SOFTER DEVELOPMENT PATHS: ASSESSING THE POTENTIAL FOR MUNICIPAL WATER CONSERVATION TO FORESTALL SUPPLY EXPANSION UNDER UNCERTAINTY

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ABSTRACT

Sarah Royster: Softer Development Paths: Assessing the Potential for Municipal Water Conservation to Forestall Supply Expansion Under Uncertainty
(Under the direction of Gregory W. Characklis)

Population growth and economic development have put increasing strain on existing water supplies, driving the need for conservation efforts to reduce municipal demand growth. Conservation activities can forestall or eliminate the need for new water supplies that can be costly and environmentally burdensome, but can introduce financial challenges for utilities. This research compares demand management activities, from conservation pricing schemes to non-price measures, in terms of their ability to postpone a supply expansion for the City of Raleigh. Results suggest that modest conservation price increases can somewhat reduce the urgency associated with expanding water supplies; however, uncertainties in demand management associated with the demand elasticity and population growth translate into high customer costs and unpredictable utility revenues. Non-price conservation tactics may be used to reduce demand (though to a lesser extent) while posing fewer risks to water utilities and can be successfully combined with price-based tactics to further reduce demand.

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CHAPTER 1. INTRODUCTION

As population growth and economic development give rise to increasing water demands, existing supplies have become strained (NRC, 2009). There is also growing evidence that climate change is altering the hydrologic cycle and potentially increasing drought risk, heightening concerns over water supply reliability (IPCC, 2007). These factors have driven the implementation of conservation efforts that have often been successful in reducing water use (Suero, 2012). This is a positive development in many ways, as conservation can forestall or even eliminate the need for developing new water supplies that can be both costly and environmentally burdensome (NRC, 2011). However, conservation measures can also pose financial challenges. Utilities implementing water conservation programs typically experience revenue reductions due to decreased water sales, but the high fraction of fixed costs in the water utility sector means that costs remain relatively constant despite reductions in treated water production (Hall, 2009). This discrepancy between costs and revenues, and the potential for budget shortfalls, can be very disruptive to utilities and can therefore impact decision making (Beecher, 1994).

Conservation efforts can take on many forms, including long-term and short-term measures, either of which can utilize price and non-price based tactics to meet conservation targets. Temporary measures, such as outdoor usage restrictions (and short-term price based tactics such as drought surcharges), are often used to reduce water consumption during drought. These temporary usage restrictions result in sharp declines in revenues that come at unpredictable intervals. Revenue reductions can be difficult for a regulated utility to quickly address given the regulatory approvals required for price increases, which are typically unpopular (Tiger, 2000). Longer-term conservation efforts can include price-based measures, such as increasing block rate structures, to provide customers with a long-term financial incentive to reduce water consumption (Boyer et al., 2012). In contrast to temporary drought-based restrictions, however, conservation-oriented price increases can actually result in additional revenue for water utilities, as demand for water in many activities is relatively inelastic (Michelsen et al., 1999). As these revenues accumulate, utilities, most of which are public sector entities, face another set of financial challenges, including limits on the size of "reserve" funds (GFOA, 2009), and issues of public acceptance. Other long-term conservation measures include non-price based conservation, such as building code mandates, community education, and rebate programs for improved water efficiency (e.g., appliances, irrigation technologies) (Suero et al., 2012).

Thus, while pricing-based methods can be very effective motivators for water conservation, there are challenges to implementation, customer acceptance chief among these. Non-price conservation measures can avoid some of these challenges, but are often costly to implement and can be less effective. Studies conducted by Suero et al. (2012) and Bennear et al. (2013) suggest that there is significant potential for residential users to reduce consumption through retrofits and rebate programs involving more efficient appliances. Nonetheless, the high costs of subsidization and low adoption rates can limit the impact of these methods. In some cases, ad hoc combinations of non-pricing conservation programs have been combined and conservation pricing schemes have successfully reduced water use, but there is little evidence of the two being coordinated (Beecher et al., 1994).

These conservation efforts are becoming increasingly necessary, given the high cost of water supply expansions, environmental/regulatory constraints, and growing demand. While many utilities plan to expand their treatment plants and increase their storage at specific times, other utilities are turning towards conservation as an alternative to supply expansion. This study assesses several conservation scenarios for the City of Raleigh. The objective is to compare available options to determine the best course of action for Raleigh to ensure reliable supply into the future, while minimizing financial burden. Programs analyzed include the expansion of the current water supply, implementing conservation-oriented price increases, non-price conservation programs, and the use of price-based conservation measures designed specifically to fund non-price conservation initiatives. Price increase regimens to forestall supply expansion while simultaneously generating revenues that allow for full funding of a supply expansion will be compared. The non-price programs analyzed include rebate programs for high-efficiency toilets and washing machines, and giveaways of low-flow showerhead devices. Estimating residential consumption reduction from non-price conservation programs can prove challenging because low adoption rates and underfunding for these programs frequently limit conservation achievements. Thus, the option of funding these hard conservation programs with price-based conservation measures will also be explored. By comparing conservation strategies and uniquely combining price and non-price based conservation, Raleigh may be able to eliminate the need for supply expansion and subsequently reduce the financial burden to their customers in the long run.

CHAPTER 2. METHODS

Much of the conservation desired by utilities can be achieved among residential water users, which often make up the majority of municipal consumption. Selecting the appropriate rate structure and price is essential for a utility's financial health (WRF, 2013), particularly if a utility seeks to use pricing as a means to manage customer demand (Hoffner, 2008). For example, an increasing block rate structure raises rates for high volume customers and increases the fraction of revenues generated by these users. While this is an effective rate structure to encourage residential water conservation, these higher consumption blocks often exhibit greater demand elasticity, so unless carefully designed, these structures can leave utilities vulnerable to revenue losses resulting from declining consumption (WRF, 2013).

The price elasticity of water demand has been extensively studied in the literature. Two meta-analyses of elasticity for residential water customers (Dalhuisen et al., 2003; Espey et al., 1997) found that average elasticity values of the sample groups varied widely, and ranged between 0 and -0.75 overall for mixed indoor/outdoor water use. Utilizing an increasing block rate structure can allow utilities to send a conservation signal to their customers, while generating some additional revenue from charging high-volume water users a larger rate (WRF, 2013). In modeling utility revenues from residential water use, small annual rate increases were applied to an increasing block rate structure (currently in use by City of Raleigh) in order to create a scenario where utility revenue could increase while creating strong pricing incentives for conservation.

2.1 Case Study

The water utility for Raleigh, NC is used as a case study in this analysis, but it is sufficiently representative that results could be extrapolated to other communities in the Southeastern U.S. Raleigh is located in the piedmont region of North Carolina and its water utility serves approximately 500,000 citizens through nearly 200,000 metered accounts with surface water derived from three separate reservoirs: Falls Lake, and Lakes Benson and Wheeler of the Swift Creek Lake system. The largest of these reservoirs, Falls Lake, has a surface area of 12,500 acres and can supply Raleigh with a "safe yield" of 66.1 million gallons per day (mgd) (annual daily average) as determined using the fifty-year period of record. The Swift Creek lake system provides a "safe yield" of 11.2 mgd (annual daily average) measured over the same fifty-year period, bringing the total safe yield for this system to 77.3 mgd. In 2011, Raleigh customers used an annual average of 51 mgd. Raleigh is considering plans to expand the city's water supply by increasing storage capacity through the development of an additional reservoir (Little River), but demand management may provide an opportunity to defer this project. Figure 1 shows the proposed site for this new reservoir. Raleigh estimates that building a new reservoir at Little River (including the construction of both the reservoir and necessary treatment plant expansions) will cost $545 million (Waldroup, 2012).

Figure 1. Site of Proposed Reservoir in Wake County, NC (City of Raleigh, 2012)

Using the population projections in Raleigh's long-term plan as well as assumptions of constant per capita consumption, Raleigh's average annual water demand would exceed its current safe yield by 2027 (Figure 2) (City of Raleigh, 2012). Peak demand is less of a measure of concern than the average annual demand of the current system, since peak demand occurs only for a short period of time, and reservoir storage enables the system to accommodate these temporary peaks. Population projections used in this calculation are from the City of Raleigh, with projections given for each decade from 2010 to 2060. Population growth estimates were interpolated between each decade population estimate using a linear growth function.

Table 1. Population and Demand Projections for Raleigh

Year	Population Projection[1]	Average Annual Demand (MGD)	Average Peak Demand (MGD)
2010	483,253	50	67
2020	638,544	66	89
2030	799,142	83	111
2040	963,217	100	134
2050	1,134,247	118	157
2060	1,316,237	137	182

[1]City of Raleigh, 2012

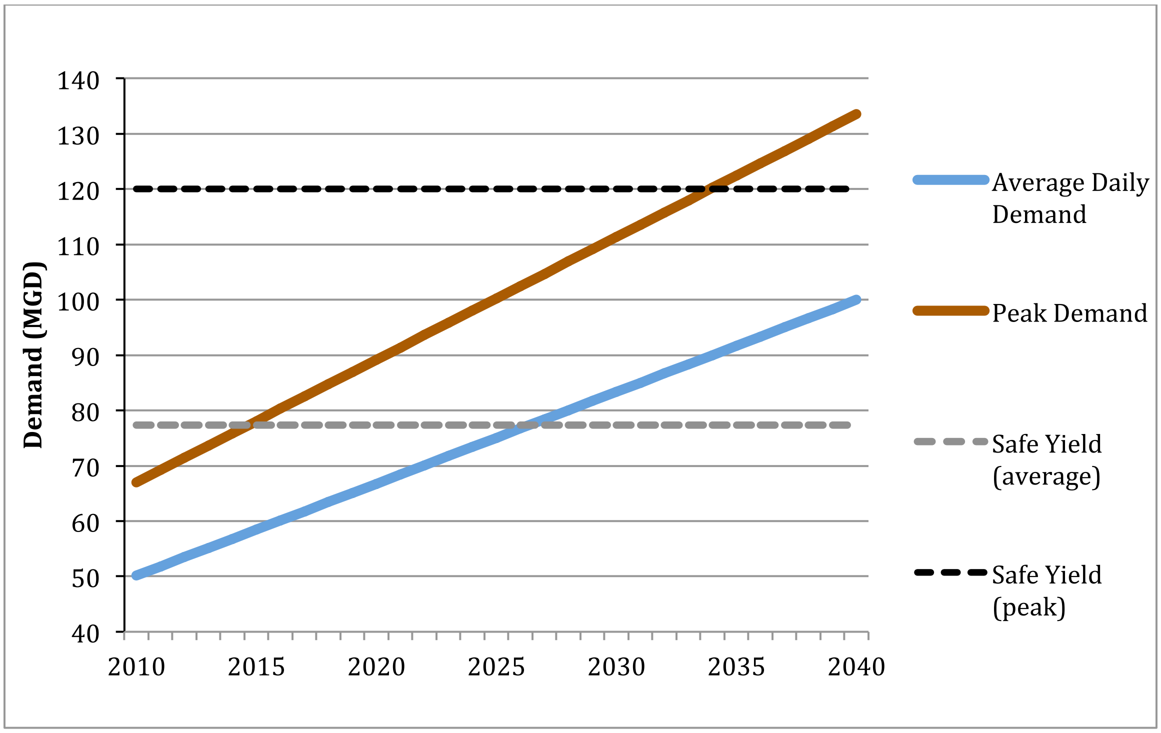

Figure 2. Demand Projections for City of Raleigh due to Population Growth Based on No Change in Per Capita Demand Relative to 2010

The distribution of consumption among households in Raleigh is similar to that of other utilities in the region (WRF, 2013). Using residential customer billing data for 2012 obtained from Raleigh via the University of North Carolina Environmental Finance Center, the distribution of households at different consumption levels from 0 to 25 thousand gallons was constructed (City of Raleigh Billing Records, 2012). Households were grouped by average annual monthly water consumption, in thousand gallon intervals (Figure 3). These data indicate that roughly 60% of residential customers use 2 to 5 thousand gallons (kgal) per month and a relatively small fraction use more than 10 kgal per month.

