment facilities. It is assumed that these systems are purchasing treated water from another system and distributing that water to individual customer accounts. Further research into these systems is likely to reveal that they may lack institutional capacity for effective water management. It is also likely that purchase only systems charge a fixed rate to all customers. More importantly, from an economic standpoint, the fact that purchase only systems do not experience any of the externalities of their water use leads this analysis to conclude that such systems receive no price or non-price signal that indicates the need to reduce their water demand, or have no mechanism to inform individual customer accounts of the need to reduce demand.

Meter replacement programs are also found to be positively influenced by participation in river basin planning initiatives. Such initiatives increase the likelihood of adopting meter replacement programs because the system must have accurate knowledge of its water use to meet the expectations of other stakeholders involved in the planning initiative. There are also possible confounding factors in establishing a causal relationship between river basin planning initiatives and meter replacement programs because it is unclear whether river basin planning always occurs prior to, or simultaneously with the introduction of meter replacement.

Results from the modeling of factors that contribute to the metering of outdoor use indicate that the ratio of the system's projected future demand to its current demand has a positive effect on the decision to adopt this program. This is likely due to the recognition that outdoor use is a low-value use for potable water in systems with high residential and commercial demand. The percentage of residential customers in a system and, possibly,

the income level of the system's customers are shown to have a negative effect on the decision to meter outdoor use. This is likely evidence to support the notion that systems with outdoor metering are more likely to charge higher rates for outdoor use, thus leading homeowners to resist. Results indicate that the level of education amongst the system's customers may counteract this effect, due to the recognition of water scarcity amongst more educated customer bases.

Leak detection programs are positively influenced by education, participation in river basin planning, and the amount of infrastructure in the water system. These are all clear determinants of the need for a water system to adopt leak detection programs to minimize unaccounted for water. The finding that the ratio of projected future demand to current demand has a negative effect on leak detection is less intuitive. One explanation is that such systems are currently expanding rapidly and consuming resources to increase water supply infrastructure under the requirements approach.

The results from the model describing participation in water conservation education programs indicate that participation in this program is only influenced by participation in river basin planning initiatives. It must be noted here that t-test results were used to confirm that there were no statistically significant differences between observations included in the probit models of individual demand strategies and those that were omitted due to insufficient data. In the case of water conservation education, the test reveals that there is a statistically significant difference between observations included in the model and those that were omitted. This could be the possible result of a statistical artifact, but there remains a possibility that observations excluded from the model of water conservation education have a lower rate of participation in such programs, on average.

The adoption of a plumbing retrofit program is shown to be positively influenced by participation in river basin planning and the education levels of the systems' customers. The two factors likely contribute to plumbing retrofit because of a strong recognition of the merits of technical efficiency as a primary method for reducing water demand. In contrast, the ratio of future projected demand to current demand is shown to have a negative influence on the adoption of plumbing retrofit programs.

A model attempting to describe adoption of conservation rate structures indicates only a slight possibility that such rate structures may be influenced by the education levels of the systems' customers. This result is not surprising, given the fact that water utilities' rates are often a matter to be decided by city council members and other elected bodies. Due to the political implications of a decision to raise water rates, only the most educated and affluent customer base is likely to see elected officials raise water rates. In such communities, utility costs are likely a negligible financial consideration for households.

Model results concerning the decision to adopt recycled or reclaimed water indicate that education has a very strong role to play in increasing the likelihood that a system will adopt this specific measure. The coefficient on education in this model is twice as large as for other individual demand management strategies. This may indicate that there is a sizable contingent of the general public that view recycled or reclaimed water as undesirable. This reaction is to be expected and it is hypothesized that public sentiment will evolve as recycled and reclaimed water are increasingly employed.

Overall, this attempt to link individual demand strategies to specific system characteristics is consistent with professional opinion and other empirical studies of

residential water demand. Asano (1990) indicates that the decision to adopt water reuse or reclamation requires close study of local conditions. Similarly, Kenney et al (2008) point out that price and non-price demand management methods interact in ways they may not be additive and that the effectiveness of different measures depends on the demographic attributes of customers or local climatic conditions.

7.2 Factors Influencing Demand Management Program Participation

According to summary statistics of North Carolina public water systems, 93% of systems have adopted one of the possible seven demand management strategies reported in the LWSP database. It is widely recognized that not all demand management strategies are equally effective at reducing the quantity of water demanded (Kenney, 2008). For example, a system that has implemented multiple demand management strategies is a clear program participant, whereas a system with only a meter replacement program might only be considered a weak participant. Table 4 presents options for which measures may be considered, for the purposes of this analysis, demand management. These are then used to inform the selection of an appropriate threshold for classifying systems as program participants. The difference in the means of the two variables “POIS7” and “POIS6_NO_MET” indicates that the decision to consider meter replacement programs as demand management strongly influences the number of systems that could be considered program participants.

