Reclaimed Water and Integrated Water Management in North Carolina

By

Lindsey Merriman
Sally Schauman, Advisor
April 24, 2009

Masters project submitted in partial fulfillment of the requirements
for the Master of Environmental Management degree in
the Nicholas School of the Environment of Duke University
2009

Abstract:

Traditionally, water has been considered a highly reliable resource, but population growth, climate change, and water quality concerns are proving otherwise. The southwestern US has utilized an integrated water resource management strategy heavily dependent upon wastewater reuse for decades as a means to supplement their waning freshwater resources. In the southeastern US, on the other hand, water resources have been historically more abundant leaving little cause for the region to incorporate more stringent water resource management strategies. Water scarcity, however, is an emerging concern for the region and integrated water resource management strategies utilizing reclaimed wastewater should be considered. This master's project focuses on the feasibility of using reclaimed water in North Carolina as a component of an integrated water resource management plan (IWRM). Through literature review and web research, this study will highlight the importance of reclaimed water and the merits of an IWRM plan which can be seen throughout the country. The bulk of this project, however, looks specifically at the costs and benefits of providing reclaimed water as a non-potable water supply for operation of the steam plant, chilled water plants 1 and 2, and for all irrigation purposes at Duke University. I examined three reclaimed water supply scenarios for Duke University including: (1) Continuing campus water usage as usual, (2) Constructing a direct distribution line from Durham's Regional reclamation facility, (3) Establishing an on campus membrane bioreactor (MBR) reclamation system. By comparing the net present values of each alternative, I illustrate the economic implications of replacing potable city water with reclaimed water in facility operations and discuss the financial feasibility of these alternatives for the University. I further demonstrate the merits of reclamation systems by identifying other non-quantifiable benefits this resource presents for both the University and the City of Durham. Utilizing the outcome of this analysis in conjuncture with other examples of reclamation and reuse in the state, I also offer recommendations that demonstrate potential environmental, social, and educational benefits that effective water reuse policy could have for future conservation throughout North Carolina.

Table of Contents

Introduction:

Throughout history water has been widely considered a limitless resource, but it is actually finite. The freshwater that exists on Earth today is the same that has always existed, but new and emerging conditions, like climate change, population growth, and pollution are beginning to exhaust this indispensable resource. Government entities worldwide are struggling to provide a clean adequate water supply not only to their citizens, but also to the agricultural and industrial sectors that rely on large allocations to grow the food and process the goods we utilize every day. Future water security requires an innovative approach to water management, and an informed understanding of unconventional yet practical water resource options for the future. This study will demonstrate the merits of wastewater reuse as a component of integrated water resource management, and how it can effectively extend the life of current water supplies in North Carolina. By examining existing literature concerning the status of global and national water resources, I will highlight the importance of integrated resource management policy and how reclaimed water can bolster potable water security at any level. On a practicable level I will conduct a preliminary feasibility study for instituting a reclaimed water system at Duke University. I will address potential costs and benefits to the University and describe how the city of Durham may also benefit from this system. The results of this study in conjuncture with other projects throughout the state will illustrate the environmental, social, and educational benefits that water reuse policy could have for future water conservation in North Carolina.

Part 1: National and Global Water Supply

Brief Overview of World Wide Water supply

Water makes up 70% of the Earth's surface with freshwater accounting for only 2.5% of that total, and even two thirds of that freshwater is locked in polar ice caps and glaciers. The remaining freshwater resources are then available for consumption and use by living organisms, and, according to calculations produced by Postel et al, that allotment constitutes a mere .77 percent (roughly 10,665,000 km^3) of all water on earth.[1] This seemingly small percentage of available resource can be reduced even further when pending population growth, the disproportionate distribution of humans to sufficient freshwater supplies, and the amount of freshwater that are becoming non-potable due to pollution, degradation, and/or inaccessibility are considered.[2] Mexico, the entire continent of Africa, and Australia are examples of these severely overpopulated and exceptionally water stressed regions. These countries' aquifers are drying quickly and those that have withstood overuse are subject to salt water intrusion. In contrast, other regions such as the US, Switzerland, and most of South America are quite fortunate and have control over a larger percentage of the world's fresh water supply; but even in these places the available water supply is unevenly distributed and/or becoming non-potable as a result of pollution.[3]

A changing plan for Water Resource Management in the US

While the US is comparably "water rich" to other countries in the world, the distribution of water resources within the continental US remains unbalanced. The arid southwestern states are very water stressed much more so than the humid southeastern states, and as a result they have had to rely on large infrastructure projects to store and accommodate their water needs. Drinking water supplies have been handled historically through the creation of dams and the diversion of water from rivers and streams into municipal water supply infrastructure such as pipelines, aqueducts and dams, something Peter Gleick refers to as "hard-path" solutions in his 2003 article.[4] The Colorado River, for instance, has provided the bulk of water required for accommodating the needs of the arid western region of the US (seven states

---

[1] Postel SL, Daily GC, Ehrlich PR. *Human Appropriation of Renewable Fresh Water*. 1996. Science 271 No. 5250: 785-788.
[2] Postel SL, Daily GC, Ehrlich PR. *Human Appropriation of Renewable Fresh Water*. 1996. Science 271 No. 5250: 785-788.
[3] De Villiers M. Water: The Fate of Our Most Precious Resource.1999. Houghton Mifflin Company. Boston p 1-26.
[4] Gleick PH. *Global Freshwater Resources: Soft-Path Solutions for the 21st Century*. 2003. Science 302: 1524-1527.

including parts of Mexico) by storing water behind at least 30 dam systems that stretch almost the entire river's length. As most of the west can attest, this type of infrastructure has been extremely beneficial on many anthropocentric fronts including: reducing flooding events, generating hydropower, and irrigating farmland.[5] These benefits plus record jumps in US water consumption in the late 1970's and early 1980's spurred investment in large scale water projects nationwide[6]. However, pressure to construct new large scale dams has subsided since water consumption hit its peak in the early 80's. Innovative technologies and practices in both irrigation and industry resulted in a 20% decrease in water withdrawals by 1995, thus reducing the need for infrastructural expansion. This waning need for such projects has allowed researchers to focus on the repercussions of these "hard-path" solutions and has in turn revealed many unanticipated social and environmental costs.[7] Large scale water projects often require the flooding of small towns, villages, and the surrounding environment with millions of gallons of water, resulting in the displacement of residents and animal species. This sizeable diversion of water from damming also decreases water flow downstream, which leaves ecologically important wetlands dry thereby damaging vital aquatic habitats. Even though dam and aqueduct systems have traditionally provided substantial benefits the consequences of their development are now being more readily acknowledged and has led to an integrated water resource management (IRWM) approach.

Integrated Water Resource Management in the US

Water is not only a significant component of most ecosystems, it is also recognized as an economic good used in the agricultural, industrial, and domestic sectors. Given the breadth of uses for water and recent scarcity concerns, integrated

---

[5] Gleick PH. *Global Freshwater Resources: Soft-Path Solutions for the 21st Century*. 2003. Science 302: 1524-1527.

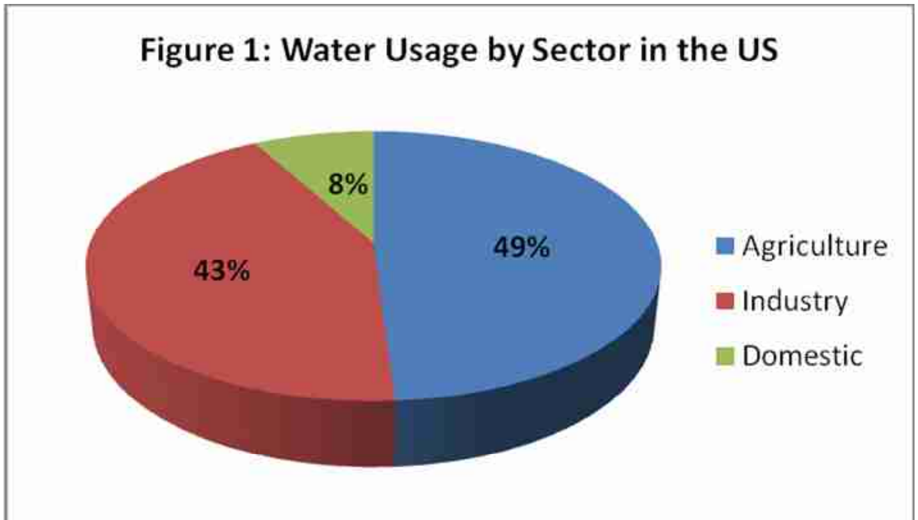
[6] US water consumption peaked at a record 2300 m^3/p/y in the early 1980's, when in 1900 the average per capita consumption was less than 700 m^3/p/y.

[7] Gleick PH. *Global Freshwater Resources: Soft-Path Solutions for the 21st Century*. 2003. Science 302: 1524-1527.

water resource management (IWRM) evolved as a means to identify how the resource can be utilized in a more sustainable manner.[8] The agricultural, Industrial, and domestic sectors, for instance, are the three largest consumers of water in the US, and their ever increasing demand for water has brought about the need for supplemental water sources, Figure 1 illustrates this current demand.[9] Traditionally, all of the water needed by these sectors has been supplied by a municipal or private drinking water system, or has been withdrawn directly from a surface water source or aquifer. The emerging social and environmental issues mentioned in the previous section, however, have inspired cities and states across the country to start considering alternative options for managing their water supplies with methods including desalination, rainwater harvesting, groundwater mining, and wastewater reclamation. These strategies are all options considered in the concept of IRWM, but because community needs, water regulations, and resources may differ from region to region, an all encompassing standard for IWRM does not exist.[10] The individual strategies should conform to the needs of the community, municipality, region, or state in order for this type of management system to be effective.[11] IWRM, however, is becoming more viable as population growth, climate change, and water pollution become more prevalent, and especially as the environmental and social implications of large infrastructure projects become more recognized.

---

[8] Radif AA. Integrated Water resources management (IWRM): An approach to face the challenges of the next century and to avert future crises. 1999. Desalination 124:145-153.
[9] UNEP. Vital Water Graphics. http://www.unep.org/dewa/assessments/ecosystems/water/vitalwater/15.htm#17
[10] Biswas AK. Integrated Water Resources Management: A Reassessment, A Water Forum Contribution. 2004. Water International , Vol.29 Num2:248-256.
[11] Radif AA. Integrated Water resources management (IWRM): An approach to face the challenges of the next century and to avert future crises. 1999. Desalination 124:145-153.