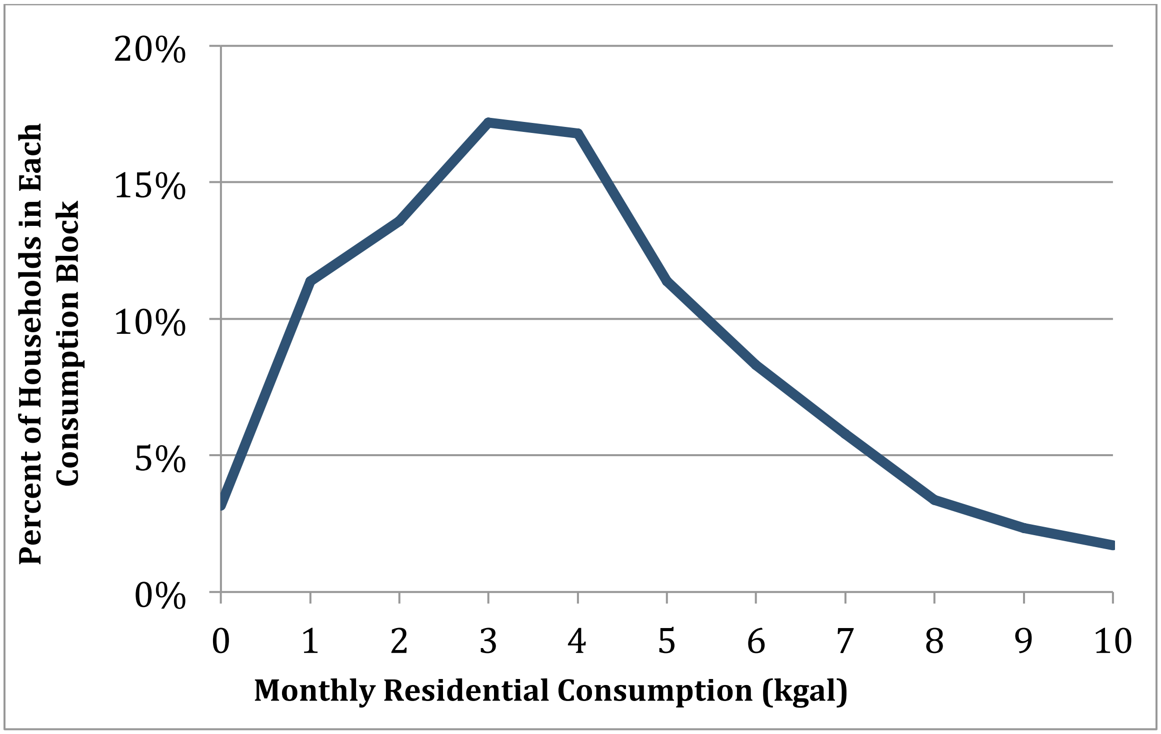

Figure 3. Distribution of Residential Customers for City of Raleigh by Monthly Consumption in 2012

Raleigh currently utilizes an increasing-block rate structure that charges customers increasingly large rates for three different monthly volumetric consumption ranges: 0-4, 5-10, and greater than 10 hundred cubic feet per month (0-2.99, 3.74-7.48, and greater than 7.48 kgal per month). Residential water use made up 42% of Raleigh's 2012 consumption, but over two-thirds of the utility's operating revenue.

2.2 Estimating Impacts of Price Increases

In order to estimate how Raleigh's residential water consumption would change in response to price increases, three different price scenarios were selected with each described relative to Raleigh's current rate structure and its current baseline level of rate increase (assumed to account for increases in the real costs of operation, maintenance, and compliance). This baseline price increase has been fairly constant at roughly 2.1% per year in real terms over the period from 2008 to 2013 (see Appendix A for a description of how this value was calculated). Additional price increases to promote conservation among residential users were added to this baseline increase of 2.1% per year. It is assumed, however, that residential customers will shift their consumption patterns based on the total annual rate increase (the baseline increase plus an increase to promote conservation). Increases in expendable revenues seen by the utility (ie. extra revenue that could be used to fund non-price conservation programs) will be limited to those above revenues obtained from the 2.1% annual baseline increase, as this baseline increase is assumed to cover the higher annual expenses in operation and maintenance due to aging infrastructure and other costs.

The two different price scenarios are explored in addition to a "no conservation" scenario. These scenarios raise household water bills by a constant percentage across each volumetric block of the rate structure with the following objectives: 1) to promote sufficient reduction in consumption to allow Raleigh's current supply to remain adequate to meet average annual demand until 2040, and 2) to generate sufficient additional revenue such that a new supply expansion is fully funded by the time demand exceeds the current supply capacity. For each scenario, price increases are made in constant annual increments until the year that the supply expansion becomes necessary. A third scenario (to reduce consumption even further so that current supplies are adequate until 2050) was also analyzed and is shown in Appendix C. Results suggest that with Raleigh's projected population growth, utilizing price-based conservation programs to forestall a supply expansion until 2050, is infeasible and results in unreasonably high price-increases and utility revenues.

While elasticities of demand for water have been evaluated extensively (Worthington et al., 2008; Reynaud, 2013; Kenney et al. 2008; Brookshire et al., 2002), differences between short-term elasticities and long-term elasticities have also been noted in the literature (Abrams et al., 2012; Martinez-Espineira et al., 2007; Agthe et al., 1980). These differences may be meaningful in evaluating changes in water consumption over a longer period of time, particularly years after a change in price. Demand in the long-run tends to be more elastic than short-run demand due to behavioral changes, as well as opportunity for implementing more hard or structural conservation measures, such as more efficient toilets and appliances (Cameron, 1990). Elasticity values also change among different groups of water users, with higher volumetric consumers typically having a more elastic demand than low volume users. A study conducted by the Orange County Water and Sewer Authority (a neighboring utility to Raleigh), yielded three different elasticity values that are used in this analysis (OWASA, 2007).

2.2a Modeling Residential Water Demand

Price increase scenarios are described using an algorithm developed in MATLAB to estimate shifts in residential water use. Subsequent utility revenues were calculated for Raleigh from 2012 to 2060 for both rate increase scenarios (which also include the annual baseline price increase) taking into account population growth estimates, and price elasticity of demand. All final inputs and results are expressed in 2012 dollars. Rates were increased at a constant annual rate over a number of years, rather than as one large rate increase, since this more accurately reflects how a utility might raise rates over time.

In order to estimate shifts in residential water use related to these price increases, residential households are separated into 26 different, 1000 gallon consumption bins, ranging from 0 to 25 thousand gallons of consumption per month, based on Raleigh's distribution of average annual household monthly consumption for year 2012 (Figure 3). As the population grows, new customers are allocated into these bins with the same distribution as the existing customers for each year. One hundred, 10 gallon subgroups within each thousand-gallon block are created for the model, and households are assumed to be evenly distributed throughout each thousand-gallon block. Using the price elasticity of demand equation, and annual price increases, Raleigh's residential users are shifted within the hundred subgroups and 26 thousand-gallon consumption blocks. The range of elasticities used is based on a 2007 study by the Orange Country Water and Sewer Authority that yielded elasticity values for three different residential consumption ranges: low, middle, and high. Elasticities for low consumption groups (0 – 4 kgal) range from 0 to -0.088, moderate consumption groups (5 – 9 kgal) range from -0.11 to -0.483, and high use consumption groups (10 – 25 kgal) range from -0.577 to -1.16 based on an interpolation of the low, mid, and high use elasticity values given (OWASA, 2007). Elasticities within these ranges are interpolated such that each of the 26, thousand-gallon subgroups has a unique elasticity value specified in the model.

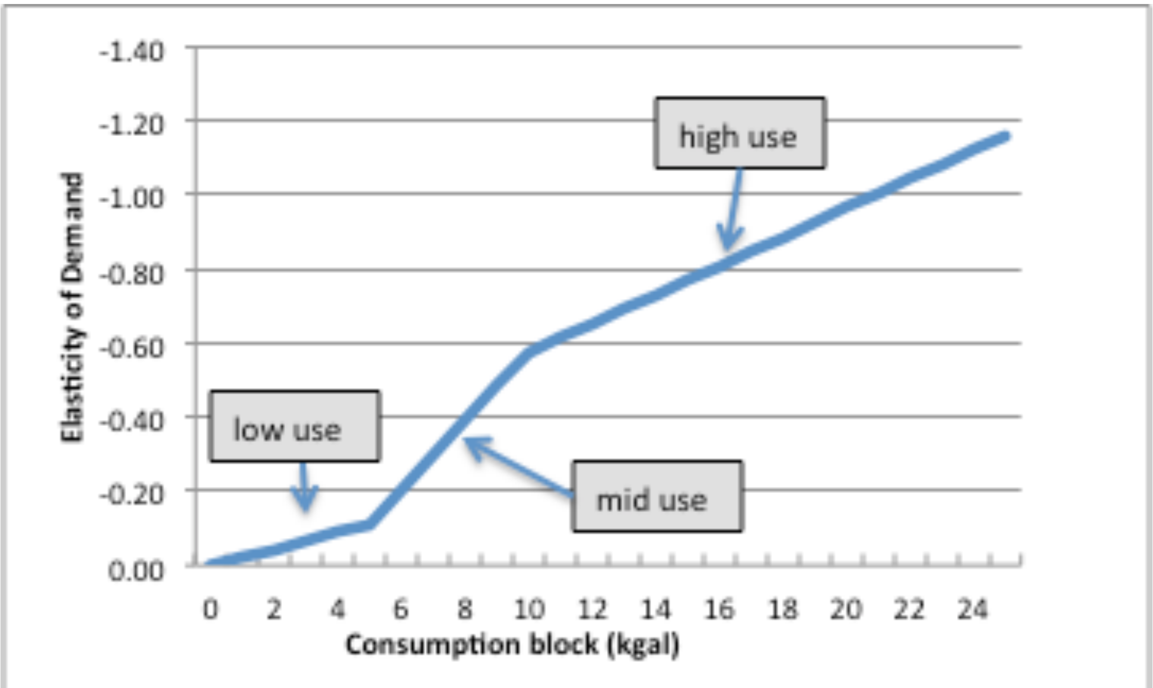

Figure 4. Elasticity values for 26 consumption blocks

Monthly water bills are calculated for households in each of the 26 blocks based on Raleigh's three-tier, increasing block rate structure. The associated monthly bills for one household in each block are based on a price per thousand-gallon rate for water, and thus there is a unique monthly bill associated with each consumption block. Monthly bills were then increased by the sum of the baseline amount (2.1%) plus the scenario specific conservation-oriented price increase, for each year from 2013 to 2060. Monthly bills are calculated each year from 2012 to 2060 for each of 26 consumption blocks and populated in a matrix. Changes in annual price each year are used in conjunction with elasticity and consumption group to determine the change in quantity demanded for each consumption block in each year using the elasticity of demand equation $\Delta Q = e(\frac{\Delta P}{P})Q$. The change in quantity demanded in each thousand-gallon consumption block is calculated using that block's unique elasticity value, the change in price relative to the previous year, and the quantity demanded from that group.