This threshold for program participation has major consequences for the ability of a statistical model to evaluate factors relevant to the participation choice. If the threshold

is artificially low, a model will over-predict program participants. Likewise, a program participation variable with a high threshold will lead the model to under-predict participation. The dependent variable specification in the probabilistic choice equation for program participation is based off of the mean values presented in Table 4. These values identify appropriate levels of program commitment that might be detectable by a statistical model. Table 5 demonstrates how this information was subsequently used to specify the dependent variables in the probabilistic choice equation for program participation.

The independent variables presented in Table 1 are hypothesized to affect a system's decision to participate in demand management programs. They represent an attempt to apply economic assumptions of rational choice, in the context of available data, and produce a probabilistic model that describes the decision to participate in demand management. The results presented in Table 6 indicate that the level of education of the systems' customers and participation in river basin planning initiatives both have a positive effect on the decision to adopt demand management. This leads to the conclusion that demand management in North Carolina likely remains a policy choice of individual systems and their customers, not an outcome of specific system characteristics.

This conclusion is consistent with studies indicating the importance of water scarcity and political concerns for effective demand management (Timmins, 2003). Systems that participate in basin planning initiatives do so because they made a political decision that recognizes physical scarcity of available raw water supplies, or because they recognize that in the absence of strong property rights for water, effective management must recognize the common and beneficial uses of available water supplies. Appendix B

indicates that this variable is not correlated with other independent variables included in the probability equation, nor does the literature on demand management strategies support basin wide planning as a formal demand management strategy. The most likely explanation of the influence of this variable on the decision equation stems from the potential for basin wide planning to provide decision-makers with knowledge about the scarcity of water availability and the status of water quality. In a similar manner, the strong significance of the education variable in all model runs influences the degree with which the water systems' customers are likely to be involved in decisions affecting water supply planning.

7.3 The Effect of Demand Management on System-wide Water Demand

Experts in water resources economics routinely indicate that domestic water use at each connection is contingent on the price of water, the income of the systems' customers, and a variable describing the effect of climate on seasonal water demands (Griffin 2006). Other researchers, such as Young (1996) and Kenney (2008), introduce the effects of prices of related goods and the existence of conservation policies on water used per connection. In the second stage of this analysis, standard OLS regression and available data are combined to measure the log of per capita summer water use as a function of the log of median county income; log of average marginal price per hundred cubic feet by system; the log of average total monthly summer rainfall by county; and the predicted values from the first stage probit model that describes participation in demand

management programs. The OLS model was estimated with robust standard errors and clustered by county to reduce the effects of within-group correlation (Nichols, 2007).

In two model specifications, these independent variables are suspected to have produced biased coefficient estimates. It is important to point out that this source of bias does not appear to be related to the multicollinearity of the chosen predictor variables (see: Appendix E). It is likely that, due to aggregation, the county median income variable did not contain sufficient variation between observations to produce a statistically significant effect. At a maximum, there are 100 different possible values of median income in a sample size of 298 observations. The variable for the log of average residential price per hundred cubic feet was significant in both models. Estimated per capita price elasticity of demand for this variable was calculated to be -0.18 (Appendix F), which is somewhat lower than previous estimates for residential price elasticity in the Southern region of the United States (Nieswiadomy, 1992) but within the range of 75% of all water price elasticity estimates (Kenney, 2008). As noted by Kenney (2008), this is likely due to the inclusion of all customer types (water use sectors) in this particular dataset.

The second model of system-wide water demand includes a variable measuring the percentage of residential customers in the system. The dependent variable measure of per capita water demand includes non-residential connections; therefore, including this variable produces a number of changes in coefficient estimates and standard errors. Of particular interest is the apparent bias that leads to a finding of significance for log of average monthly summer rainfall. Similarly, including the percentage of residential

customers also lessons the effect size for the demand management variable. As presented in Appendix E, this bias is not presumed to be a result of multicollinearity.