Recreated from data:

The western US has utilized IWRM practices for decades to offset water scarcity, and relieve some of the strain that has historically been placed on major regional water supplies such as the Colorado River. As mentioned before, IWRM strategies identify and develop supply options that can supplement traditional water sources including tapping groundwater aquifers, creating desalinization facilities, encouraging rainwater harvesting, and instituting wastewater reclamation programs. The least sustainable option is drilling for groundwater. Subterranean aquifers are especially unsustainable if they are the only source being used as overdrafting is a common occurrence.[12] Heavy groundwater consumption will continually reduce resources levels until the entire aquifer is depleted and no longer useful. Groundwater can be a beneficial alternative as long as it is properly managed in conjuncture with other resources like surface water supplies and reclaimed wastewater. Desalinization is another integrated method and is often used by coastal cities that lack adequate water resources. This process sustainably transforms sea water into a potable product, but the process is often very expensive and access and distribution is limited to users located in or near coastal regions. Rainwater harvesting is also considered a management tool, but mostly on a smaller scale. Cities and municipalities often encourage rainwater reuse for lawn irrigation and gardening on the residential and

[12] Where the extraction of water exceeds the rate at which it is naturally replen ished.

commercial levels to complement increasedregulatory emphasis on domestic water conservation. Reclaimed wastewater is the management tool with the most potential, but is also the most controversial. This resource can help supplement diminishing water resources in both a potable and non-potable capacity.[13] Many regions of the western US have already come to accept reclaimed water as a viable resource, and are reaping the benefits of a more stable water supply. Tucson, Arizona in the early 1990's implemented a reclaimed water system to reduce strains on diminishing groundwater resources by employing it for non potable uses. This reclaimed water system allowed Tucson to irrigate many of its large golf courses that, when irrigated conventionally, monopolized a large portion of the city's potable water supply.[14] Other regions of the west, like Santa Ana California, have come to rely on reclaimed water for potable purposes. Santa Ana uses an indirect reclamation and reuse system to provide potable water for 2.3 million customers in Orange County.[15] This region has experienced substantial growth in recent years and, like Tucson, has been consistently overdrawing from its aquifers. These actions have created an intense strain on the water supply as well as increased the amount of salt water that is intruding upon existing groundwater aquifers. This "Groundwater Replenishment System" (their wastewater reclamation system) provides a safe source of drinking water to the citizens of Santa Ana, while other processes incorporated in this system prevent further saltwater intrusion into the region's remaining healthy aquifers.[16]

Necessity has driven the western United States to adopt integrated water resource management plans rely heavily upon reclaimed water to supplement waning water resources. Other more "water rich" regions of the US have recognized

---

[13] Potable uses include: drinking water and bathing. Non-potable uses include: irrigation, industrial cooling, fire extinguishing.

[14] Thomure T, Kmiec J. The importance of the Tucson Water Regional Reclaimed water system to the economic vitality of the city of Tucson-Pima County region.

[15] Royte E. "A Tall, Cool Drink of….Sewage?" 2008. The New York Times p1-4. http://www.nytimes.com/2008/08/10/magazine/10wastewater-t.html?pagewanted=1&_r=1.

[16] Royte E. "A Tall, Cool Drink of….Sewage?" 2008. The New York Times p1-4. http://www.nytimes.com/2008/08/10/magazine/10wastewater-t.html?pagewanted=1&_r=1.

the need for conservation, but unlike the southwest, they have seen little need to significantly alter their consumption habits. Uncertainties of climate change, pending population growth, and threats to water quality, however, are making these regions more aware of the need to maintain stable base supplies. Most conservation efforts in the eastern regions of the US are less invasive than those mentioned above and are geared heavily toward educating the public about domestic consumption habits and water conservation. These conservation efforts and water management policies, however, do become more rigid during prolonged or intense periods of drought when surface water supplies have noticeably declined. These situations necessitate behavioral modifications like encouraging the use of low flow toilets and shower heads, setting municipal water restrictions, and creating a more distinctive water rate structure. Limitations become more stringent as water resource supply concerns become palpable. In these instances city governments will further limit non-essential irrigation and watering, prohibit municipal water supply use for decorative fountains and water intensive businesses such as car washes, and encourage or require drought tolerant landscaping. The affects of climate change and water scarcity are easily recognizable when you consider water resources loss on the national and international level, but those concerns becomes less ominous in regions, like the southeast, where water is traditionally more abundant. The southeast's moist climate has traditionally offered consistent surface water and groundwater supply replenishment, but changing climatic conditions and future growth in population, industry, and agriculture makes IRWM programs important considerations for maintaining adequate potable water supplies. Integrated management programs, geared especially toward reclamation and reuse, have the most applicability in the southeast. These programs could help the region avoid scarcity issues, like those plaguing the west, as well as ensure adequate potable water supplies exist for future use.

Part 2: Reclaimed water

The potential of reclamation and reuse systems require an initial explanation of both the benefits and concerns associated with the resource. Three main drivers prompt a region, organization, or municipality to supplement their water supply with reclaimed water. The first driver, and most prevalent concern in the southwest, is water scarcity and droughts. The extremely dry conditions and lack of adequate water supply has forced the western US to invest heavily in reclamation systems to help supplement their drinking supply. The second main driver is regulatory. Nutrient loading limitations for surface waters in agricultural irrigation, for instance, may necessitate the institution of a reclamation system. Utilizing reclaimed water in an irrigation capacity would limit the amount of nutrient rich wastewater being returned to the system, thus reducing nutrient loading in a city or county's natural stream network. The final reason would be for promoting integrated resource management and urban sustainability. For example, interest in LEED building certification, conservation, and smart development continues to grow, and the use of reclaimed water in smart design and LEED projects helps the building gain sustainability credit and/or LEED points. All of these components have helped legitimize the use of reclaimed water making it a viable resource for the present and the future.

While there are perceptible justifications and definite beneficial uses for reclaimed water, there are also some legitimate concerns associated with this resource. Reclaimed water is typically described as any type of waste water that is treated to standard at which point it is clean enough to be purposefully recycled.[17] The term "waste water" can include: rainwater from roof runoff, grey water from washing machines and sinks, industrial wastewater from cooling processes and manufacturing, stormwater from parking lot and road runoff, and lastly, black water, which goes to the wastewater treatment facility via the sanitary sewer system. My primary focus will be on wastewater recovery from a sanitary facility, as it is the most

[17] Water Recycling and Reuse: Potential, safety, and best practices. IWA Water Reuse Flyer, Version 1, December 14, 2008.

abundant and most widely utilized and most controversial of all methods. Considering the nature of black water, you can imagine that the most obvious concerns are for health and safety in terms of human contact and environmental exposure. The treatment process and subsequent quality of reclaimed water is at least the same as, if not better in many cases, than the effluent rereleased into our rivers, lakes, and streams for downstream human consumption from a traditional wastewater treatment plant. The quality of effluent utilized for reclaimed water has been widely studied and results indicate that if properly managed, reclaimed wastewater can be as clean if not cleaner than standard drinking water. [18] Regulations and guidelines for reclaimed water are difficult to standardize because the function provided by this resource often differ.[19] For instance, reclaimed water quality standards in Santa Ana, California are going to be stringent enough for human consumption as their indirect reclamation and reuse system provides potable water for 2.3 million customers in Orange County.[20] Other areas of the world have less stringent water quality requirements. The World Health Organization (WHO) recently revised its international water reuse regulations entitled, "Guidelines for the Safe Use of Wastewat er and Excreta in Agriculture and Aquaculture".[21] This guidebook provides broad and rather generalized principles for ensuring the safety of reclaimed water. The generalized nature of these guidelines allows countries, choosing to adopt these policies, the ability to tailor the standards to meet the country's own needs. Somewhere in between these two regulatory extremes lies the majority of the US, where reclaimed water provides a non-potable service that does not require the resource to meet drinking water quality standards. This does not mean that because reclaimed water is not being treated to drinking water standards

---

[18] Asano T, Cotruvo JA. *Groundwater recharge with reclaimed municipal wastewater: health and regulatory considerations*. 2004. Elsevier. Water Research 38:1941-1951.

[19] Some type of figure that shows baseline wastewater effluent standards (BOD, TSS, TP, TN, etc) for California, NC, and Some other state as comparison. Look at EPA website.

[20] Royte E. "A Tall, Cool Drink of….Sewage?" 2008. The New York Times p1-4. http://www.nytimes.com/2008/08/10/magazine/10wastewater-t.html?pagewanted=1&_r=1.

[21] Sobsey MD, Kase JA, Simmons OD, Swanson K. Evaluation of the Proposed OWASA Water Reclamation System for Production of Non-potable Water for UNC Chapel Hill. 2005. University of North Carolina: Department of Environmental Sciences and Engineering.

that it is not safe for human contact. The designation is simply in place to ensure additional precautions are taken with regards to public safety. For example, the results of a local study conducted by Mark Sobsey, a professor in Environmental Sciences and Engineering department at the University of North Carolina (UNC) at Chapel Hill, demonstrates the reputable quality of reclaimed water produced by a pilot projected located in Chapel Hill. His evaluation was made of a proposed reclaimed water treatment system designed to provide reuse water to UNC-Chapel Hill by the Orange Water and Sewer Association (OWASA). This study tested effluent quality at every stage of the tertiary treatment system and concluded that the design and subsequent processes adequately "achieved a quality of reclaimed water that meets the needs for the intended use and is protective of public health."[22] Mark Sobsey, in his analysis, even agrees that the health risks associated with reuse systems are easily minimized as long as the water is treated with "a reliable treatment system that consistently reduces microbiological contaminants to allowable limits…"[23] The outcome of this study and many similar studies demonstrate that a properly designed and monitored system can eliminate associated health and safety concerns almost entirely.

It is easier to address and accept the various benefits of wastewater reuse systems with the base knowledge and understanding that the resulting resource is of a safe and innocuous quality. Once that trust is established we are free to explore the suitable applications for the varying qualities of reclaimed water. The effluent of highly treated reclaimed water derived from tertiary treatment systems plus additional advanced treatment, like reverse osmosis[24] or a similar treatment process, can usually be released at drinking water quality. These types of systems are utilized primarily in

---

[22] Sobsey MD, Kase JA, Simmons OD, Swanson K. Evaluation of the Proposed OWASA Water Reclamation System for Production of Non-potable Water for UNC Chapel Hill. 2005. University of North Carolina: Department of Environmental Sciences and Engineering.
[23] Sobsey MD, Kase JA, Simmons OD, Swanson K. Evaluation of the Proposed OWASA Water Reclamation System for Production of Non-potable Water for UNC Chapel Hill. 2005. University of North Carolina: Department of Environmental Sciences and Engineering.
[24] Explain what reverse osmosis is

the western US where water resources are scarce. More conventional applications of reclaimed water in the US are for industrial, agricultural, and, on occasion, domestic use. The most economically beneficial occurs in industrial processes, where reclaimed water is often used as cooling, boiler, and process water. Conventionally these processes utilize large quantities of potable water, but the incorporation of reclaimed water systems may offer the industrial, power generation, and manufacturing sectors a practicable and valuable resource that serves their purposes while also conserving potable water. The agricultural community also requires significant hydrologic inputs to irrigate crops and fields. New techniques (like drip irrigation) have helped the industry conserve water resources already, but the use of reclaimed water could help reduce potable water applications appreciably. Domestic use of reclaimed water has also become more prevalent especially in communities where neighborhoods and viable users are in close proximity to the reclamation facility. The facility can then run distribution lines to the users and pump the reclaimed water to provide services like, irrigation, vehicle washing, dust control, and pressure washing. All of these applications consume a considerable amount of our freshwater resources unnecessarily. Reclaimed water can be treated to a standard that can drastically reduce any perceived or associated health risks, provide a practical and constructive function, while also promoting the importance of conservation to consumers and the community alike.