Households are then split into one hundred, ten-gallon subgroups that are evenly distributed within the 26, thousand-gallon groups. The change in quantity demanded as a result of annual price increases is accounted for within each of the ten gallon subgroups. Households are shifted into a new subgroup for every ten gallon change in consumption so that the number of households within each of the 26 consumption blocks changes incrementally each year in response to price increases. This process is repeated for each year from 2012 to 2060, and yields the total number of households in each of 26 consumption groups for each year. Total revenues are then calculated for each year by multiplying the number of households in each consumption group, by the monthly bill for that group, multiplied by twelve. While monthly household consumption varies throughout the year, the initial distribution of households within the 26 consumption blocks was calculated based on annual average monthly household consumption, thus annual revenues are based on a monthly average. Revenues from each group are then summed.

Price increases to promote conservation as well as the baseline price increase of 2.1% per year have an impact on total revenues. However, since this research focuses on revenues for spending on capital projects (such as a water supply expansion) or conservation programs (such as rebate programs), it is assumed that revenues from the annual baseline price increase of 2.1% per year do not contribute towards additional expendable utility revenues. Revenues from this baseline annual increase are likely negated by annual increases in utility operation and maintenance expenses (aside from inflation) and will subsequently not impact the revenue available for capital projects and rebate programs.

2.3 Funding Non-Pricing Based Conservation With Price-Based Conservation Programs

This research uniquely explores conservation options in which revenues generated from price based conservation programs are used to further reduce demand, by funding non-price conservation programs. Revenue calculations, funding allocation programs, and hard conservation measures (including rebate programs for toilets, washing machines, and showerhead giveaways) are described in this section.

2.3a Estimating Revenue Gained from Price Increases

The increased revenues accruing each year under each price increase scenario are estimated relative to those accruing during the same period under the baseline price increase scenario (2.1% annual price increase), such that:

$$Additional\ Revenue = \left[\sum_{1\ year}^{X\ years} \sum_{0\ kgal}^{25\ kgal} (N) \times (\ monthly\ bill\ with\ scenario\ dependent\ annual\ rate\ increase) * 12\right] - \left[\sum_{1\ year}^{X\ years} \sum_{0\ kgal}^{25\ kgal} (N) \times (\ monthly\ bill\ with\ 2.1\%\ annual\ rate\ increase) * 12\right]$$

where N = the number of households in each thousand-gallon consumption block

X = the number of years until the expansion is needed

While revenues typically rise due to price increases, in some cases during the first few years of implementation, revenues fall. Generally, however, prices increases can lead to additional revenue for water utilities, which can be used to fund capital projects (such as supply expansions) or conservation programs. While these conservation oriented price increases serve to reduce residential water consumption, the additional revenues generated can be spent on furthering conservation through non-price based programs.

2.3b Non-price Conservation Programs

Non-pricing conservation programs are used extensively to curtail water use in the residential sector, and have often been a more common means of promoting conservation than price increases mostly due to the latter's unpopularity with consumers (Reynaud, 2013). Successful non-price conservation programs have been studied and implemented; however, it is often difficult to generalize the savings generated by these programs because adoption rates can be hard to quantify. A toilet rebate program recently implemented in Cary, North Carolina (essentially a suburb of Raleigh) involved the utility offering a rebate of $150 per high-efficiency toilet installed. While each household was responsible for the installation of the toilet, it is assumed that the utility incurred an additional administrative cost of $25 per toilet based on a study of utility rebate programs (Suero, 2012). A different, multi-city study looked at high efficiency washing machine rebates of $150 per machine with administrative costs of $25, and low-flow showerhead devices, which cost roughly $5 per device (Suero, 2012). These rebate values and cost estimates serve as the basis for funding non-price based conservation programs in Raleigh. Toilets account for nearly thirty percent of all residential indoor water use, making them the largest single source of indoor water use (US EPA, 2008). The same study estimates that replacing pre-1990 toilets with high efficiency models can reduce water consumption for a family of four by an average of 21,500 gallons per year. However, a number of utilities have offered toilet rebates as part of a conservation program, and evaluations of these programs suggest that, in practice, the level of conservation is lower. In addition, research suggests that while low flow devices such as toilets and showerheads reduce water use, the savings are often less than those touted by manufacturers (Syme et al., 2000). Bennear et al. (2013) estimates that Cary households conserved an average of 3,612 gallons per year by retrofitting one pre-1991 toilet with a newer, high-efficiency toilet (HET). In addition to toilets, retrofitting washing machines and installing low-flow showerhead devices is typically used to generate residential water savings (US EPA, 2008). While installing high efficiency clothes washing machines yields higher expected water savings according to the EPA, the adoption rate for high-efficiency washing machines is significantly lower than that of toilets, likely due to its greater expense. Though difficult to determine the level of conservation that may be achieved using giveaway and rebate programs, Bennear et al. (2013) found that Cary households taking advantage of the rebate program, experienced significant reductions in mean monthly water use after implementation of the program, as compared against neighboring, non-retrofitting households (Figure 5). These reductions are also compared with water consumption before program implementation for those households taking advantage of the rebate.

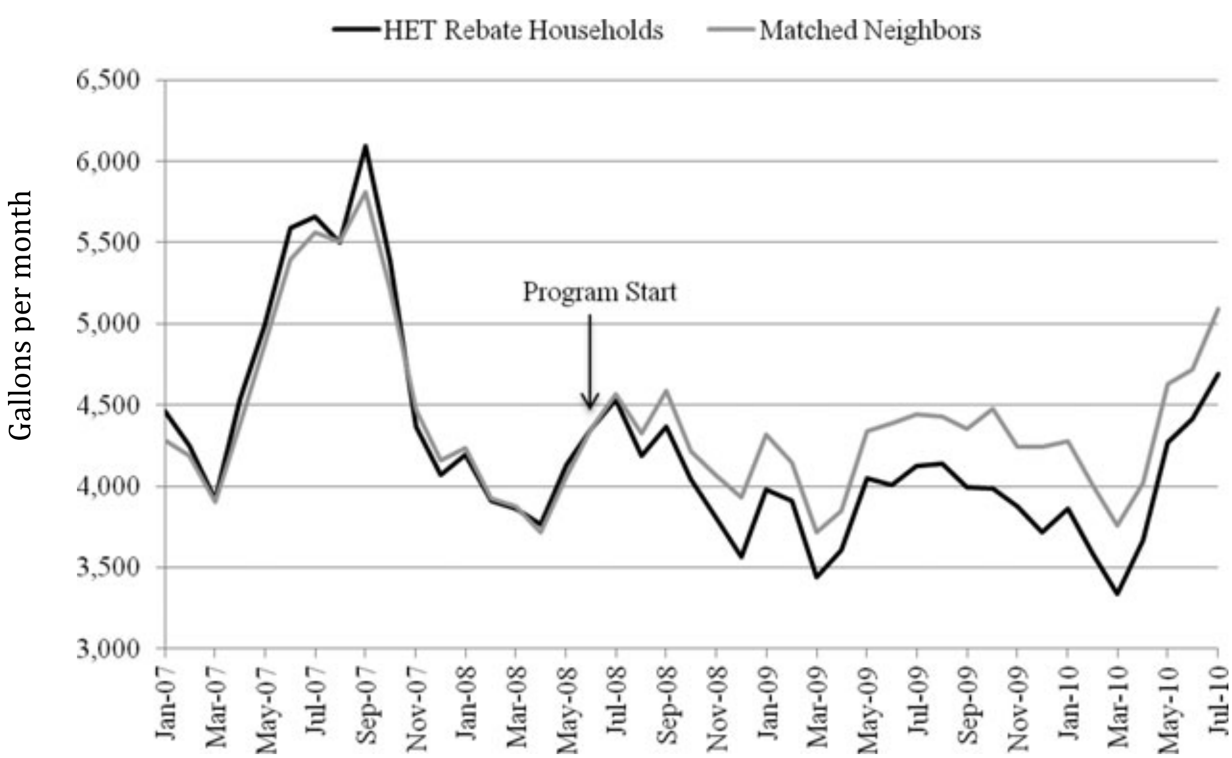

Figure 5. Mean Monthly Water Use (Gallons) for 683 HET Rebate Participants Compared with 25,100 Matched Neighbors for Cary, NC (Bennear et al. 2013)

In order to estimate the annual water savings from each of the three hard conservation programs being studied, the number of households eligible for each type of rebate is estimated based on residential housing data for the City of Raleigh (City-data, 2013). Details of how these estimates are calculated are described in Appendix B. Conservation from non-price based programs is calculated in two ways: 1) conservation is estimated assuming a 100% adoption rate for only households deemed eligible for the rebate program, and 2) conservation is estimated using adoption rates for all residential households of 1.8% for toilets, 2.0% for washing machines, and 2.0% for showerhead devices (Eskaf, 2012; USCCSC, 2012). While these adoption rates are low, they represent the percentage of residential households likely to adopt water efficient appliances through an incentive program (such as rebate or giveaway programs).

This work then takes the relatively unique step of directly using revenues generated from conservation based price increases to fund these hard conservation programs. Additional revenues generated from the rate increase scenario 3, used to forestall supply expansion until 2033, are used to analyze various non-price conservation programs. Four different non-price conservation programs are evaluated over a five-year period in order to determine the level of achievable conservation:

1) 50% of excess revenues funding toilet rebates, 40% funding washing machine rebates, 10% funding showerhead replacement,

2) 75% towards toilet rebates, 15% to washing machine rebates, 10% to showerhead replacement,

3) 15% towards toilet rebates, 75% to washing machine rebates, 10% to showerhead replacement, and

4) 80% towards toilet rebates, 15% to washing machine rebates, 5% to showerhead replacement.

The date that a supply expansion is needed when price-based conservation alone is undertaken, is then compared with the expansion date at which supply expansion is required under these four non-price based conservation programs.

CHAPTER 3. RESULTS

3.1 Price Based Conservation Analysis

Three different price increase scenarios were compared and in all cases, reached the objective date (or objective date and funding goal) with demand remaining below the safe yield of the current supply system (Figure 6). Although these conservation-oriented price increases are used to reduce demand, additional demand experienced from population growth was sufficient to offset this price-based reduction in demand in all cases.