The positive coefficient on the demand management variable does not conform to the hypothesis that demand management leads to a decrease in per capita levels of water use in North Carolina systems. Explanations for this lead back to the discussion of how individual demand management strategies should be classified. Meter replacement programs, at best, only have an indirect effect on water demand by allowing systems to more accurately track water use. If meters are added or broken meters are replaced, an increase in reported water use is a reasonable expectation. When meter replacement programs are included as demand management strategies, as they are for 66% of observations, demand management could lead to a positive effect on per capita use. This effect is also likely in the case of leak detection programs. In the case of systems that use reclaimed water, it is not clear if reclaimed water is counted as part of a system's reported water use value. If so, this would also lead demand management to have a positive coefficient.

In conclusion, the results of the second stage analysis of system-wide water demand showed unexpected results attributable to a number of possible explanations. Primarily, the probit regression was unable to identify system characteristics that are significant determinants for the adoption of demand management. This failure causes a high degree of model error in the first stage model to be propagated into the second stage model. These large error terms primarily result from unclear definitions for how demand management measures affect to the measurement of system-wide water use. They are also likely due to a range of criteria used by water system operators to report their

participation in the individual demand management strategies recorded in the LWSP database.

8. Conclusion

The results of this analysis indicate that many public water systems in North Carolina have begun the transition away from a pure application of the requirements approach. The dataset used in this analysis contains variables that measure the existence of seven different programs that may be classified as demand management approaches; only 7% of water systems have failed to adopt any one of these programs. Depending on the viewpoint of the researcher or decision-maker, these demand management approaches represent a spectrum of technically efficient and economically beneficial strategies for managing the scarcity of physical water supplies and infrastructure.

Given the evidence that most public water systems in North Carolina have some form of demand management in place and the fact that all forms of demand management are not considered equal, the best method for classifying systems as participants in demand management is their degree of participation. The degree to which a public water system in North Carolina pursues demand management programs is strongly influenced by factors that are correlated with a high degree of civic engagement, such as levels of education. More importantly for statewide water policy development, a systems' participation in river basin planning initiatives is shown to have a strong statistical effect on the adoption of demand management programs. These two pieces of evidence indicate that demand management remains, for the present, a policy choice that precludes the influence of scarcity on how North Carolina systems choose to meet their projected water requirements.

The second half of this analysis presents results that indicate the marginal price does have a statistically significant effect on reducing average levels of per capita water demand across systems. Although this effect is somewhat smaller than other estimates of how price affects residential water demands, decision-makers should be aware that this is an average effect across all types of water users in North Carolina public water systems. In the face of artificially low water rates, this means that aggressive conservation pricing should be considered an economic tool for demand reduction, especially when it is combined with non-price tools for technical efficiency.

The case for demand management remains strong, especially when one considers that many water systems in North Carolina have very limited experience in collecting and analyzing the data provided in Local Water Supply Plans. State officials should be encouraged to pursue more comprehensive study of public water systems. In particular, technical guidance to systems undertaking the mandated Local Water Supply Plan process should include simple criteria for determining participation in individual demand management strategies and aggregating system-wide use.

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Appendix A: Pearson Correlation Matrix for Model Independent Variables

Variable	log_income	rc_pctbachhigh	efc_rev_exp	must_purch	perc_resid	perc_loss	fut_cur_ratio	pipemiles_percap	basin
log_income	1.000								
rc_pctbachhigh	-0.1314 <i>0.0027</i>	1.000							
efc_rev_exp	0.0520 <i>0.2624</i>	-0.0413 <i>0.3701</i>	1.000						
must_purch	0.00114 <i>0.7956</i>	-0.724 <i>0.0969</i>	-0.0154 <i>0.7386</i>	1.000					
perc_resid	0.0070 <i>0.8731</i>	0.0129 <i>0.7680</i>	0.1562 <i>0.0007</i>	0.1345 <i>0.0020</i>	1.000				
perc_loss	0.0403 <i>0.3588</i>	-0.0668 <i>0.1256</i>	-0.0304 <i>0.5101</i>	-0.0492 <i>0.2597</i>	-0.0727 <i>0.0954</i>	1.000			
fut_cur_ratio	0.0123 <i>0.7800</i>	0.0467 <i>0.2848</i>	0.0383 <i>0.4061</i>	0.1192 <i>0.0062</i>	0.0423 <i>0.3329</i>	-0.0727 <i>0.0954</i>	1.000		
pipemiles_percap	-0.0111 <i>0.8014</i>	-0.0334 <i>0.4453</i>	0.0374 <i>0.4186</i>	0.112 <i>0.0103</i>	-0.0301 <i>0.4917</i>	0.0423 <i>0.3329</i>	0.0221 <i>0.6138</i>	1.000	
basin	0.0724 <i>0.0991</i>	0.1973 <i>0.000</i>	0.0203 <i>0.6592</i>	-0.0016 <i>0.9705</i>	0.0411 <i>0.3469</i>	-0.0608 <i>0.1632</i>	0.0177 <i>0.6855</i>	0.0341 <i>0.4355</i>	1.000