Part 3: Water Management in North Carolina

It is easily reasoned that the water supply struggles of North Carolina are not nearly as dire as those situations dominating political agendas in the other more water strained regions of the nation and world. This does not mean, however, that they lack water resource issues at all; recent developments within the state concerning changing climate, population growth, and nutrient loading in surface water have brought water resource management to the forefront of the state's agenda.

Historically, North Carolina has benefited hydrologically from a humid subtropical climate, frequent rainfall, and ample groundwater recharge potential. Weather patterns have changed in recent years though, leaving much of North Carolina to contend with more frequent and persistent droughts. Many regions of the state were under moderate to severe drought watches for much of 2002, 2007, and 2008. The state legislature and governor Easley since have established both mandatory and voluntary availability and usage limitations for NC water resources to combat the alarming water shortages triggered by these exceptionally dry conditions. The drought has subsided some since the summer of 2008, but state and county governments continue to enforce many of the conservation efforts the General Assembly set in place that including a number of water saving approaches mentioned previously such as: distributing educational material to advise residents on water conservation strategies, offering low flow devices, and restricting lawn irrigation. Some restrictions implemented by the state were largely precautionary, while others were incisive responses to this uncharacteristic strain on such a vital natural resource.

The two other drivers threatening North Carolina's water supply have less to do with climate change and more to do with supplying water to meet the demands of future populations while combating the negative water quality impacts that usually accompany the growth of urban communities such as stormwater runoff and stream degradation. North Carolina is 10th in total population, it is the 6th fastest growing state in the US; and it is expected to house 12 million strong by 2030.[25] Counties around Charlotte and the Research Triangle Park have been North Carolina's fastest growing regions since 2000 due to the substantial industrial infusion that has helped stimulate the job market for both local citizens and for out of state transplants alike.[26] This high rate of growth is further intensified by the rate of development, which has most recently occurred at twice the rate of population growth. In a report presented at a

---

[25] Polk E, Kleczek L, Olander L, Holman B. 2007. The Future of Water in North Carolina: Strategies for Sustaining Clean and Abundant Water. NC State University. Nicholas Institute.
[26] North Carolina Rural Economic Development Center, Inc. Updated Last December 20, 2005. Visited February 19, 2009 http://www.ncruralcenter.org/databank/trendpage_Population.asp

Nicholas Institute conference entitled "The Future of Water in North Carolina in March of 2007, Polk et al states that "urban lands in all three of North Carolina's major metropolitan areas increased by just over 88% between 1982 and 1997."[27] North Carolina is now feeling the impacts of this growth in its watersheds as 10% of streams and 36% of lakes and reservoirs are currently considered impaired by the state.[28] These statistics make water quality a key interest for the state. The North Carolina General Assembly is currently trying to address these concerns with the implementation of policies and rules to limit nutrient loading and non-point source pollution in these highly impaired water bodies. The institution of the Jordan Lake Rules and the Coastal Rules are examples of this regulatory strategy, and have created a great deal of friction between dischargers and policy makers, as these regulations are much more stringent than past regulatory standards for water. However, despite firm opposition, these rules have withstood several iterations, and remain important legislation that could not only effectively improve overall water quality throughout the state, but also provide a positive step toward creating a more comprehensive and innovative water management plan.

Reclaimed water use in North Carolina

North Carolina's legislature has recognized the importance of maintaining a healthy supply of water and has made great strides to promote conservation. The state has made a conscious effort to educate the public on domestic water use, to establish conservation goal for large potable water consumers, to limit unnecessary and avoidable polluting activities, and most importantly for the purposes of this paper, they have begun to recognize the merits of reuse. The first reclamation and reuse regulations and permitting procedures were compiled by the North Carolina

[27] Polk E, Kleczek L, Olander L, Holman B. 2007. The Future of Water in North Carolina: Strategies for Sustaining Clean and Abundant Water. NC State University. Nicholas Institute.
[28] Polk E, Kleczek L, Olander L, Holman B. 2007. The Future of Water in North Carolina: Strategies for Sustaining Clean and Abundant Water. NC State University. Nicholas Institute.

Environmental Management Commission (EMC) in 2006.[29] The EMC was established, at the authority of the governor, to "preserve and enhance" the state's air and water resources, and as such they were challenged in 2006 to assemble a set of rules to ensure the safe distribution and application of reclaimed water projects throughout the state.[30] These rules are amendable, and have been under revision since 2008. These revisions, if passed, allow the EMC to keep legislation and standards up to date as innovative ideas and technologies emerge.[31] These reclaimed water rules outline the allowable uses, health standards and requirements, construction and operational parameters, as well as the effluent quality standards for this resource.[32]

There are over one hundred municipalities and institutions in North Carolina that have recognized the potential for reclaimed water and hold permits that make this resource available for citizen use. These project span the public and private sector and include a number of different system applications ranging from small decentralized or satellite systems, to bulk distribution systems, to direct distribution systems.[33] While some of these localities deliver reclaimed water directly to consumers, distribution networks remain largely non-existent in most due to constraints like high capital costs and the lack of year round users. Given these financial limitations and insufficient demand, the most widely accepted and economically feasible method for providing reclaimed water is through bulk distribution. Bulk distribution makes reclaimed water available at the regional treatment facility for customers to retrieve as needed. Consumers are responsible for retrieving and transporting their supply and

---

[29]North Carolina Division of Water Quality. Water Conservation http://www.ncwater.org/Water_Supply_Planning/Water_Conservation/hb1215/ February, 2009

[30] North Carolina Department of Natural Resources. Environmental Management Commission. http://h2o.enr.state.nc.us/admin/emc/

[31]Water Wiki. Draft Water reuse rules. February 2009. http://sogweb.sog.unc.edu/Water/images/d/df/Dwqdraftreuserules062408.pdf

[32] House Bill 1215: Water Conservation and Reuse. North Carolina Department of Environment and Natural Resources: Division of Water Resources. January 2009 http://www.ncwater.org/Water_Supply_Planning/Water_Conservation/hb1215/documents/HB1215_Summary_Update.pdf

[33]A full list of permit holders can be found at the University of North Carolina Water Wiki: http://sogweb.sog.unc.edu/Water/images/6/66/Ncreusesystem070908.pdf

usually there is little to no cost associated with using reclaimed water in bulk. A few more progressive communities and institutions in North Carolina, like Cary and UNC-Chapel Hill, have integrated distribution networks into their regional wastewater reclamation system. Distribution networks are less common in North Carolina because of the high capital costs from the regional facility to consumers, but these piping systems make reclaimed water more accessible and often result in more widespread use. Other emerging approaches for reclamation and reuse are decentralized and satellite facilities that perform comparably to centralized facilities, but are scaled down to more effectively and efficiently treat and distribute wastewater for more localized or concentrated use. Decentralized systems are comprised of treatment facilities roughly equal in size and strategically placed across a large service area that handle and distribute smaller loads of reclaimed wastewater to consumers, but are connected to one another through a piping network.[34] Decentralized systems are not currently a pervasive method in North Carolina, but Brunswick County has broken its service area into 4 regional treatment sites as a means to better handle future population growth and reclaimed water demands.[35] Satellite systems are similar to a decentralized system in that they handle smaller loads, but conversely, satellite facilities manage the needs of one site, a small group of customers, or a small community virtually independent of a central facility except for solid waste management.[36] Satellite facilities are present in some communities in NC, like the Cannonsgate Community located near Carteret County, but they are not widely utilized. The decentralized and satellite systems are becoming an increasingly viable options for future water management particularly as centralized wastewater

[34] Safrit D. Waterscapes: Satellite and Decentralized MBR Systems- Their Role in a Sustainable Approach. HDR. http://www.hdrinc.com/Assets/documents/Publications/Waterscapes/September2004/SatelliteandDecentralizedMBRSystems.pdf. December 2008.
[35] Comprehensive Wastewater Master Plan for Brunswick County, North Carolina. 2006. HR Engineering, Inc. of the Carolinas.
[36] Safrit D. Waterscapes: Satellite and Decentralized MBR Systems- Their Role in a Sustainable Approach. HDR. http://www.hdrinc.com/Assets/documents/Publications/Waterscapes/September2004/SatelliteandDecentralizedMBRSystems.pdf. December 2008.

treatment infrastructure continue to age, as treatment technologies progress, and as reclaimed water usage becomes more established in North Carolina.

Part 4: Reclaimed water in Durham and at Duke University

A number of factors must be assessed to accurately determine the most suitable reclamation facility for a community, including: the regulatory requirements affecting an area, the characteristics of the community, the physical environmental attributes, and of course the financial feasibility of the system. All of these criteria proved to be very important for determining how extensive the need for reclaimed water is in Durham, and, if expansion is necessary, how to appropriately increase its use within the community as a means to preserve future potable water supplies. The applicability of a reuse system, however, can only be established after first understanding the current conditions in Durham and how they affect water resources.

Current and Future Options for Water Supply in Durham

Durham is subject to many of the same water supply concerns affecting most of North Carolina, which are principally attributable to population growth and regulatory restrictions. Current water resource conditions are fairly stable in Durham. Two main water supply sources service this community, Lake Michie and the Little River. Lake Michie was established on the flat river in 1926 and has since remained Durham's largest source and provides 19 million gallons per day (MGD) of potable drinking water. The Little River is the other main water supply, providing 18MGD, and was established on the Little River in the late 1980's.[37] These two sources alone provide a combine 50 year safe yield of 37 MGD to the city, which exceeds current extraction rates for public use of 32 MGD.[38,39,40] Durham also has the contingency option to draw 5 MGD of water from the Eno River as well as a 10,000 MGD allocation from Jordan

---

37 Comprehensive Plan for Durham, North Carolina. Chapter 7. 2002. (look up reference)
38 Public Use: includes water withdrawn from public supply by residential, commercial, institutional, and industrial users.
39 Safe yield is defined as water storage sufficient to meet a state average-day demand during a 50 year frequency drought.
40 Durham's Comprehensive Plan. 2006. Chapter 11 Existing Conditions.