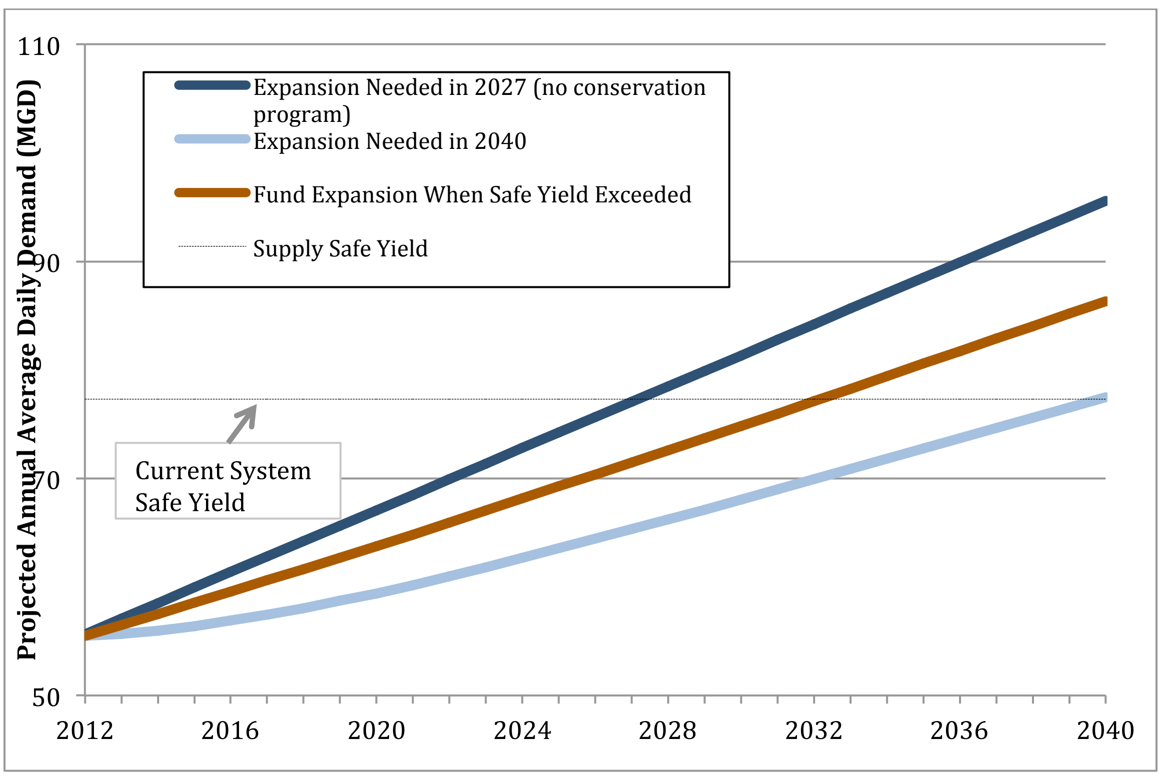

Figure 6. Total Consumption Projections by Conservation Goal

The shift in residential demand for each of these three scenarios is evaluated (Figure 7). As the annual price increase needed to forestall expansion increases, the percentage of households in each consumption block is shifted towards the lower consumption blocks. For the expansion in

2040 scenario, consumption has shifted such that larger numbers of households are using 3kgal and 4kgal per month, and a very small percentage of households remain in consumption blocks greater than 8kgal.

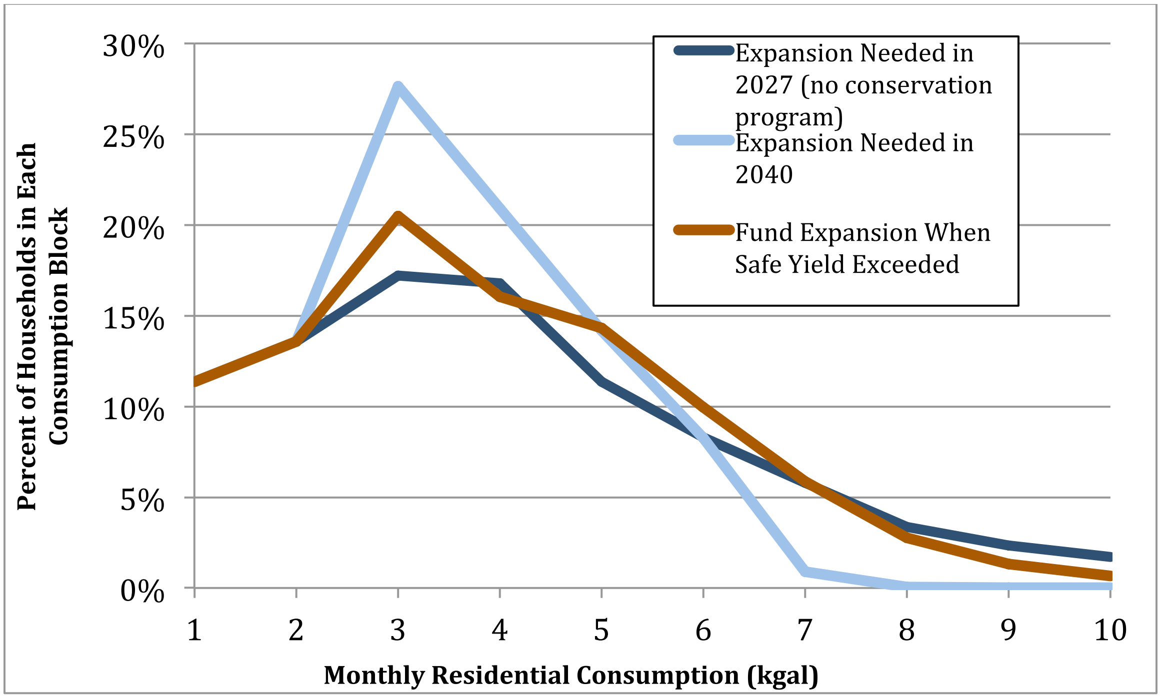

Figure 7. Percentage of Residential Demand by Monthly Residential Consumption Class

Shifting demand significantly using only price-based tactics, however, requires large price increases. To accomplish certain demand goals (particularly for forestalling expansion until 2040), annual rate increases became high, leading to unrealistic water bills. A total annual bill increase (including the baseline annual rate increase of 2.1%) of 12.6% was sufficient to keep residential demand below the safe yield of the current water supply until 2040. This increase resulted in monthly bills of $356 in 2040 (for the expansion in 2040 scenario) in 2012 dollars for 3kgal of water. This increase also resulted in extremely large additional revenues for the water utility (Table 2 and Figure 8).

Table 2. Conservation Price-Increase Results

Conservation Scenario:	Total Annual Rate Increase	Additional Revenue Generated (millions of dollars)
Expansion Needed in 2027 (no conservation program)	2.1%	--
Expansion Needed in 2040	12.6%	$9,490
Fund Expansion When Safe Yield Exceeded (year 2033)	5.6%	$584

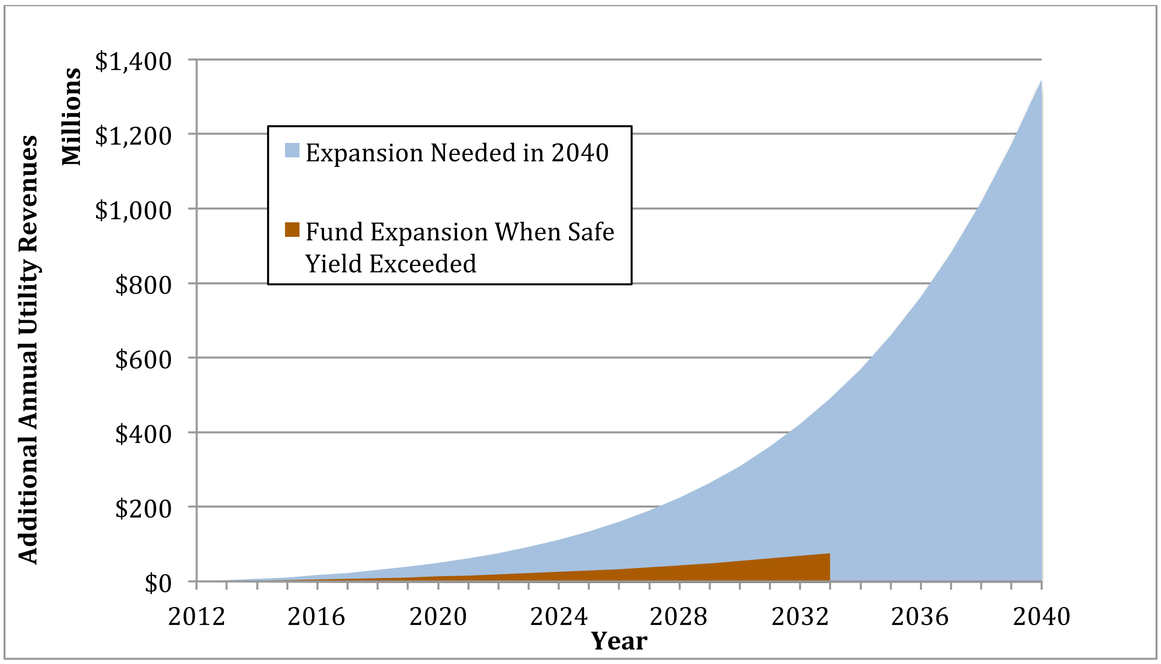

Figure 8. Additional Annual Revenue from Price-Based Conservation Programs

The case for forestalling expansion until 2033 however, (when enough additional revenue has been generated to fund the $545 million expansion), is a more reasonable one. While most utilities fund large capital projects with debt, an increasing number of utilities are choosing a "pay as you go" method, where capital projects are funded directly through utility revenues, saving utilities (and subsequently customers) the interest on this debt, which can be substantial (WRF, 2013). In order for Raleigh to fund supply expansions using "pay as you go", an additional $545 million is required by the date that the supply expansion is needed. In order to generate this sum, a rate increase of 5.6% per year (inclusive of the 2.1% annual baseline increase) is needed to fully fund the expansion by the date 2033, when demand exceeds the safe yield of the current system under this price increase. This results in a monthly bill of $40 in 2033 for 3kgal in 2012 dollars.

3.2 Non-Price Based Conservation Analysis

The number of toilet rebates, washing machine rebates, and showerheads funded in order to promote non-price based conservation is calculated using two methods: 1) assuming 100% adoption rates for all households estimated to be eligible for each adoption program in each year, and 2) assuming the low adoption rates found in practice. The level of conservation achievable from non-price based conservation using these two methods is dependent on fund availability, the cost per device, the number of devices installed each year, and for method 2, adoption rates. Non-price conservation programs were evaluated using the additional revenue available from the price increase scenario used to forestall expansion until 2033. The additional revenues generated from this 5.6% annual increase, were evaluated over 5 years. These annual rate increases were used to fund three hard conservation programs simultaneously (toilet rebates, washing machine rebates, and showerhead giveaways). In method 1 (100% adoption rates for all eligible households), these funds were allocated to each program over a period of 5 years. Four funding programs are compared under the assumption that there is 100% adoption among households estimated to be eligible for a rebate program during this five year timespan (Figure 9).