Appendix B: Spearman Correlation Matrix for Model Independent Variables

Variable	log_income	rc_pctbachhigh	efc_rev_exp	must_purch	perc_resid	perc_loss	fut_cur_ratio	pipemiles_percap	basin
log_income	1.000								
rc_pctbachhigh	-0.1970	1.000							
efc_rev_exp	0.0719	-0.0198	1.000						
must_purch	-0.0031	-0.0793	-0.0555	1.000					
perc_resid	-0.0310	0.0335	0.0683	0.1458	1.000				
perc_loss	0.230	-0.0467	-0.0874	-0.1243	-0.04160	1.000			
fut_cur_ratio	-0.0229	0.2704	0.0328	0.0152	0.1699	-0.0938	1.000		
pipemiles_percap	-0.0006	0.1376	0.0161	0.0962	0.1615	-0.0289	-0.0706	1.000	
basin	0.0726	0.093	0.0166	0.0274	-0.0186	-0.0263	0.1119	-0.0259	1.000


```
. ttest leak_detect, by(no_probit) unequal
```

```
Two-sample t test with unequal variances
```

Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
0	463	.3110151	.0215365	.4634097	.2686935	.3533367
1	64	.296875	.0575616	.4604927	.1818473	.4119027
combined	527	.3092979	.0201531	.4626433	.2697075	.3488883
diff		.0141401	.0614586		-.1081283	.1364086

```
diff = mean(0) - mean(1) t = 0.2301  
Ho: diff = 0 Satterthwaite's degrees of freedom = 81.6545
```

```
Ha: diff < 0 Ha: diff != 0 Ha: diff > 0  
Pr(T < t) = 0.5907 Pr(|T| > |t|) = 0.8186 Pr(T > t) = 0.4093
```

```
. ttest wc_education, by(no_probit) unequal
```

```
Two-sample t test with unequal variances
```

Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
0	463	.3671706	.0224262	.482555	.3231006	.4112407
1	64	.265625	.0556446	.4451569	.1544281	.3768219
combined	527	.3548387	.020862	.478919	.3138556	.3958219
diff		.1015456	.0599938		-.0177418	.220833

```
diff = mean(0) - mean(1) t = 1.6926  
Ho: diff = 0 Satterthwaite's degrees of freedom = 84.8232
```

```
Ha: diff < 0 Ha: diff != 0 Ha: diff > 0  
Pr(T < t) = 0.9529 Pr(|T| > |t|) = 0.0942 Pr(T > t) = 0.0471
```

```
. ttest plumb_retro, by(no_probit) unequal
```

```
Two-sample t test with unequal variances
```

Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
0	463	.2397408	.0198624	.427387	.2007091	.2787726
1	64	.203125	.0506882	.4055053	.1018328	.3044172
combined	527	.2352941	.0184952	.4245855	.1989605	.2716277
diff		.0366158	.0544408		-.071654	.1448856

```
diff = mean(0) - mean(1) t = 0.6726  
Ho: diff = 0 Satterthwaite's degrees of freedom = 83.564
```

```
Ha: diff < 0 Ha: diff != 0 Ha: diff > 0  
Pr(T < t) = 0.7485 Pr(|T| > |t|) = 0.5031 Pr(T > t) = 0.2515
```

```
. ttest v105, by(no_probit) unequal
```

```
Two-sample t test with unequal variances
```

Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
0	463	.5550756	.0231206	.497495	.5096411	.6005101
1	64	.5	.0629941	.5039526	.3741164	.6258836
combined	527	.5483871	.0216987	.498126	.5057603	.5910139
diff		.0550756	.067103		-.0784404	.1885916

```
diff = mean(0) - mean(1) t = 0.8208  
Ho: diff = 0 Satterthwaite's degrees of freedom = 80.9163
```

```
Ha: diff < 0 Ha: diff != 0 Ha: diff > 0  
Pr(T < t) = 0.7929 Pr(|T| > |t|) = 0.4142 Pr(T > t) = 0.2071
```

```
. ttest reclaimed, by(no_probit) unequal
```

```
Two-sample t test with unequal variances
```

Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
0	463	.0691145	.0118008	.2539231	.0459246	.0923044
1	64	.0625	.0304969	.243975	.0015569	.1234431
combined	527	.0683112	.0109999	.2525189	.0467021	.0899203
diff		.0066145	.0327004		-.0584251	.071654

```
diff = mean(0) - mean(1) t = 0.2023  
Ho: diff = 0 Satterthwaite's degrees of freedom = 83.0247
```

```
Ha: diff < 0 Ha: diff != 0 Ha: diff > 0  
Pr(T < t) = 0.5799 Pr(|T| > |t|) = 0.8402 Pr(T > t) = 0.4201
```

Appendix E: Test of Multicollinearity Between Variables Included in Second-stage System Demand Estimation.

```
. pwcorr log_summer_use log_income log_price log_rain perc_resid dms, sig
```

	log_su~e	log_in~e	log_pr~e	log_rain	perc_r~d	dms
log_summer~e	1.0000					
log_income	-0.0373 0.4033	1.0000				
log_price	-0.1346 0.0139	-0.0060 0.9141	1.0000			
log_rain	0.0385 0.3922	0.0620 0.1703	0.0300 0.5896	1.0000		
perc_resid	-0.4720 0.0000	0.0045 0.9203	0.0613 0.2648	0.1020 0.0229	1.0000	
dms	0.1465 0.0019	-0.0732 0.1212	0.0825 0.1590	-0.0023 0.9615	-0.1680 0.0003	1.0000

Appendix F: OLS Regression Output for Second Stage Demand Estimation.

Model 1:

```
. reg log_summer_use log_income log_price log_rain dms, robust
cluster(county)
```

```
Linear regression                               Number of obs =      287
                                                F( 4,      88) =      4.11
                                                Prob > F       =      0.0042
                                                R-squared      =      0.0519
                                                Root MSE      =      .62436
```

(Std. Err. adjusted for 89 clusters in county)

	Coef.	Robust Std. Err.	t	P> t	[95% Conf. Interval]	
log_income	.2251155	.2202751	1.02	0.310	-.2126349	.6628659
log_price	-.1800603	.0684445	-2.63	0.010	-.3160795	-.0440412
log_rain	.0656796	.165047	0.40	0.692	-.2623165	.3936758
dms	.7242057	.3015446	2.40	0.018	.1249493	1.323462
_cons	2.353798	2.352537	1.00	0.320	-2.321375	7.02897

```
. mfx, dyex
```

```
Elasticities after regress
y = Fitted values (predict)
= 4.9864597
```

variable	dy/ex	Std. Err.	z	P> z	[95% C.I.]		X
log_in~e	2.363963	2.31313	1.02	0.307	-2.16969	6.89762	10.5011
log_pr~e	-.1847186	.07022	-2.63	0.009	-.322338	-.047099	1.02587
log_rain	.0964609	.2424	0.40	0.691	-.37863	.571551	1.46866
dms	.3569567	.14863	2.40	0.016	.065648	.648265	.492894

Model 2:

```
. reg log_summer_use log_income log_price log_rain perc_resid dms, robust
cluster(county)
```

```
Linear regression                               Number of obs =      287
                                                F( 5,      88) =     21.81
                                                Prob > F       =      0.0000
                                                R-squared      =      0.2915
                                                Root MSE      =      .54071
```

(Std. Err. adjusted for 89 clusters in county)

	Coef.	Robust Std. Err.	t	P> t	[95% Conf. Interval]	
log_income	.0834006	.1987835	0.42	0.676	-.3116398	.478441
log_price	-.1433365	.0603731	-2.37	0.020	-.2633154	-.0233576
log_rain	.1922571	.1084757	1.77	0.080	-.0233155	.4078297
perc_resid	-1.380619	.1727212	-7.99	0.000	-1.723866	-1.037372
dms	.4130928	.2216283	1.86	0.066	-.0273468	.8535323
_cons	4.496584	2.188547	2.05	0.043	.1473061	8.845862

. mfx, dyex

Elasticities after regress

y = Fitted values (predict)
= 4.9864597

variable	dy/ex	Std. Err.	z	P> z	[95% C.I.]	X
log_in~e	.8757988	2.08745	0.42	0.675	-3.21552	4.96712	10.5011	
log_pr~e	-.1470447	.06194	-2.37	0.018	-.268435	-.025654	1.02587	
log_rain	.2823599	.15931	1.77	0.076	-.029889	.594609	1.46866	
perc_r~d	-.7248492	.09068	-7.99	0.000	-.902582	-.547116	.525017	
dms	.203611	.10924	1.86	0.062	-.010494	.417716	.492894	