Lake if necessary.[41] These water resources adequately sustain the existing needs of the community, but population growth is a major factor influencing future water resource planning in Durham. According to the city's comprehensive plan, population grew by 22.8% county wide and 37% city wide between 1990 and 2000. These estimations are only expected to increase over the next few decades as population is projected to increase annually by 1.29% or by a total 47% by 2030.[42] This 47% projected growth rate also necessitates a comparable increase in water resource consumption, which is expected to reach 49.5 MGD by 2030.

The expected water resource demand in 2030 clearly outpaces the capacity of current water supplies in Durham, so consideration of future water resource management options is critical. Durham has recognized the need to plan for future growth, has identified plausible solutions to match future water resource needs, and has prioritized them based on ease of employment as well as on costs to implement.[43] These projects primarily include expanding current reservoirs to increase capacity and increase dependence on interbasin transfers from neighboring municipalities. The Nicholas Institute conducted research on these future capital improvement projects to establish the conventional costs such as materials, engineering, and land acquisition associated with each option. These estimates essentially express what Durham is willing to invest to ensure sufficient potable water resources exist for the future. There are also other costs associated with these projects in addition to the explicit costs stated above that are often ignored or overlooked. Environmental externalities, for instance, often follow reservoir expansion and time and effort associate with negotiating contracts or agreements with regard to resource sharing are not easily quantifiable, yet are costs that exist and, if considered, could add significantly to the bottom line. Table 1 describes these potential projects as well as some of the realized and unrealized expenses associated with them.

[41] Durham's Comprehensive Plan. 2006. Chapter 11 Existing Conditions.
[42] Durham's Comprehensive Plan. 2006. Chapter 11 Existing Conditions.
[43] Landis B. Draft: Water Quality Infrastructure in the Upper Neuse River Basin, North Carolina: Asset Values and Management Trends. August 2008.

Table 1: Water Resource Capital Planning Options and Associated Costs for Durham

Future Resource Project	Brief Project Description	Identified Costs	Additional Non-Quantified Costs
(1) Inter Basin Transfer from Jordan Lake	Durham would expand state allocations for Jordan Lake from 10 MGD to 20 MGD. Supply exists little to no capital costs.	$75,000 per year to hold the permit plus Durham would pay 1.25-1.45 above current water rates in Cary for treated water.	• Dependency upon resources from another municipality • Time and effort negotiating contract by city officials
(2) Employ Teer Quarry as Water Storage Facility	Teer Quarry would be brought online as additional storage for Lake Michie and would increase supply by 7MGD	14.5 Million plus the cost of equipment rental	• **Environmental impact**: Constructing subsequent facilities and environmental impact of change over process.
(3) Raising Lake Michie	Durham proposes to build a new dam immediately downstream of existing dam and 24 feet higher. Would increase the safe yield of reservoir from 19 to 37 MGD. Pushes lake Michie into Person County	106 Million	• **Environmental Impact** on endangered species (freshwater mussels), inundate 440 acres • **Time** spent negotiating with other municipalities • **Ownership disagreements** when expansion crosses municipal boundaries
(4) Tap into Kerr Lake as potential source of Raw Water	Construct piping system from Kerr Lake to Durham. Lake straddles the NC-Virginia border and is owned by Army Corps of Engineers for hydroelectric, flood control, water supply, and recreation.	Estimated costs are not available, but would be expensive with a lot of strings attached.	• **Distance** of Lake from consumers (50 miles) • **Environmental implications** • **Contractual impediments** from interstate agreements • **Time** spend resolving discrepancies between Virginia, Army Corps of Engineers, and Durham

(All the options, costs, and descriptions for the of future projects expressed in the above table were originally collected and compiled by Ben Landis working at the Nicholas Institute.)

The implementation of the future management options listed it table 1 are contingent upon future population growth and water resource demand outpacing Durham's ability to provide adequate water resources given current capacity limitations. The necessity to employ these options, however, can be delayed or indefinitely postponed with a commitment from Durham to promote water conservation efforts and wastewater reuse. Following actions taken by the state in response to the drought, Durham has done its part to promote conservation and responsible domestic consumption habits. James Lim and Vicky Westbrook, with Durham's Water Management Department, explained that public education and conservation programs comprise the foundation of the city's approach for addressing current water shortages in light of recent droughts. Water Management has increased public awareness by employing methods ranging from poster contests and community presentations to toilet rebate initiatives and offering low flow devices to receptive citizens. Durham has also begun collaborating with neighboring municipalities to encourage conservation strategies on a regional level, and have even implemented a moderately tiered rate structure for potable water. Concern over the drought has also spurred city officials to establish a wastewater reuse system that is still emerging, but could prove to be a valuable resource in the future.

Reclaimed Water in Durham

Proposal of the North Durham Reclamation Facility began in 2002 in response to the extreme drought and the resulting drop in water supply in Lake Michie and the Little River reservoir. Enthusiasm for the facility quickly lost steam after a drought breaking series of rain events. The idea was resurrected in December 2007 under similar circumstances, and this time came to fruition. The North Durham Treatment Facility was renamed the North Durham Water Reclamation facility and began distributing reclaimed water in 2007. Since wastewater reclamation for Durham largely consists of replacing the tertiary step with chemical disinfection, the transition from a wastewater facility to a reclamation facility was fairly easy given chemical purchase is the only additional cost incurred (approximately $11,000/year).[44] The treatment process standard at this facility for discharge of wastewater into Ellerbee Creek (a tributary of Falls Lake) include: advanced treatment with biological nutrient removal, followed by effluent filtration, and lastly is disinfected with an ultraviolet light treatment. This treatment process produces effluent that must be compliant with the state discharge levels, which ensures reclaimed water is safe for acceptable applications. The procedure for generating reclaimed water differs only slightly from conventional wastewater treatment. Reclaimed water goes through the first and second steps of

---

[44] Personal Communication with John Dodson of the North Durham Reclamation Facility. March 2009.

the purification process, but bypasses UV disinfection and is treated with chlorine instead. Chlorine is equally as effective in disinfecting reuse water, but is cheaper and the residual stays in the water to ensure continued disinfection.[45] The wastewater portion of the facility is permitted to produce 20 MGD, 80,000 gallons per day of which on average is set aside for reuse. The reclaimed water is stored on site until it is picked up by consumers via bulk distribution or is returned back to the natural discharge system after it has been held for a maximum retention time of 72 hours.

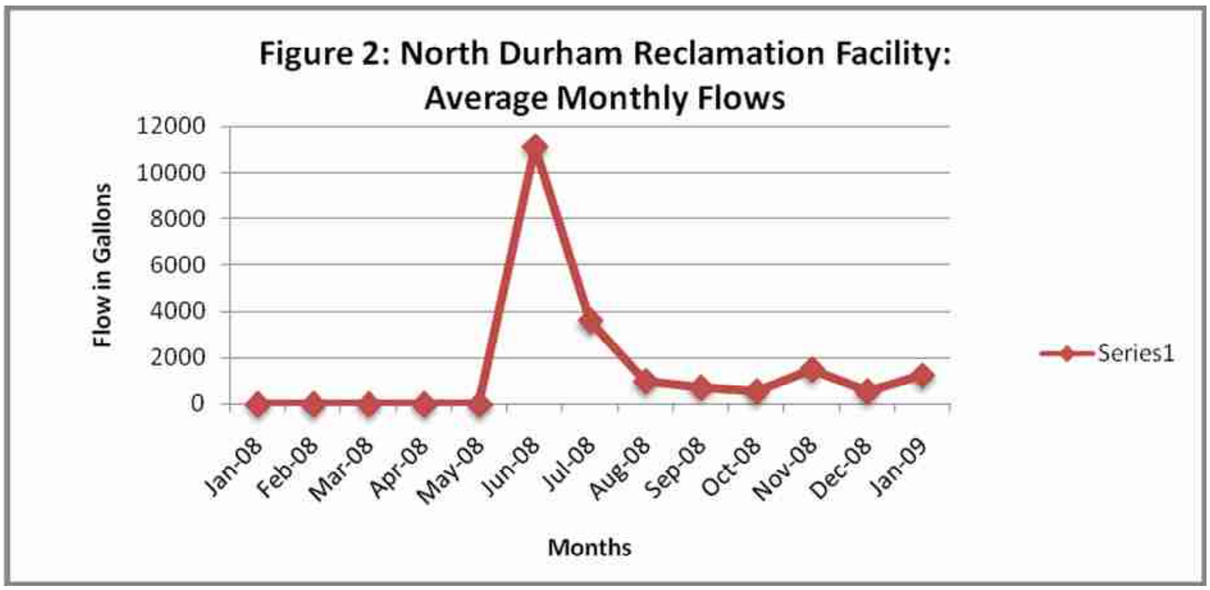
Water utility representatives from the city commonly agree that bulk distribution is the most cost effective approach for Durham given current financial constraints and a lack of consistent demand.[46] The bulk distribution method is the most financially sound design for accommodating present demand because it allows the city to offer reclaimed water as a resource for interested consumers without having to fund an expensive distribution system. Providing reclaimed water in bulk is cost effective for the city because production costs are negligible given suitable infrastructure already exists. Consumers are also not charged a fee for utilizing this resource. City officials believe it is unfair to charge consumers for a resource which is assigned very little value and that must be retrieved at the customers own expense. While the city may be undervaluing the worth of this resource, their concern regarding lack of demand is valid. John Dodson, manager of the North Durham Reclamation Facility, provided the 2008 reclaimed water flow data presented in Figure 2. The data reveals that bulk consumption patterns are largely seasonal, increasing significantly in summer months when the weather is hottest. Mr. Dodson explains that most reclaimed customers are landscape contractors who haul 300-700 gallons at a time to use primarily for irrigation. The American Tobacco complex, probably the largest user, hauls between 18,000-20,000 gallons a day as fill until their decorative rivers is full, and then may come by monthly to pick up loads to supplement any noticeable water loss from the river, but

---

[45] Interview with John Dodson at the North Durham Reclamation Facility. October 2008

[46] Representatives from Water Management and from the N. Durham Reclamation Facility cited these as limiting factors.

refill trips are limited. The city of Durham is permitted to produce a maximum 80,000 GPD of reclaimed water, but as is illustrated below, initial demand for the resource has remained significantly less. These low outflow rates are partially attributable to the immaturity of the system, but also reflect the low demand cited by city officials. Current support and interest in reclaimed water does not necessitate investment in a distribution system at present, but if the city will acknowledge and embrace the benefit of reclaimed water, they would find significant potential exists for this resource among some of the larger non-residential Durham consumers.