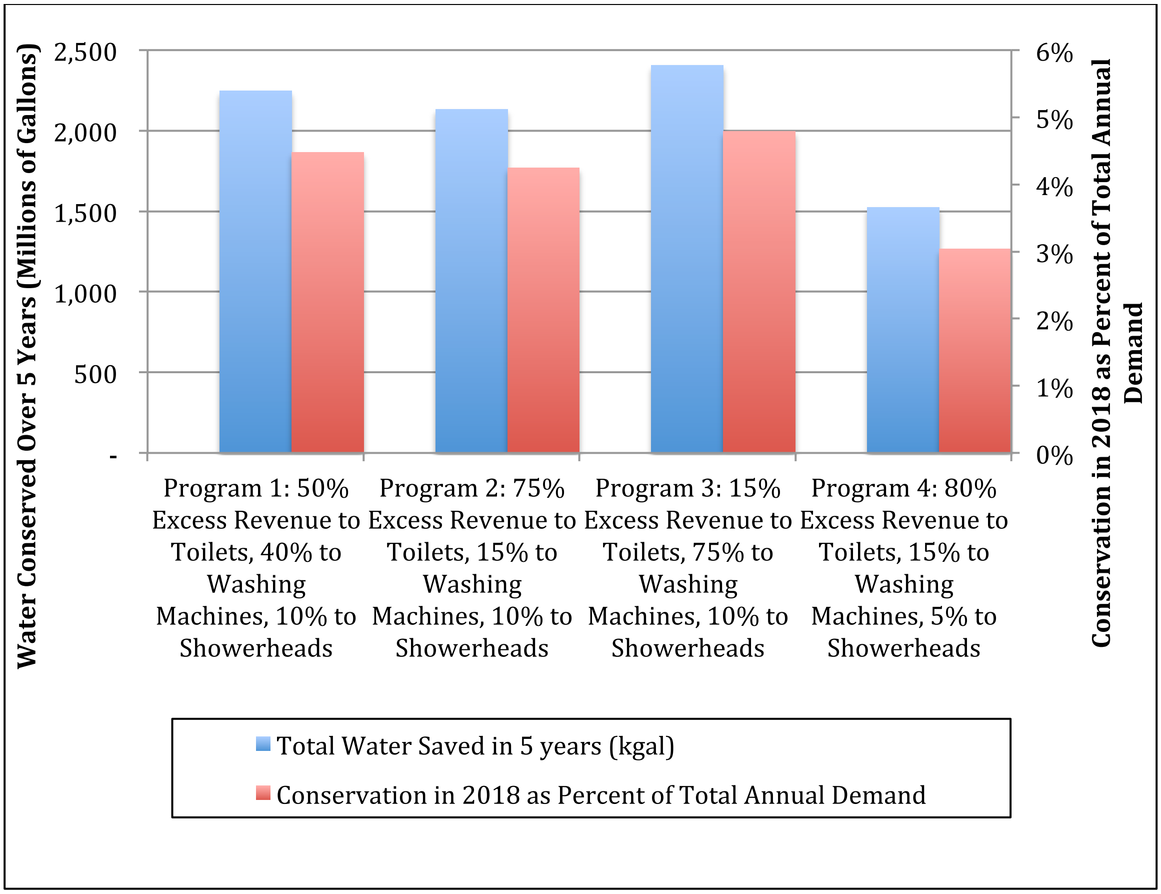

Figure 9. Water Conserved Over 5 Years by Non-Price Conservation Program (left axis) and Conservation in 2018 as a Percent of Total Annual Demand (right axis)

Program 3 was shown to be the funding program with the largest estimated potential for conservation from these devices. Showerhead replacement proved to be the most cost-effective hard conservation measure, as these devices save an estimated 1585 gallons of water per year at a cost of only $5 to the utility ($3.15/kgal water saved). The natural turnover rate for these devices (10 years) and estimated number of households in need of a water-efficient showerhead each year, however, limited the estimated amount of possible conservation. Need for these devices was low, and was the limiting factor to conservation from a showerhead giveaway program. Available revenue, however, rather than the number of eligible households, limited the achievable conservation from the other devices. Washing machines typically result in greater annual consumption reductions than high-efficiency toilets on a dollar per kgal basis. Washing machine rebate programs yielded a higher level of conservation when all of the additional revenues went towards washing machine rebates. This, however, does not take into account the higher cost that customers incur when buying a washing machine, which may reduce the influence of rebates on the customer. With a $100 rebate, customers could still pay between $300 and $1300 for a high-efficiency washing machine (Sears, 2015). A subsidy this small may not be effective at enticing more households to purchase an efficient appliance than would have in the absence of the rebate program. The cost efficiency in dollars per kgal conserved of each type of hard conservation device is calculated (Table 3).

Table 3. Cost Efficiency of Hard Conservation Devices

	High Efficiency Toilet	Low-Flow Showerhead	High Efficiency Washing Machine
Annual Water Savings (gal)	3612[1]	1585[2]	5548[2]
Cost to Utility per Device	$175[1]	$5	$175[1]
% of Total Devices Eligible for Replacement	16% (at year 2012)	10% per year	7% per year
Cost Efficiency ($/kgal saved)	48	3	32
Adoption Rate	1.8%[4]	2%	2%[2]

[1]Bennear et al., 2013
[2]Suero et al., 2012
[3]USCCSC, 2012
[4]Eskaf, 2012

Since program 3 (15% of excess revenue to toilets, 75% to washing machines, and 10% to showerheads) resulted in the highest amount of water conservation over a five year period, this program was compared to the price-based conservation program in scenario 3 (a 5.6% annual increase) to determine a maximum estimated level of water conservation. Figure 10 shows the projected residential water use for Raleigh if no additional conservation measures were taken beyond the baseline 2.1% rate increase each year, if price-based conservation measures were used (in the form of a 5.6% annual rate increase over 5 years), and if both price and non-price based conservation measures were used simultaneously with low and high adoption rates.

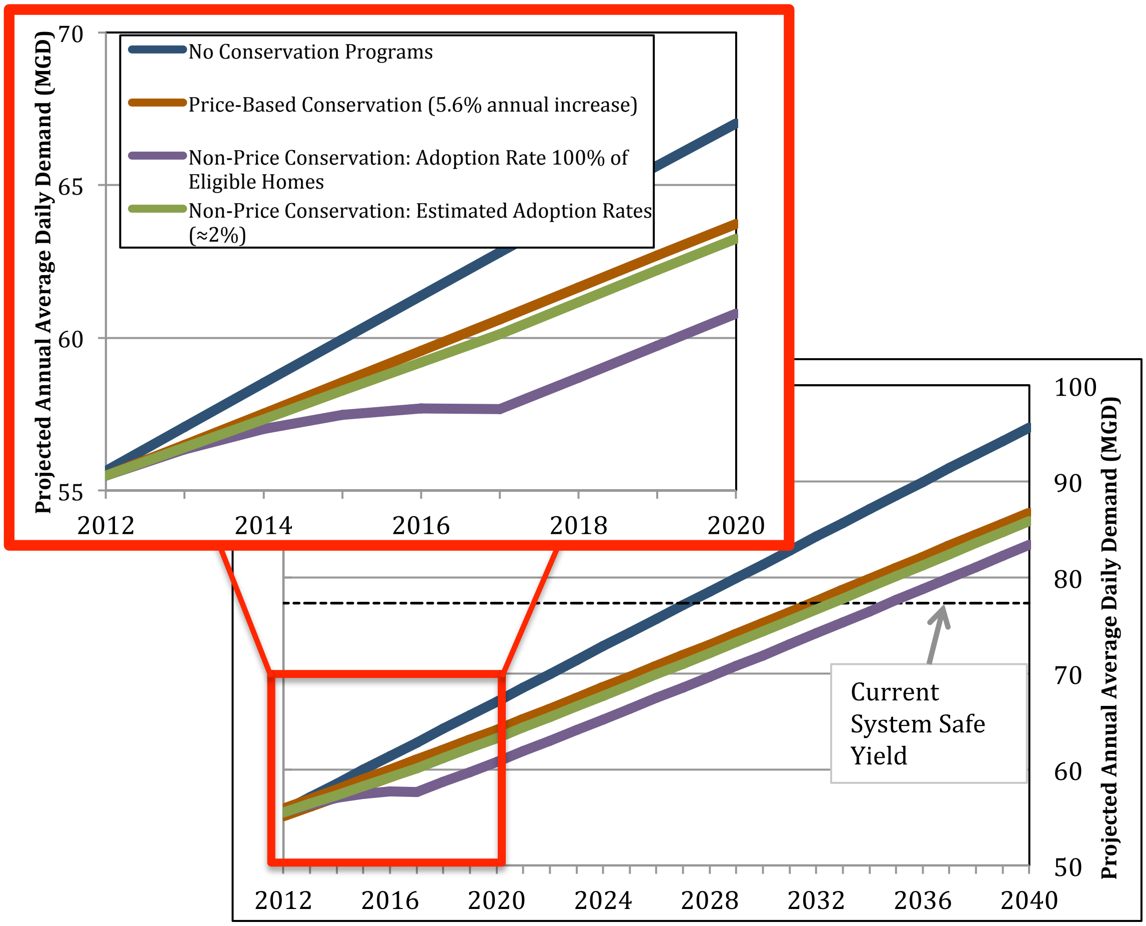

Figure 10. Projected Water Use For Price-Based Conservation Funding Non-Price Conservation

With no conservation measures taken, Raleigh would exceed the average safe yield of the current water supply by 2027. Using price-based conservation measures, Raleigh could increase their rates by 5.6% annually and forestall supply expansion until 2033. Considering both price-based and non-price conservation measures in tandem (using additional revenues from the price-based program to fund hard conservation measures), Raleigh's residential water use would still exceed the safe yield by 2033 if estimated adoption rates are used, rendering hard conservation measures insufficient to further forestall expansion. If an adoption rate of 100% is assumed for those households eligible for each type of hard conservation program, the average safe yield would not be exceeded until 2035, two years later than with price-based conservation alone. Comparing these hard-conservation funding schemes, low adoption rates limit the achievable conservation in one case, and available revenue for funding hard-conservation programs is the limiting factor in the other. These results would indicate that significantly more consumption reduction can be achieved using price-based tactics than with non-price based tactics, which is consistent with the literature (Beecher et al, 1994; Kenney, 2008; Reynaud, 2008). Participation rates for non-price based conservation programs are typically low, and there is evidence that rebate programs may not entice many customers to replace outdated appliances that were not already planning to do so in the absence of the rebate program. A study of Cary, North Carolina, neighboring Raleigh, estimated that only 37% of the water savings associated with high efficiency toilet installations was directly attributable to a rebate program, and concluded that overall, high efficiency toilet rebate programs were a relatively weak demand management tool (Bennear et al., 2013). Although there was an estimated 5% reduction in total demand by 2018 (Figure 9) through hard conservation with all eligible households participating, achieving this level of adoption in practice is unlikely.

3.3 Sensitivity Analysis

A sensitivity analysis is performed on factors influencing both price-based and non-price based conservation measures. For non-price based measures, variability in adoption rates of water efficient appliances has a huge impact on the estimated achievable conservation. Adoption rates of 100% of eligible households (10% to 16% of the total number of households each year, depending on the device) increased conservation somewhat, but only forestalled expansion two years, while adoption rates of 1.8% to 2% of total households were too low to forestall expansion beyond a few months. In addition to uncertainty in adoption rates, estimates regarding the annual water savings from these appliances are also highly variable. The U.S. Environmental Protection Agency, for example, estimates a much higher potential for water reduction with bathroom retrofits than is actually observed in practice based on a study of three U.S. cities (EPA, 2005). This is due in part, to the assumption that a household would retrofit all toilets simultaneously, whereas in actuality, households do not typically replace all toilets at the same time (Bennear et al., 2013). Sensitivity due to estimates of annual water savings for each hard conservation device has some impact on overall conservation estimates, and is detailed in Table 4. Responses to ±25% changes in the conservation estimate per device are shown below for both low and high adoption rates. While these values are somewhat sensitive to changes in appliance conservation estimates (particularly in the case of 100% adoption in eligible households), this is largely overshadowed by the sensitivity of non-price based conservation to adoption rates.

Table 4. Sensitivity Analysis on Annual Conservation Estimates for Water Efficient Appliances

	% Change in Annual Consumption from Price-Based Conservation in 2018	Year Water Supply Capacity Exceeded
Price Based Conservation Only (5.6% Annual Price Increase)	--	2033
Non Price Based Conservation: Adoption Rate 100% of Eligible Homes	-4.9%	2035
+25% of Appliance Conservation Estimate	-6.1%	2036
-25% of Appliance Conservation Estimate	-3.7%	2035
Non Price Based Conservation: Estimated Adoption Rates (≈2%)	-0.8%	2033
+25% of Appliance Conservation Estimate	-1.0%	2033
-25% of Appliance Conservation Estimate	-0.6%	2033

Estimates of price-based conservation largely dwarf savings from non-price based conservation programs, particularly when adoption rates are held at the low observed levels. Sensitivity in factors impacting price-based conservation programs are possibly more important in terms of estimating conservation than sensitivity among factors impacting non-price based conservation. Sensitivity of conservation estimates (in terms of the year Raleigh's supply expansion is needed, and revenues generated) to elasticity, population projections, and changes to the baseline annual price increase are estimated for the "expansion needed in 2033" price increase scenario (Table 5).

Table 5. Sensitivity Analysis for Price Based Conservation Scenario: Expansion Needed in 2033, 5.6% Annual Price Increase

Parameter Changed	Year Safe Yield is Exceeded	Cumulative Additional Revenues in 2033	Cumulative Additional Revenues at Year Exceeded (or 2033 if not exceeded)	Total Demand in 2033 (MGD)	Sufficient Revenue to Fund Expansion at Year Exceeded?
Original (5.6% annual increase)	2033	583,662,918	583,662,918	78.27	
Elasticity					
more elastic demand (+25%)	2034	545,732,041	626,024,211	76.39	yes
less elastic demand (-25%)	2026	810,271,070	274,589,757	90.70	no
Population Projection					
25% larger growth	2023	974,863,913	185,938,685	86.97	no
25% less growth	2041	465,212,092	1,253,658,353	71.16	yes
Annual Baseline Price Increase of 2.1%					
+25% of baseline: baseline = 2.63 (6.13% total annual increase)	2034	693,794,834	796,006,597	77.17	yes
-25% of baseline: baseline = 1.58 (5.08% total annual increase)	2031	484,282,678	365,955,660	79.75	no

Changes in elasticity have some impact on residential demand, but conservation estimates are much more sensitive to other factors. An increase of 25% to all elasticity values (25% more elastic) will reduce demand such that supply expansions aren't needed until 2034, while the same reduction in elasticity (25% less elastic) will push the expansion date forward to 2026. Changes in the distribution of residential demand due to changes in elasticity are shown in Figure 11. The distribution of households in each consumption block in 2033 are shifted slightly left, towards lower consumption blocks, for more elastic demand, and skewed more towards higher consumption blocks for less elastic demand. These shifts in consumption, however, are relatively small.

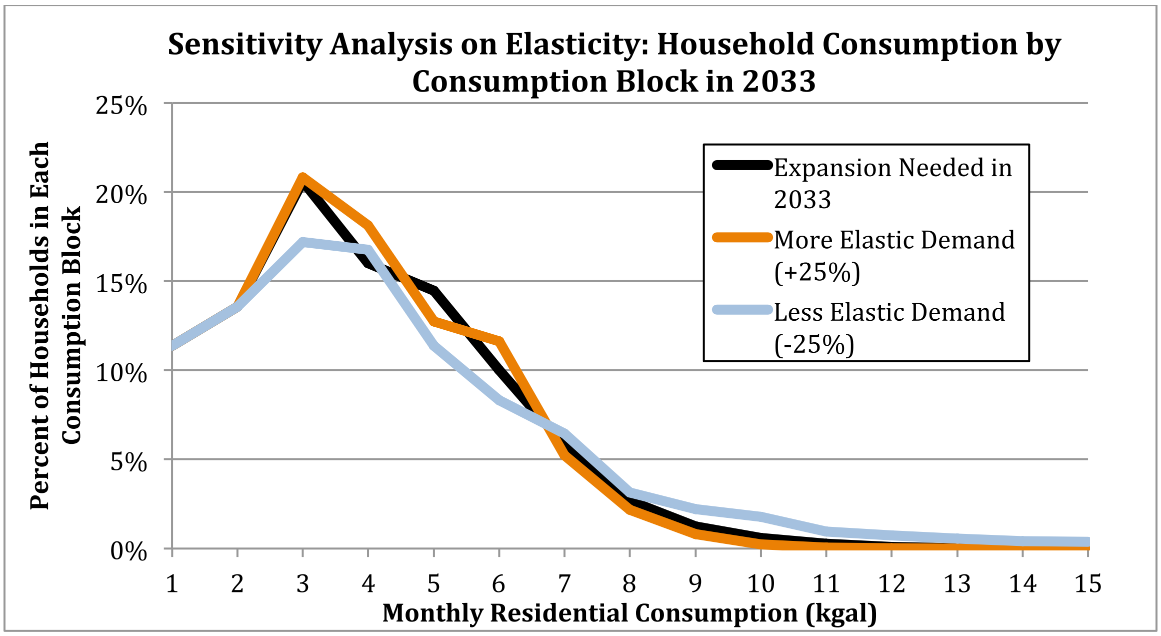

Figure 11. Sensitivity Analysis on Elasticity: Household Consumption By Consumption Block in 2033

Results were much more sensitive to changes in the population projections given by City of Raleigh and have a significant impact on the estimated date a supply expansion is needed. Additional population growth of 25% would result in Raleigh's supply capacity being reached at 2023, ten years earlier, whereas a 25% reduction in projected growth would allow the city to extend their water supply until 2041. Additionally, revenue sensitivity to changes in the baseline annual price increase of 2.1% had somewhat substantial impact on the additional revenues gained from price increases as well as small shifts in the needed expansion dates. Sensitivity to the baseline price increase, however, as with sensitivity to elasticity values, was largely overshadowed by sensitivity to changes in population growth.

CHAPTER 4. DISCUSSION

In the case of Raleigh, both price-based conservation measures and non-price based conservation used in tandem with price-based measures, can forestall the expansion of water supply and/or treatment capacity well past the date that would be projected in their absence (2027). Rate increases can be used to promote conservation, but can be unpopular and hindered by governing boards due to problems arising from utilities generating large revenue surpluses (Krause et al., 2003). Funneling this excess revenue into hard conservation programs, which can be easier to justify, seems to be a relatively ineffective measure, as adoption rates severely restrict conservation. It is also difficult to predict the adoption rates for non-price conservation measures and hard to distinguish conservation due to the rebate program from that which would occur naturally, in the absence of these programs (Bennear, 2013). Significantly more consumption reduction was achieved using price-based tactics than non-price tactics when adoption rates were considered, which is consistent with the literature (Beecher et al, 1994; Kenney, 2008; Reynaud, 2008).

In using price-based conservation measures to fund hard conservation efforts, Raleigh can achieve a higher level of consumption reduction with a reasonable annual price increase (5.6% annually) to ensure supply capacity is extended to 2033. Price increases to expand supply capacity beyond 2040, however, are past the range of acceptable increases and are likely infeasible as conservation tactics (WRF, 2013). The price-based conservation programs analyzed are mildly sensitive to changes in elasticity, and highly dependent on population growth projections, both of which are subject to uncertainty. The sensitivity analysis on the elasticity of demand indicates that even with some variability in elasticities, revenues for Raleigh will not decrease beyond the first few years of implementation, which is a deterrent for many utilities implementing conservation-oriented price increases. Utilities assessing the need to expand their supply system could benefit from exploring demand management options, such as small, conservation-based price increases to forestall a potentially costly and environmentally burdensome supply expansion. There is some evidence, however, that other policy-based initiatives may out-perform price-based conservation measures and could be viable alternatives to reduce residential consumption without the need for large price increases. Outdoor water use mandates, for example, may out-perform price-based conservation and rebate programs at reducing water use (Maggioni, 2015). Household consumption is likely to fall over time outside of these types of conservation programs due to trends in implementation of more water efficient appliances, advancements in technology, and changes in behavior (Davies, 2014). Improvements in water metering, customer education, long-term changes in elasticity, technological advancements, and changes in climate may all have a long-term impact on residential water consumption (Inman and Jeffrey, 2006), and may allow Raleigh to forestall or eliminate the need for a supply expansion in the future.

CHAPTER 5. CONCLUSIONS

Promoting conservation through both price and non-price based measures can help to reduce costs associated with expanding the water supply (through forestalling or eliminating the need for expansion), can support growing populations, can be financially beneficial to utilities, and is less environmentally burdensome. While these conservation tactics often lead to increases in bills for customers in the short run, they may reduce customer bills in the long run. Customers could lessen this short-term impact by reducing their consumption (and thereby reducing their monthly bill). Price based tactics are effective for reducing demand for a time; however, utilities may not want to place undue financial hardship on their customers, particularly if they are looking to forestall expansion for ten years or more using price-based tactics alone. Non-price based tactics can be expensive for utilities, but can be funded through revenues generated from fairly small price increases. Conservation from these programs is often limited by adoption rates, but over time, can lead to some reduction in water consumption. Increasing adoption rates for these programs would be beneficial for reducing demand without increasing the price beyond the level of customer and utility comfort. Ideally, both price and non-price conservation measures would be used in tandem to send a pricing signal to customers to reduce demand, allowing utilities to save for expansion projects while funding hard conservation programs. Conservation measures can be effective at forestalling supply expansions for a time; however, some conservation will occur naturally in the absence of these conservation programs due to behavioral changes, technological advances (Davies, 2014), and increased prevalence of water-efficient appliances (Zadeh, 2014).

APPENDIX A. BASELINE PRICE INCREASE CALCULATION

A baseline rate increase of 2.1% each year was added to the three conservation oriented rate increase scenarios used in this analysis, to account for increasing operation and maintenance costs each year. This value was calculated using the median bill increase for 484 North Carolina utilities in 2013 (a 5.2% bill increase, as shown in Figure A1) and removing the estimated effects of inflation using the Producer's Price Index for water utilities from 2008 to 2013 (Bureau of Labor Statistics, 2013).

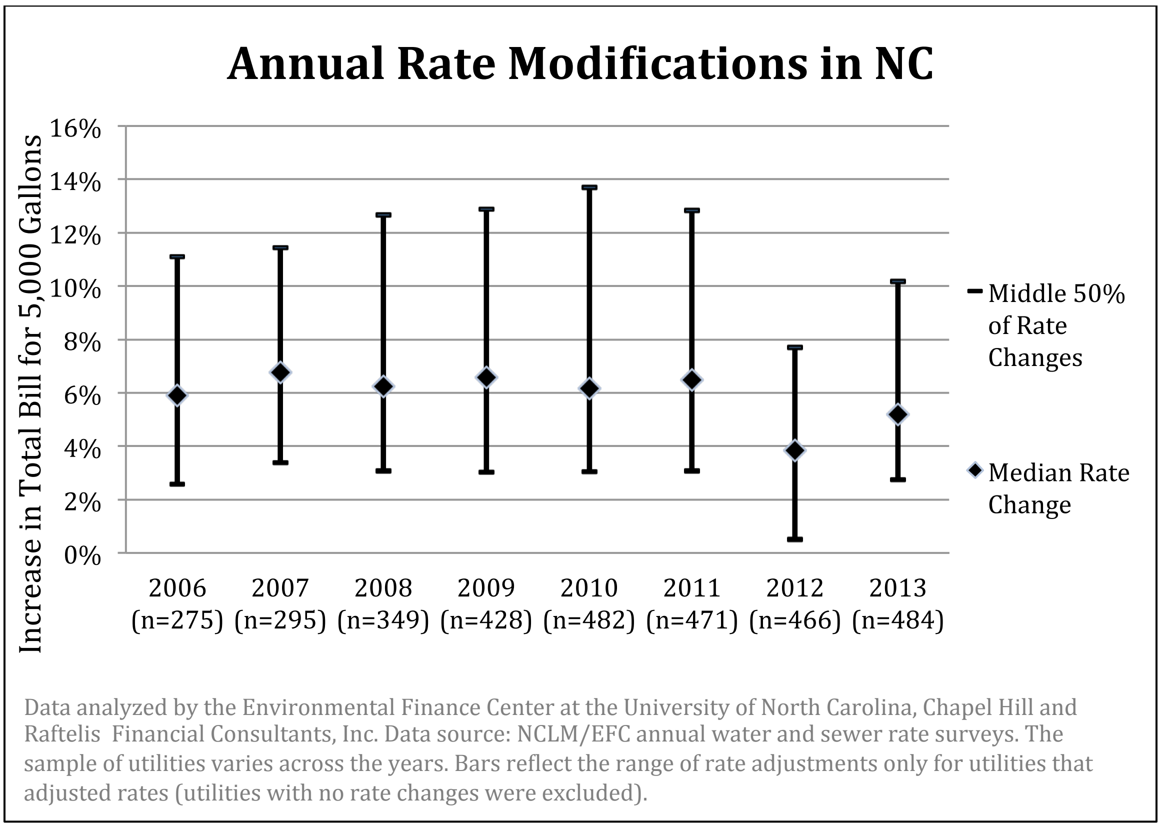

Figure 12. Annual Rate Modifications of North Carolina Utilities from 2006 – 2013

This figure, however, only includes utilities that modified rates from the previous year, so while the rate increases in each scenario are considered to fall within a normal range, they are occurring each year for a set number of years and will subsequently result in higher overall water rates than utilities that implement these rate increases once, or on a multi-year basis.