There are only two designations of water usage in Durham: a small fraction (.2%) is designated for mine dewatering and the rest, approximately 32.4 MGD, is dedicated as public water supply. The public supply is controlled by the city of Durham and provides water to all residential, commercial, institutional, and industrial customers.[47] Durham is highly residential, and water resources are used primarily to serve the potable and non-potable needs of these communities. Significant water savings

[47] North Carolina Department of Natural Resources: Division of Water Resources. January 30, 2009. http://www.ncwater.org/Water_Withdrawals/ResultsTabJS.php?tab=desc&fip=063

potential lies in offering reclaimed water on a domestic level for non-potable uses, like irrigation and toilet flushing. However, Durham's current water metering method does not readily differentiate between the non-potable and potable uses on the residential level making accurate use calculations more difficult. Conversely, finding this differentiation is much easier for non-residential customers because they often employ discrete metering systems to measure large consumptive processes.[48] This category monopolizes a significant portion of the potable water sold in Durham. Over 15% of all water sold in Durham in 2007 alone was allocated to the top ten non-residential consumers in the city and is only projected to rise.[49] These top customers include organizations such as North Carolina Central University, IBM, Durham County, EPA, and Duke University who rounds out the list controlling over 15% of non-residential use.[50, 51] The public water allotted to these companies and organizations is not strictly for potable use. Many of these organizations employ public water in operational processes like heating and cooling, toilet flushing, and irrigation; all of which can be adequately executed with reclaimed water. Duke University, being one of the city's largest consumers, has significant water reuse potential, but getting reclaimed water to the University's campus requires a look beyond conventional infrastructural processes to a more holistic and integrated approach to water management.

Feasibility of Incorporating Reclaimed water at Duke University

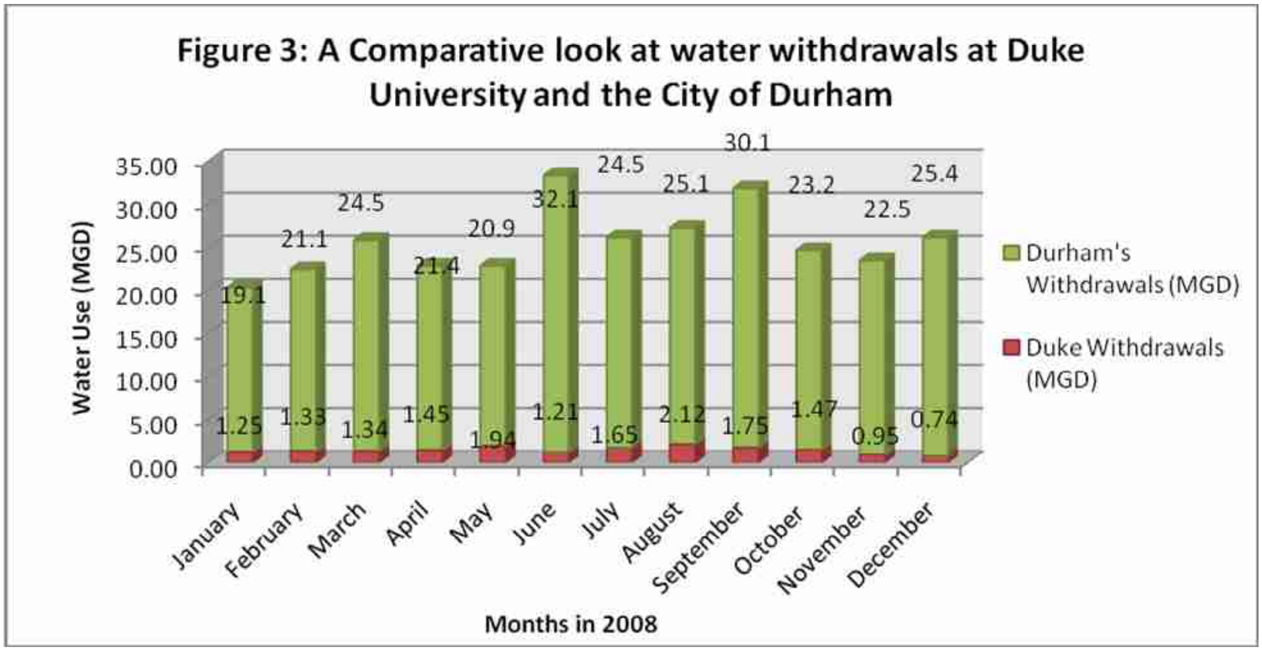
Duke University consumes an average of 6%, approximately 524 million gallons, of the 24 MGD utilized by Durham over the course of 2008 (Figure 3). Duke's allocation supports a multitude of operations across campus including: food preparation, hospital function, dorm services, building needs, irrigation, as well as heating and

[48] Non-residential consumers include commercial, industrial, and institutional users.
[49] Information obtained from a meeting with Vicki Westbrook from Durham Water Management Department, January 23, 2009.
[50] Personal Communication with Vicki Westbrook and the Water Management Department. January 2009
[51] Percentages given in personal communication with Vicki Westbrook from Durham Water Management Department. January 23, 2009.

cooling requirements.[52] About 36% of that total is designated for facility operations of the chiller and steam plant as well as for grounds irrigation. Durham public water currently supplies the input for these systems, even though a lower quality of water would be sufficient for operations. Water for chiller and steam plant operation and for landscape irrigation are being more commonly supplemented with reclaimed water throughout the country and even on other campuses in North Carolina including UNC Chapel Hill. The facilities department at Duke also has recognized the potential of reclaimed water as a supplement for these systems make-up water and have employed to system that provide reuse water in its chiller plant 2 including a condensate reclaim system and a reverse osmosis system. The condensate collection system operates by accumulating condensation from the air conditioning system at Duke's medical center. Water condenses off of the coils and is collected in a basin; the condensate water is then piped back to the central chiller facility, where it is fed back into the cooling process and thus recycled through the closed loop chiller system. The second method is a reverse osmosis system (RO) whichintercepts the dirty process water that would normally be lost to the drain. This system super filters that water by adding pressure to the normal osmosis system causing the water to move from the highly pressurized gradient to the lower non-pressurized gradient and results in a cleaner effluent that can be returned to the cooling system. These reclaim systems have been in operation for almost a year now, and while they are progressive steps for the University, the sparse data collected thus far shows highly variable flow rates. The condensate reclaim system has the most data collected, but statistics show that it only provides anywhere from 3% and 11% of the necessary inflow water. This data also shows that flow varies seasonally, with a higher percent of condensate being reclaimed during summer months when the central air system at the medical center is most active. Data for the RO system only exists for January and February of 2009, and these statistics state that only 4% and 2% reclaim was provided each month

[52] University consumption generated from data presented by the Facility's Management Department at Duke University.

respectively. The low percentage of reclaim and high variability in flow of these systems will not provide the necessary make up to effectively diminish the supply purchased from Durham's system, so alternative reclaimed systems need to be evaluated

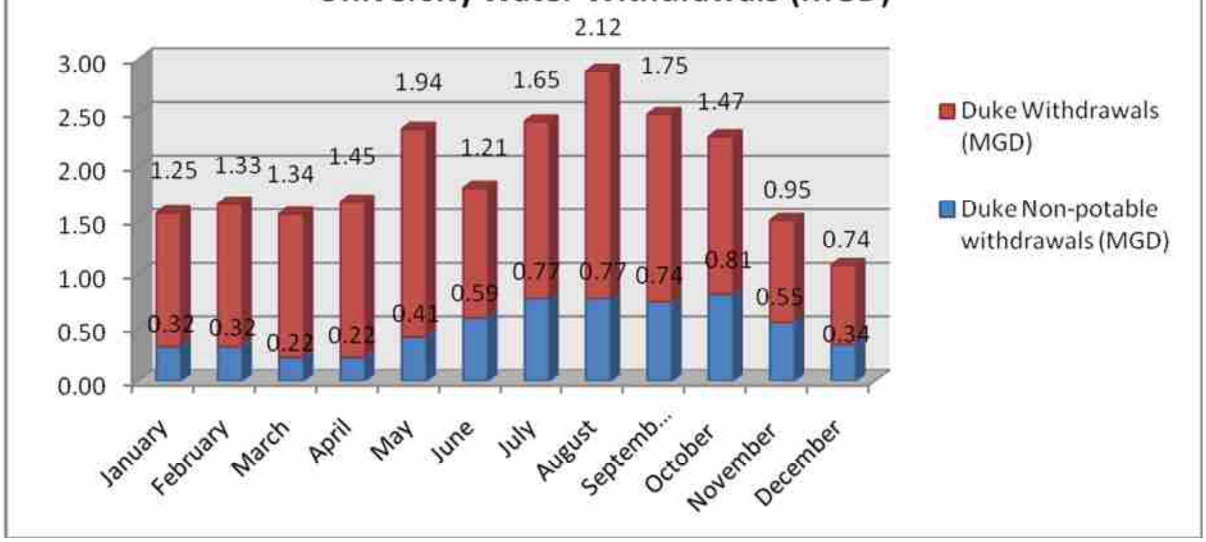


For this study I assessed three reclaimed water system alternatives that could feasibly supply enough reclaimed water to the University to offset dependence on Durham's public water supply. However, given a time constraints, it was necessary to make a few assumptions. I first assumed that the available wastewater effluent would provide adequate influent to the proposed reclamation processes. I also assumed that the effluent produced by reclamation system alternatives two and three will completely offset the potable water Duke University uses for non-potable applications. For instance, in alternative two (direct distribution line from the North Durham Reclamation Facility) the facility is only permitted to produce 80,000 GPD of reclaimed water. In order to provide an adequate supply of non-potable water to the University, the permit would have to be revised to cover the University's reclaimed water needs; so I assumed modification of this permit could be accomplished relatively easy. Current consumption patterns dictate that successful reclamation alternatives would need to supply approximately 900,000 GPD for peak daily flows and approximately 600,000 GPD for average daily flows. The final assumption was to keep current non-potable water consumption constant throughout the 20 year period. Consumption rates are likely to increase with the growth of campus, but demand projections were inconsistent, so it was best to keep consumption rates constant. These alternatives were compared both quantitatively and qualitatively. Financial feasibility was measured by comparing the net present value (NPV) of each system over a project lifespan of 20 years. Twenty years was chosen for the project life as that length of time is a conservatively comparable estimate for a treatment facility given most established conventional regional wastewater systems in the US have existed for at least that long. Beyond this cost analysis, I also outlined other "non-tangible" benefits reclaimed systems offer to both the city of Durham and to the University.