APPENDIX B. ESTIMATING CONSERVATION FROM NON-PRICE CONSERVATION PROGRAMS

In order to estimate the annual water savings from each of the three hard conservation programs being studied, an appliance adoption rate was estimated based on residential housing data for the City of Raleigh (City-data, 2013). The number of homes in 2009 falling into twenty-four different housing value ranges (from $10,000 to greater than $1,000,000) was used in conjunction with an average cost per square foot of Raleigh homes in 2009 of $116 (Trulia, 2014). This data yielded a distribution of homes grouped by a range of square footages. The House Cleaning Alliance performed an assessment in 2008 of pricing tools for home cleaning services. This included a study of the correlation between the number of toilets in a home and the square footage, with results shown in the figure below (Ksrisuwan, 2008).

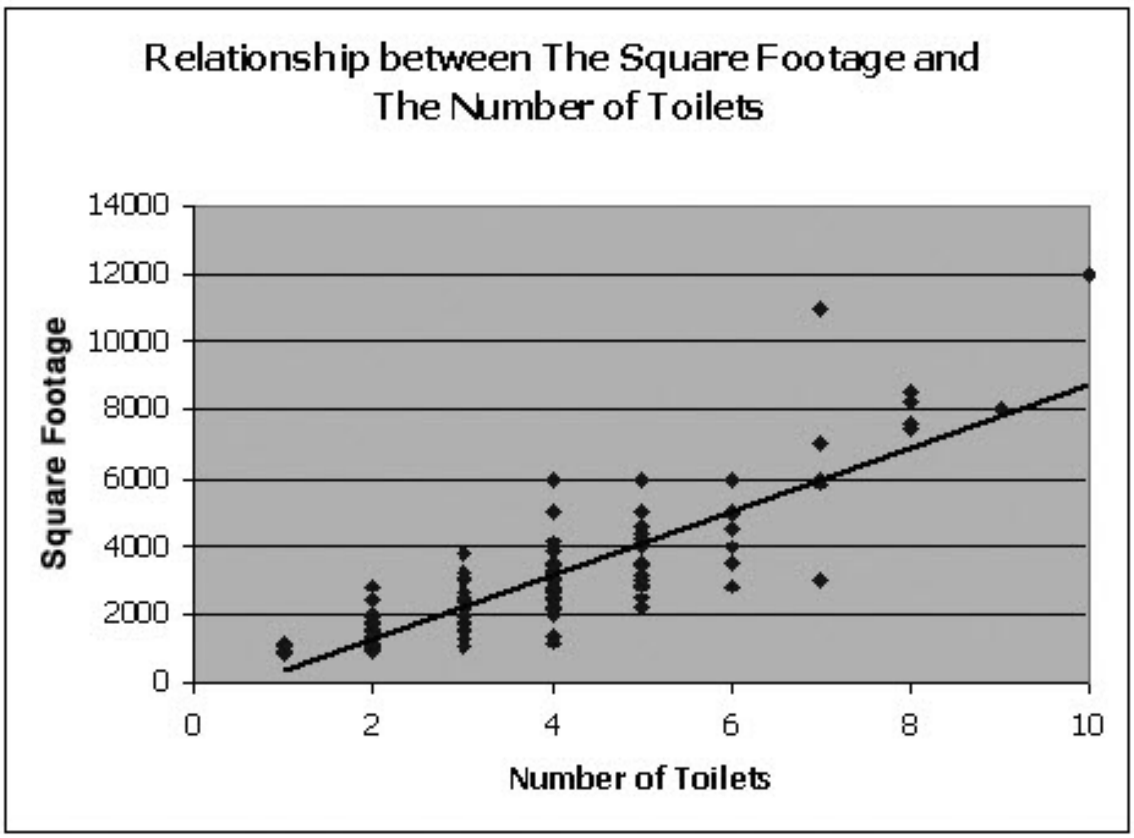

Figure 13. Correlation between the number of toilets and the square footage of homes (Ksrisuwan, 2008)

This study found that these two measures were highly correlated, with a correlation coefficient of 0.86. This data was used to assign a number of toilets to each home based on the square footage ranges listed in Table B1.

Table 6. Toilets assigned to each home by square footage

Square Footage of Home	Number of Toilets Assigned
≤1000	1
1000 < x ≤ 2000	2
2000 < x ≤ 3000	3
3000 < x ≤ 4000	4
4000 < x ≤ 5000	5
5000 < x ≤ 6000	6
> 6000	7

Based on the 2009 housing value distribution, the number of toilets in each price range was estimated and summed, to obtain the total number of toilets in Raleigh households of 211,024 with an average of 2.51 toilets per household. The distribution of the number of residential toilets among Raleigh households is shown in Figure B2.

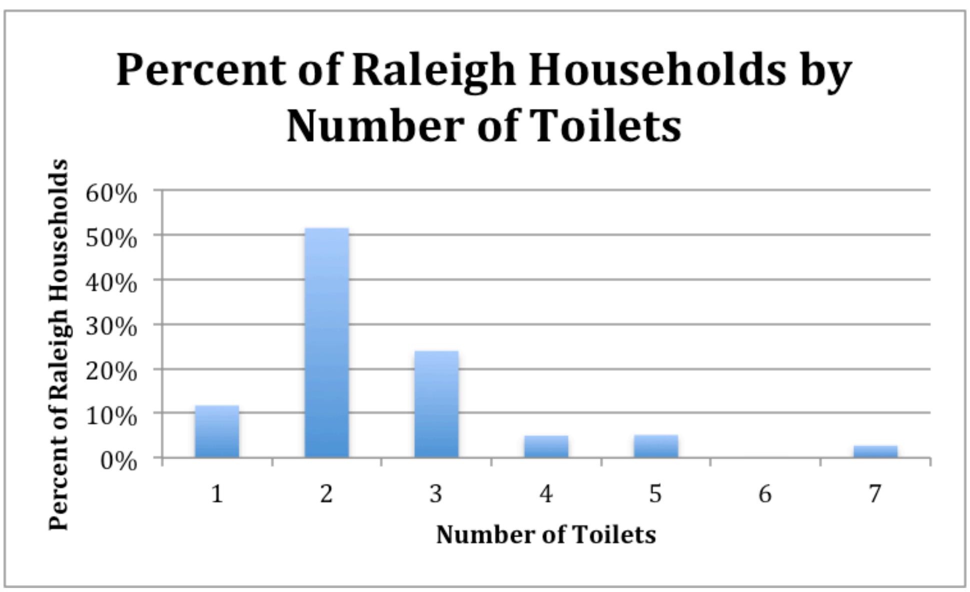

Figure 14. Percent of Raleigh Households by Number of Toilets

Based on this estimation of the total number of toilets in residential homes in Raleigh, the number of showers and washing machines was estimated. Based on evidence compiled by the House Clean Alliance, the total number of showers in use in residential homes tends to be one less than the total number of toilets in the home for homes with more than one toilet (likely due to the fact that two people will typically share a master bathroom) (Ksrisuwan, 2008). To calculate the number of estimated showers in use, homes were categorized by the estimated number of toilets present. The number of residences with one toilet was added to the number of toilets minus one, for each of the subsequent categories. This yielded an estimated 136,878 showers in residential homes in Raleigh.

The total number of washing machines in Raleigh residences was based on the total number of residences in 2009. The 2009 American Housing Survey National Data indicates that 84% of U.S. homes have a washing machine (USDHUD, 2009). It was assumed that Raleigh had the same distribution of washing machines among its residential housing for an estimated total of 70,554 washing machines.

After the total number of toilets, showers, and washing machines in Raleigh residences was established, the percentage of these that would be eligible for replacement was estimated, given the distribution of housing age and natural turnover rates for these devices. Table 3 below gives the average lifespan and turnover rates used in this analysis for the given devices. To estimate the fraction of Raleigh toilets that would be eligible for the rebate, residences were grouped by year built. Homes built after 1991 (the year that high efficiency toilets using ≤1.3 gallons per flush became available) were assumed to have a functioning, high-efficiency toilet and thus would not participate in a toilet rebate program. It was assumed that homes built prior to 1991 would get replacement toilets ever 25 years, based on a study done by the University of

Southern California (USCCSC, 2012). The most recent year that toilets would have been replaced assuming toilets were replaced exactly every 25 years, was calculated for homes built in each year from 1930 to 1990. Based on the 25-year replacement cycle, the percentage of total homes still using a pre-1991 toilet by year 2012 (the year that the revenue analysis for Raleigh begins) was calculated. Homes built from 1938-1940, 1963-1965, and 1988-1990 would still contain a pre-1991 toilet in year 2012 and would thus be eligible to receive a new toilet through a rebate program. This accounts for 16% of Raleigh homes. Assuming that the distribution of the number of toilets in Raleigh homes is consistent across these years, a total of 33,080 toilets meet the rebate program eligibility requirements. In estimating the number of out-of-date showerheads in Raleigh homes, an average showerhead lifespan of 10 years was used (USCCSC, 2012). Assuming this replacement cycle of 10 years, 10% of Raleigh residential showerheads are eligible to be replaced each year. Unlike high-efficiency toilet rebate programs, which require toilets to be manufactured before 1991 to meet rebate eligibility requirements, many showerhead rebate programs (including one currently in use by the City of Raleigh) only require that the old showerhead be brought in for a replacement to be given. There are no restrictions on age or flow to receive a replacement showerhead (City of Raleigh, 2013). Similarly, rebates for washing machines do not mandate that a specific type of washing machine be replaced. Many programs, such as the N.C. Energy Star Appliance Rebate Program, only require that the rebate be used to replace an "older" washing machine with a new Energy Star® appliance (N.C. Department of Commerce, 2012). Thus, the estimated average lifespan of 14 years and turnover rate of 7% was used to determine the number of washing machines eligible to be replaced in Raleigh (USCCSC, 2012).

Table 7. Natural Turnover Rate of Conservation Devices

Device or Appliance	Average Lifespan	Turnover Rate per Year in Absence of Rebate
Toilets	25 years	4%
Washing Machines	14 years	7%
Showerheads	10 years	10%

USCCSC, 2012

Non-priced based conservation programs for toilet and washing machine rebates and low-flow showerhead devices are implemented at some expense to the utility. The feasibility of funding such hard conservation programs is evaluated by paying for these programs with excess revenues earned from small residential rate increases. Additional revenues gained from a 5% annual rate increase over a 5-year time period are calculated. These excess revenues are then used to fund the three hard conservation programs simultaneously. The percentage of funds allocated to showerhead device giveaway programs was maximized at the amount necessary to fund replacement showerheads for roughly 10% of the estimated devices in use in Raleigh homes (this was assumed to be the maximum amount of showerheads that residential customers would be willing to replace in a given year based on natural product turnover rates). Rebate values for both high efficiency toilets and washing machines were set to $150, with a $25 administration fee. The optimal allocation of additional revenues was calculated based on the natural turnover rates for washing machines and showerheads, and the estimated number of pre-1991 toilets in Raleigh residences.

APPENDIX C. PRICE-BASED CONSERVATION TO FORESTALL EXPANSION TO YEAR 2050

Four different price increase scenarios were initially compared and in all cases, reached the objective date (or objective date and funding goal) with demand remaining below the safe yield of the current supply system (Figure 6). Although these conservation-oriented price increases are used to reduce demand, additional demand experienced from population growth was sufficient to offset this price-based reduction in demand in all cases except scenario 2 (price increases to forestall expansion until 2050). In this case, total household demand was reduced for the first seven years of implementation.

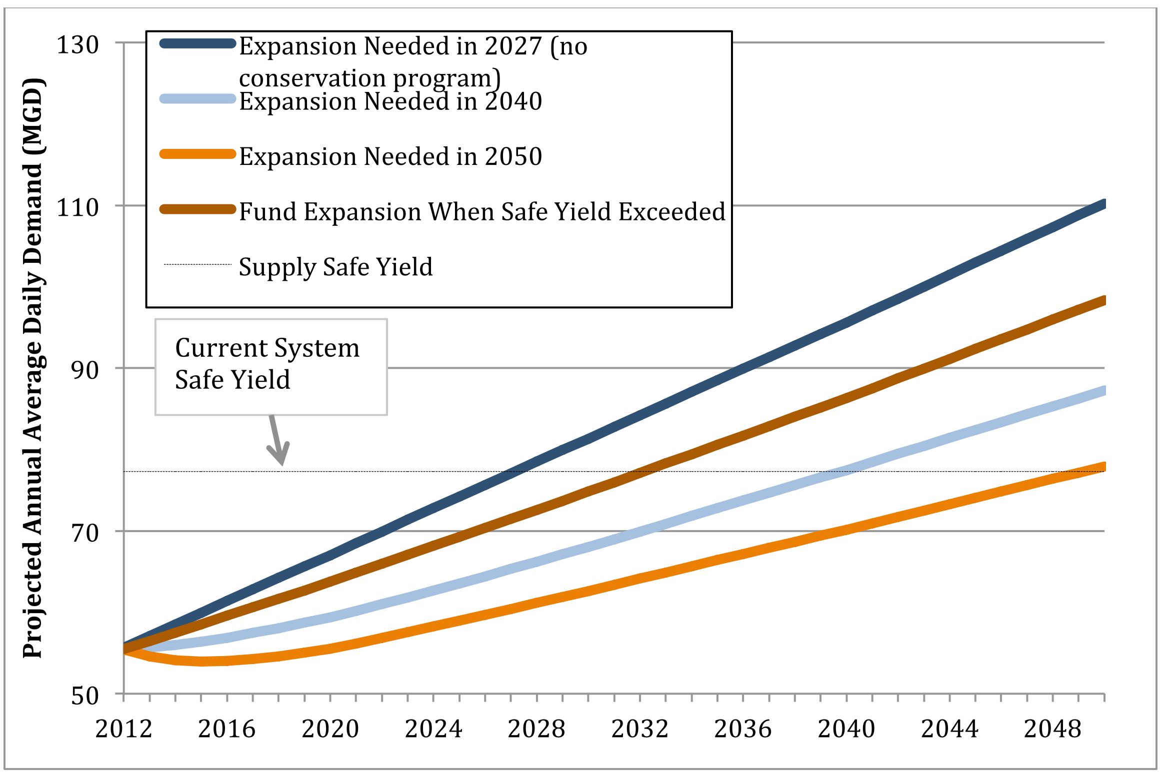

Figure 15. Total Consumption Projections by Conservation Goal, with Expansion Needed in 2050 Scenario

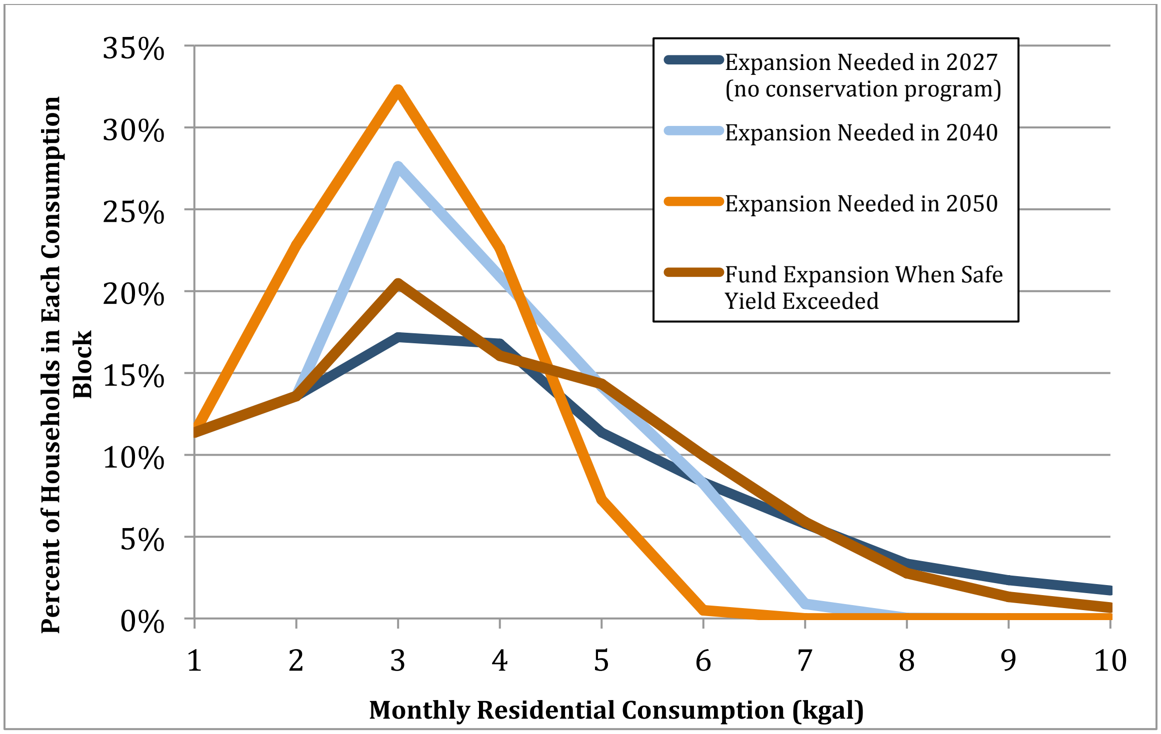

Figure 16. Percentage of Residential Demand by Monthly Residential Consumption Class, with Expansion Needed in 2050 Scenario

Shifting demand significantly using only price-based tactics, however, requires large (and in some cases unreasonable) price increases. To accomplish certain demand goals (particularly for forestalling expansion until 2040 and 2050), annual rate increases became high, leading to unrealistic water bills. Total annual bill increases (including the baseline annual rate increase of 2.1%) of 12.6%, and 23.6%, were sufficient to keep residential demand below the safe yield of the current water supply until 2040 and 2050, respectively. These increases resulted in monthly bills of $356 in 2040 (for the expansion in 2040 scenario) and $40,233 in 2050 (for the expansion in 2050 scenario) in 2012 dollars for 3kgal of water. They also resulted in inappropriately large additional revenue for water utilities (Table C1 and Figure C3).

Table 8. Conservation Price-Increase Results, with Expansion Needed in 2050 Scenario

Conservation Scenario:	Total Annual Rate Increase	Additional Revenue Generated (millions of dollars)
Expansion Needed in 2027 (no conservation program)	2.1%	--
Expansion Needed in 2040	12.6%	$9,490
Expansion Needed in 2050	23.6%	$856,633
Fund Expansion When Safe Yield Exceeded (year 2033)	5.6%	$584

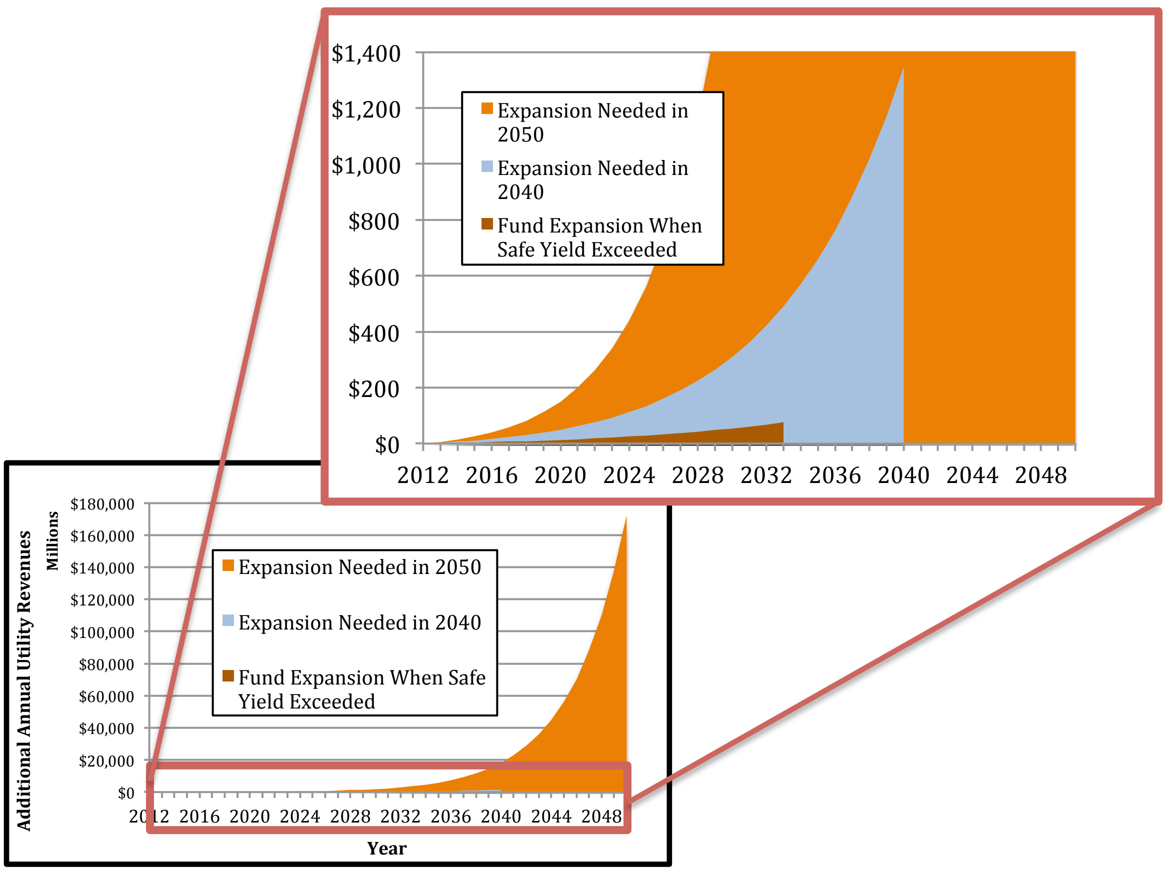

Figure 17. Additional Annual Revenue from Price-Based Conservation Programs, with Expansion Needed in 2050 Scenario

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