Alternative 1: Continue With Operations as Usual

The first option for Duke University is to continue with operations as usual. For reference, Figure 4 shows the portion of total water Duke University withdraws from the city managed for non-potable use at both chiller plants, the steam plant, and for irrigation based on 2008 data. Projected price per one-hundred cubic feet (ccf) for all incoming water from the city of Durham for fiscal year 2010 is $2.33 which equates to approximately $3.11 per thousand gallons (Tgal). Given consumption rates in calendar year 2008, total cost for water was approximately $562,000 for potable water delivered to the University. The city also charges the University $1.78 per ccf ($2.38/Tgal) for sewer charges which affixes another $25,000 annually. The cost of sewer services, however, was only totaled for the chiller plants because the steam plant's contribution to the sewer system is negligible as most excess water is lost in evaporation, and irrigation runoff generally returns to the system via storm sewers. In this alternative the university would continue to develop the condensate reclaim system and the RO system to provide as much reuse water as possible. Present statistics indicate that both systems combine would provide monthly savings of $600 to $700. There would be no capital costs associated with this scenario as the system is already implemented and established, though the University is still subject to rate increases for public water and sewer services. To calculate the NPV for the option, I predicted how much the University would spend on potable water from the City of Durham given predicted rate increases based on information provided to by Linda Sims from Durham's Department of Water Management. Durham's Water Management group is currently perfecting its future rate indicator model, so the rate increases used to calculate the NPV for this scenario are based abstractly on the rate increases seen by Duke University in 2008. To estimate NPV over twenty years in this scenario, I totaled annual water and sewer costs the University currently paid in 2008 and subject that cost to a 7.3% real rate increase in year one. Year two saw an additional 2.5% rate increase to incorporate inflation, but all subsequent years (3-20) saw no additional rate increases. The NPV of continuing operations as usual over a 20 year time period with a real interest rate of 5.5% (interest rate given to the University for 20 year projects) was about $9.5 million.

Figure 4: Non-Potable Water Use as a Percentage of University Water Withdrawals (MGD)



Alternative 2: Direct Distribution Line from the North Durham Reclamation Facility.

This alternative was briefly discussed in the previous section. The concept of this alternative would be to create a pipeline system that stretches from the North Durham

Reclamation Facility to Duke University. While no formal evaluation was performed to compute the costs of such a system, the city of Durham has assumed expense would outweigh the benefits of this project given the high capital cost of a distribution system and substantial distance between the facility and any viable users. The capital costs for the distribution network were generated using sample capital costs from a reclamation project being implemented by Durham County.[53] To generate my total capital cost calculations, I used the estimates given for an 18 inch pipe and extrapolated that cost over the length of the distribution line (8 miles). More than one pipe size would normally be used in distribution line construction project, but since 18 was the middle piping size and offered the median price, I based piping cost for the distribution line on that figure. Other fixtures and components needed to complete the distribution line were incorporated to round out the capital costs. Combine capital costs of constructing a distribution line extending from the North Durham Reclamation Facility to Duke University would cost approximately $9.8million. This relatively high initial cost is largely attributable to average cost per foot for piping to facilitate a distribution line needed to traverse approximately 8 miles from the reclamation facility to the University. The facility and process to create reclaimed water already exists, so the operation and maintenance costs will be minimal, consisting of $10,800 annually to purchase chemicals for the reclamation process.[54] As mentioned before, John Dodson pays approximately $10,800 annually for the chemical chlorine used in the city's current reclamation system. The North Durham Reclamation Facility would also need to make a few more changes to accommodate an increased demand in reclaimed water including: increase the amount of reclaimed water they are permitted to produce as well as create a larger storage facility to accommodate this increase in production. The NPV for this scenario was calculated by adding the capital costs of the distribution system itself and the minimal operation and maintenance costs the city current pays for chemicals. Annual payments for this scenario were

[53] Cost estimates for Durham County's project were provided to me by Joe Pearce of the County Wastewater Treatment Facility.
[54] Personal Communication with John Dodson of the North Durham Reclamation Facility. March 2009.

determined using Durham's triple A bond rating of 4.68% provided for 20 year capital improvement projects. A 20% contingency factor was also included in the total expense of the project to offset some cost variability that exists in the project planning stage. The NPV for this system was calculated to be approximately $18 million.

Alternative 3: MBR System at Duke University

Scenario three involves placement of a satellite reclaimed water system on Duke's campus that could supply the necessary non-potable water for use in facility operations. A satellite plant, or a scalping plant, is still connected to the regional wastewater treatment facility, but performs the treatment operation on site. The onsite reclaimed system then extracts the useful water and shuttles the concentrated effluent not being reclaimed back to the central plant via the existing sewer line. This connection to the central system prevents the need for on-site solid waste handling and thus decreases the land area needed to house the plant. The influent for this onsite treatment system would originate from campus sewer mains and may include both stormwater and domestic wastewater. There are a number of systems that could be implemented on a campus that are small and compact that treat ranging from 200,000 GPD to .5 MGD, but because Duke would require such a large supply of reclaimed water (.9 MGD peak .6 MGD average) these small systems would be unable to sufficiently manage campus demands. Instead, Duke would need to install a larger system that shares design parameters similar to large regional facilities. However, more advanced technologies are available improve system efficiency and make it more compact to reduce the system's footprint. There are several emerging design technologies that adequately treat and reclaim wastewater, but I have chose to evaluate the Membrane Bioreactor System (MBR) system because of it produces a higher quality effluent that may prevent corrosion of facility's machinery.

As explained above, traditional regional treatment systems employ a tertiary treatment train that involves biological treatment, followed by a clarifying stage, and rounded out by tertiary filtration, like chlorine or UV disinfection. The MBR system is a newer technology that utilizes a multiple membrane system that essentially replaces both the clarifying and tertiary filtration stages of the traditional treatment process and filters the water to superior levels of clarity. The membranes act as a barrier that retains "colloidal and macromolecular materials including bacteria".[55] The first step of this MBR treatment train is able to operate given heightened concentrations of biomass, which ultimately reduces the space requirements for this procedural step in a conventional system. These systems have also been proven to increase nutrient removal, especially where BOD and pathogen elimination are concerned. MBR systems offer more efficient processes which reduce land area requirements, and employing a satellite system eliminates the need for extended aeration basins to treat the solid waste material. That concentrated waste material can instead be pumped back to the central facility via an existing piping network. A satellite facility also offers the opportunity to not-treat wastewater. For instance, if on campus demand for wastewater treatment is low, the sewer system can bypass the satellite plant and convey the wastewater directly to the central facility instead. The University currently has space for such a system, which would theoretically occupy approximately 13,000 square feet. The compact nature of this treatment facility allows for installation of a building enclosure that could match the aesthetic needs of the University as well as mask any unpleasant odor. This system could also significantly reduce if not eliminate completely the University's reliance on Durham's public water supply for non-potable uses in facility operations. By eliminating inflow of potable water from the city for non-potable purposes, the University will see significant reductions in its water bill.

Since peak demand for non-potable water on campus is about .9 MGD, I estimated that the University would need to build at least a 1 MGD on campus treatment facility. Costs for this MBR system were generated much like they were for the direct distribution line described in alternative 2. I acquired the costs for the MBR system alone from Monte Ridenhour, a representative from Croker and Associates

[55] Jefferson B, Laine AL, Stephenson T, Judd SJ. Membrane bioreactors and their role in wastewater reuse. School of Water Science, Cranfield University.

incorporated who had recently completed a 1 MGD MBR facility earlier this year. Additional costs for this system including: concrete for the MBR basins, water pumps to move water to and from the process, the storage facility to house the MBR unit, and the fine screening component for initial particulate removal. The relative costs for each of these other factors were obtained from project material provided to this project as reference from Don Safrit, an engineering consultant at McKim&Creed. Much like the construction costs for the distribution system, I extrapolated the cost for each component based on the reference cost/gal provided in the reference material and applied it to the 1 MGD size system proposed for Duke University. Again, these costs are highly variable in the planning stage, so I included a 20% contingency factor to correct for project cost variability. The capital costs for this 1 MGD satellite MBR system on at Duke University was approximately $5.2 million, while the NPV over a 20 year time frame reached about $13.5 million.

Results and Discussion

When comparing the NPV calculated for each scenario, it is obvious that continuing with operations as usual is the most economically efficient option (as depicted in Table 3). Alternative 1 costs about half as much as either reclamation scenario over the 20 year life span. The major contributing factor to the high differentiation of cost between the first alternative and the last two is the high capital costs of each reclamation project. Alternative 1 is already established necessitating no start up expenses associated with continuing with business as usual. It is important to note, however, that the cost for scenario 1 is highly dependent on future rates attached to Durham's water supply. Representatives from Durham Water Management Department are currently unsure of future rate increases, as they are now working on their rate model, so the scenario I constructed may not be representative of the actual predicted rate increases. For instance, city residents saw a 9.7% increase in 2008, and while city officials hope to create a stable rate increase in future years of 2-3%, rate increases in the next few years are likely to surpass that percentage.[56] The uncertainty of future rate increases and the imprecise nature of capital cost estimation at the planning stage demonstrate that further financial analysis of each of these options will be necessary to get a more definitive comparison. Completion of Durham's rate model and a more accurate prediction of the University's future non-potable water usage could provide a more precise picture of the financial cost for continuing business as usual. Reclamation options may then become more financially competitive if an analysis is conducted with a more clearly defined future water rate scenario. Other qualitative benefits for reclaimed water exist for the University and for the city of Durham beyond what the financial analysis indicates, and should be considered in determining the most suitable reclamation and reuse alternatives .

Table 3: Comparative Costs for Reclaimed Water Alternatives

Costs for Alternatives	
Alternative	**Project Costs over 20 years**
Operations as Usual	• NPV: $9.5 million • 7.3%, 2.5%, then no rate increase. • Rate increase is not definitive • Save $600-$700 a month w/ reclaimed systems
Direct Distribution from NDRF	• NPV: $18million • Assuming Duke is the sole customer, incur all costs • Pay assigned reclaimed water rate
MBR System at Duke University	• NPV: $13.5 million • 5.5% discount rate and 2.5% increase for sewer rates • Adequate influent can completely supplement potable water supply from city for campus operations.

[56] Personal Communication with Linda Simms Business Analyst with Department of Water Management, Durham NC.

Overall Benefits of Reclaimed water to Duke University

Duke University has taken major strides to create an environmentally responsible campus. In 2007 Duke signed the American College & University Presidents Climate Commitment in an agreement with other universities expressing a call to action for reducing greenhouse gas emissions at the college and university level.[57] Duke has taken major strides to increase efficiency in current campus operations and structures and also strives to adhere to building standards reflective of LEED Certification guidelines for all new campus facilities. The University employs a healthy recycling program and is working toward assembling a more environmentally responsible transportation fleet. It is Duke's commitment to water conservation though, that makes establishing a reclaimed water system a practicable opportunity for growth toward a sustainable future.

Beyond any financial savings seen for a reclaimed system, the University will also notice significant social, environmental, and educational benefits from this system. Any type of reclaimed system Duke implements, whether it be a distribution line from the regional plant or an on campus satellite plant, the University will be setting a community standard endorsing reclaimed water as a practicable and valuable resource. The city will clearly see a savings in potable water supply which may prompt other large non-residential institutions and industries to explore the benefits of reclaimed water for their own operations. The University will also see clear environmental benefits associated with this system in terms of water savings and in fulfilling the campus environmental initiative concerning sustainability. If Duke relied completely on reclaimed water for its heating, cooling, and irrigational needs, there would be about a 28% reduction in campus water usage based on statistics from fiscal year 2008 (Figure 5). Peak demand for non-potable reclaimed water would be about .9 MGD, but water demands are expected to increase with projected campus growth rates of 75,000 square feet per year. The growth of Duke's built environment increases

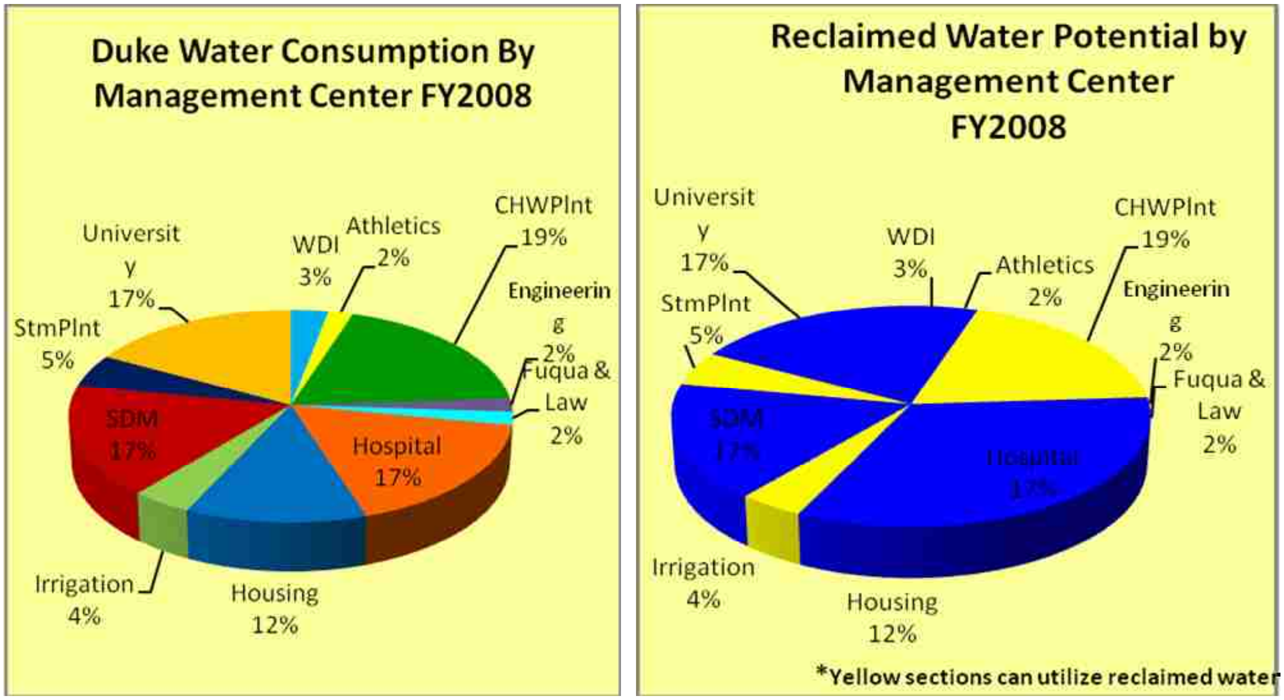
---

[57] Duke Sustainability. Climate Action Plan http://www.duke.edu/sustainability/campus_initiatives/climate_action/index.html March 5, 2009.

demand for operation of the chilled water plants and steam plant, which in turn will increase the need for reclaimed water to run these processes. Water conservation is already a key concern for the University, and discussion about offsetting public water supply especially for the chiller plants and irrigation is already occurring. Reclaimed water would be a good source of this non-potable supply because it offers a sustainable resource for the University's use that flows with relative constancy independent of water restrictions. Wastewater is produced whether North Carolina is in a drought or not, so when potable water resources are limited, the university will be able to continue at normal production rates.

The use of reclaimed water for campus operation can also provide a number of educational benefits for the University. The viability of reclaimed water is only projected to rise in the future, which leaves numerous policy, environmental, engineering, and technological research opportunities. Reuse technology is expensive at present, but will become more economical with continued research and public acceptance. University departments like the Nicholas School and the Pratt school of engineering offer excellent research resources for advancing reuse technology and monitoring the environmental implications of reuse systems. Having reclaimed water as an available resource on campus would also help new structures and building achieve higher levels of LEED certification and thus conform to the President's Climate Commitment. Separate reclaimed water lines for toilet flushing, for ground irrigation, and connecting to a central chiller plant running on reclaimed water are all criteria considered when assigning LEED certifications. These benefits will continue to emerge as more strain is placed on water resources. Universities are learning institutions and as such have the unique opportunity experiment with societal trends. A steady financial inflow provides them the opportunity to experiment with new designs, technologies, and to focus on environmental and social movements that municipalities and other institutions are inhibited from exploring by financial constraints and the need to address other pressing public concerns. Leveraging this position in society can allow the University to positively and persuasively influence future growth and development of the Durham community.

Figure 5: Management sectors that could presently benefit from reclaimed water.



Benefits of establishing Reclaimed water distribution for the city of Durham

Durham's wastewater infrastructure is aging and monthly flows to the system are getting closer to design capacity. Maximum monthly flow to the North Durham Reclamation Facility today is about 68% of the plants 20 MGD design capacity. Expansions for this facility are recommended when max monthly flows reach about 90% of capacity, a level expected to be realized by 2017.[58] The distribution lines of the current system are also 60 years old and are in need of repair and replacement, so investment in system improvements is not far off. This gives the city an opportunity to reinvent its current waste management system and incorporate more opportunity for reclamation and reuse. City investment in a pipeline system stretching from the North Durham Facility to Duke University would provide the trunk of a reclaimed system from which smaller distribution lines could branch for future facilities seeking reclaimed

[58] Durham's Comprehensive Plan. 2006. Chapter 9 Water and Wastewater Element.

water. This central line could provide the convenient connection option that would incentivize other institutions and industries to begin utilizing reclaimed water. This particular line would be especially convenient because some of Durham's other large potable non-residential consumers, like the VA hospital and the Hillandale golf course, are located near Duke and could easily tap into the system. The city would also only bear the expense of the central line; any consumer looking to tap into the system would need to cover the cost of connection. The city could also create a rate system for reclaimed water, which would aid in offsetting the capital cost of the distribution line, in compensating any loss of revenue from the drop in demand for public potable water, and add value to water resources throughout the city of Durham by equating value to all water resources natural and reclaimed.

The establishment of a satellite facility near or at Duke University could also be beneficial to the city, if it is controlled and operated by the city. With the increasing need to upgrade the wastewater treatment facility, creating a more decentralized or a satellite regional system could be a practical alternative to the traditional regional system currently in operation. For example, Brunswick County, North Carolina has gone to a more decentralized system and has incorporated treatment facilities within the four smaller regions of the greater County.[59] Brunswick County covers a large land area, and incorporating these small decentralized systems was more efficient than a conventional regional facility.[60] This structure has allowed the County to best meet the wastewater needs of its citizens. Decentralized or satellite facilities decrease the cost of wastewater transport by reducing the length of the piping system and makes reclaimed water more readily available to customers. Decentralized facilities also reduce the energy needs for wastewater conveyance by reducing the distance wastewater needs to travel, thus energy costs for pumping also decrease. Reclaimed water also preserves potable water supplies, by transferring some of the need for

---

[59] Safrit, Don. Power point presentation on the Preliminary Engineering Report for Brunswi ck County. HDR Incorporated. February 2009

[60] Safrit, Don. Power point presentation on the Preliminary Engineering Report for Brunswick County. HDR Incorporated. February 2009

potable water to the increasing demand for reclaimed water. Theoretically, a well received and pervasive wastewater reclamation system could potentially reduce potable water demand enough to postpone the implementation of expensive and controversial water supply expansion projects, like damming Lake Michie or incorporating raw water flow from Kerr Lake. Increasing the production of reclaimed water also reduces the flow of treated wastewater into Durham waterways like Ellerbee creek. The institution of the new Jordan Lake Rules could also have major implications for wastewater treatment facilities in Durham, as these rules call for aggressive reductions in Nitrogen and Phosphorus loading in North Carolina Waterways. Dedicating more treated wastewater for a reclamation system would not only provide a valuable resource for customers, but would also help wastewater facilities more easily meet effluent nutrient limitations set by the Jordan Lake Rules. Within the next decade the city of Durham is going to incur the cost for: replacing aging wastewater infrastructure, adhering to increased nutrient control requirements, and supplying water to a growing population, so incorporating reclamation and reuse into new infrastructure could be a useful alternative to aid in addressing these emerging concerns.

Part 5: Policy Opportunities for NC

The success of projects like the one at Duke University and other pilot reclaimed water projects across the state could be testament to the prospect of developing state policy regarding reclaimed water. Water demands are expected to increase in North Carolina by 35% (2.2 billion gallons per day) over the next 20 years, so understanding current water allocations will help determine potential consumer segments within the state that could benefit from IWRM strategies and wastewater reuse.[61] 2008 statistics provided by the North Carolina Department of Natural Resources Division of Water Quality (DENR-DWQ) show that combine state ground and surface water supplies totaling 15.4 billion gallons are available for consumption each

---

[61] Polk E, Kleczek L, Olander L, Holman B. 2007. The Future of Water in North Carolina: Strategies for Sustaining Clean and Abundant Water. NC State University. Nicholas Institute.

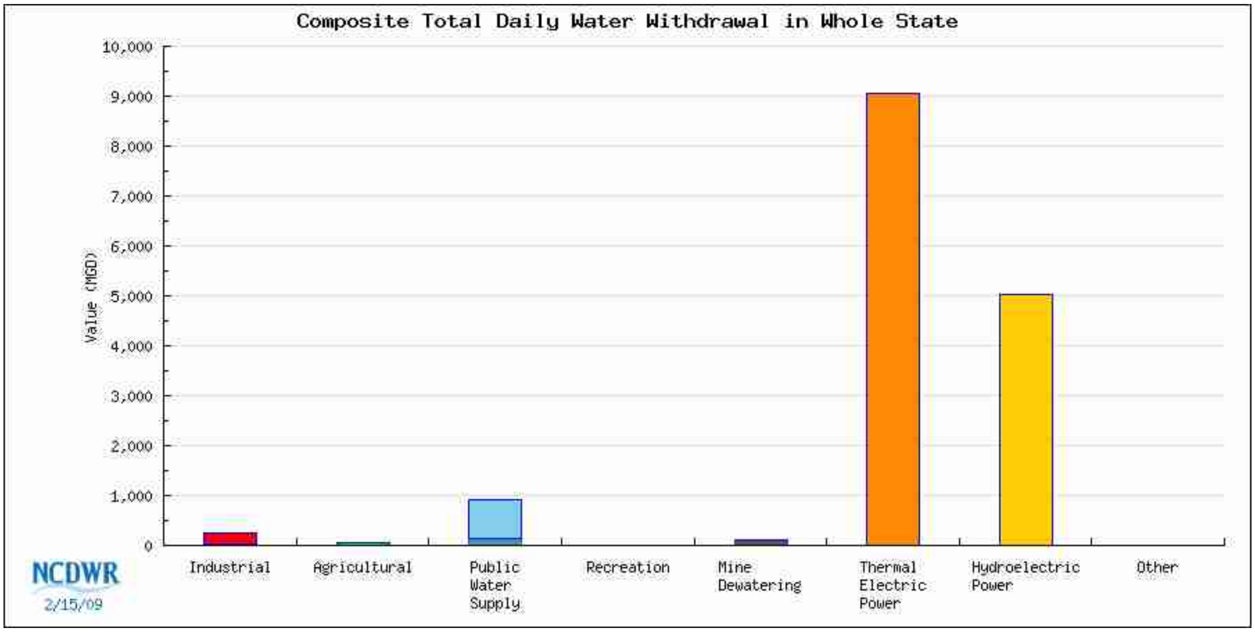
day.[62] This amount would translate into a significant and seemingly infinite source of water for North Carolina's eight billion residents. This is especially true considering some statistics indicate yearly water requirements of approximately 528,000 gallons of water/person/year are needed to provide "adequate living standards in western and industrialized countries".[63] This number quickly diminishes, however, as freshwater supplies are stretched across all North Carolina consumer sectors, as is indicated in Figure 6.[64] For instance, the three largest consumers of water resources in NC, thermoelectric power generators[65], hydroelectric power generators[66], and public supply users, utilize 99% of the available resource leaving little more than 140 million gallons/day available across the remaining market segments (refer to figure 6).[67] Public use is the third largest consumer segment in the state of North Carolina, and utilizes 5.9% of all available resources, but this category is not specified for domestic use only. Instead, "Public supply" includes any water withdrawn from public water systems for customers including: residential, commercial, institutional, and industrial; which means that only a fraction of the 5.9% freshwater allocation is dedicated to human consumption and use.[68,69] It is important to understand the significance of these consumption patterns because only then does it become evident that the majority of available freshwater is tied up in industrial processing, manufacturing, and power generation. All of these processes are utilizing potable water to run processes that would continue to run efficiently with non-potable water, yet it is primarily the general public that is being required to conserve and change their consumption habits, while large users remain unregulated. Responsible consumption and natural resource

---

[62] NC DENR-DWQ: data tab http://www.ncwater.org/Water_Withdrawals/ResultsTabJS.php?tab=graph
[63] Bouwer. 1998. Original conversion was in m3. Integrated Water Management: Emerging issues and Challenges
[64] NC Department of Natural Resources: Division of Water Quality http://www.ncwater.org/Water_Withdrawals/ResultsTabJS.php?tab=graph
[65] **Thermoelectric power:** includes withdrawals used for cooling in thermoelectric power plants
[66] **Hydroelectric power:** Includes water that id diverted from a stream and conveyed to a hydroelectric generation facility. It does not include water that flows through a hydroelectric facility that is located directly on a stream channel.
[67] http://www.ncwater.org/Water_Withdrawals/ResultsTabJS.php?tab=graph
[68] http://www.ncwater.org/Water_Withdrawals/ResultsTabJS.php?tab=graph
[69] Percentage derived from statistics provided by NC DENR.

conservation are important on the household level, and North Carolina, collectively, has made this a priority leading to a significant reduction in domestic consumption rates. A more definitive approach for preserving future water supplies in NC, however, lies with supplementing the potable water allocation of larger consumer segments like power generation, manufacturing, irrigation, and educational institutions with reclaimed water resources where possible.

Figure 6: Total Water withdrawals for the state of North Carolina by consumer sector.[70]



Pilot programs across the state have implemented reclamation and reuse systems in many different capacities. Institutions like UNC Chapel Hill and UNC Wilmington have begun discussions and are in the preliminary stages of constructing these systems at or to their respective institutions. Municipalities like Cary have incorporated reclamation and reuse systems into their water management plans, and areas like Brunswick County are seriously considering offering reclamation and reuse as a major service to its communities. There is also legitimate potential for reuse in the energy production sector. Figure 6 shows that approximately 98% of all potable water used in the state is monopolized by the energy production sectors. Most of this water is

70 Chart provided by North Carolina Division of Water Res ources. Summarized Reported Daily Water Withdrawals by State. http://www.ncwater.org/Water_Withdrawals/ResultsTabJS.php?tab=graph

used for non-potable purposes, and does not even require that the water quality be highly pure. The use of reclaimed water for use as make-up in these operations would help preserve valuable ground and surface water supplies for direct use. Decreases in human demand of this resource would reduce surface water withdrawals, which would essentially help protect the health of valuable aquatic ecosystems. The new federal administration has offered funding to encourage wastewater reclamation and reuse projects across the country, and the state of North Carolina should take advantage of this resource. North Carolina has enacted rules to promote conservation throughout the state on a domestic level, but has neglected to address the consumptive habits of large industrial and institutional users that monopolize the majority of the state's water supply. Conservation opportunities lie in those sectors and the state should take decisive action to address their consumption, so legislation encouraging the use of reclaimed water at large institutions and industries could definitively promote water conservation across the state, and may result in significant reductions in potable water usage.

Part 6: Conclusion

While the financial feasibility of incorporating a full reclaimed water system may still be more expensive than traditional potable water use at this time, other non-tangible benefits accompany a well planned and efficient reclamation and reuse system. The City of Durham and Duke University could see many benefits from the use of reclaimed water including: significant reductions in potable water consumption, creation of a more environmentally responsible sustainable community, and could possibly delay costly water supply expansion projects in the region. Many areas across the state of North Carolina beyond Duke University and the City of Durham are having difficulty maintaining a healthy water supply given nutrient loading caps imposed by the state and persistent drought conditions. These areas are also experiencing water problems unique to their own communities and cannot necessarily be fixed with a prescriptive solution created by the General Assembly. I do, however, believe that integrated water resource management with the incorporation of reclaimed water is a step in the right direction to help solve state water problems. Reclaimed water is a water resource that can be used beneficially in many applications. Wastewater is produced every day, it can be easily purified to functional levels and can help preserve our potable water resources for critical uses like for human consumption and maintain the health of our natural ecosystems.

Appendix: Computations for Duke University

Total Cost for Water in Facility Operations			Water Consumed in Facility Operations	
	Water	Sewer	Consumed (Gallons)	Lost to Drain (Gallons)
Chiller Plant 1	$148,524.07	$2,399.36	47,684,000	1,008,340
Chiller Plant 2	$288,234.39	$22,455.47	92,538,324	9,437,000
Steam Plant	$104,964.87		31,398,583	0
Irrigation	$140,903.00		45,237,237	0
Total	**$682,626.33**	**$24,854.83**	**216,858,144**	**10,445,340**

Flow Rates		
	Average Daily Flow	Max Daily Flow
Chiller Plant 1	156,359	250,516
Chiller Plant 2	252,763	396,213
Steam Plant	92,447	111,004
Irrigation	17,498	53,401
Total	**519,066**	**811,134**

Steam Plant			
	Water		
Month	Gallons	**Price/Month**	ccf
January	2,807,289	**$8,744.02**	3,753
February	3,074,119	**$9,575.14**	4,110
March	3,299,134	**$10,276.00**	4,410
April	2,677,203	**$8,338.84**	3,579
May	2,770,784	**$8,630.32**	3,704
June	2,319,859	**$7,225.80**	3,101
July	3,441,114	**$10,718.23**	4,600
August	2,937,226	**$9,148.75**	3,927
September	2,973,207	**$9,260.82**	3,975
October	2,218,049	**$6,908.68**	2,965
November	2,880,598	**$8,972.36**	3,851
December	2,300,634	**$7,165.92**	3,076
Total	31,398,583	**$104,964.87**	

Irrigation			
	Water		
Month	Gallons	**Price/Month**	ccf
January	1,151,801	**$3,587.58**	1,540
February	399,861	**$1,245.47**	535
March	992,170	**$3,090.37**	1,326
April	6,433,493	**$20,038.77**	8,600
May	4,823,969	**$15,025.49**	6,449
June	6,887,610	**$21,453.23**	9,207
July	4,049,404	**$12,612.91**	5,413
August	6,224,800	**$19,388.74**	8,321
September	5,763,012	**$17,950.38**	7,704
October	4,166,177	**$12,976.63**	5,569
November	3,000,908	**$9,347.10**	4,012
December	1,344,033	**$4,186.33**	1,797
Total	45,237,237	**$140,903.00**	

Chiller Plant 1						
	Water			Sewer		
Month	Gallons	**cost/Month**	ccf	Gallons	**Cost/Month**	ccf
January	2,053,000	**$6,394.60**	2,744	75,000	**$178.46**	100
February	2,040,000	**$6,354.10**	2,727	74,900	**$178.23**	100
March	0	**$0.00**	0	0	**$0.00**	0
April	0	**$0.00**	0	0	**$0.00**	0
May	3,915,000	**$12,194.27**	5,234	37,990	**$90.40**	51
June	7,370,000	**$22,955.76**	9,852	71,610	**$170.40**	96
July	7,766,000	**$24,189.20**	10,382	80,700	**$192.03**	108
August	7,685,000	**$23,936.91**	10,273	81,360	**$193.60**	109
September	7,053,000	**$21,968.38**	9,428	13,020	**$30.98**	17
October	5,077,000	**$15,813.62**	6,787	252,760	**$601.45**	338
November	2,636,000	**$8,210.50**	3,524	252,300	**$600.35**	337
December	2,089,000	**$6,506.73**	2,793	68,700	**$163.47**	92
Total	47,684,000	**$148,524.07**		1,008,340	**$2,399.36**	

Chiller Plant 2						
	Water			Sewer		
Month	Gallons	**Price/Month**	ccf	Gallons	**Price/Month**	ccf
January	3,407,140	**$10,612.41**	45,546,837	440,000	**$1,046.99**	588
February	3,965,148	**$12,350.47**	53,006,319	343,000	**$816.17**	459
March	5,957,000	**$18,554.61**	79,633,507	564,000	**$1,342.05**	754
April	7,800,000	**$24,295.10**	104,270,833	495,000	**$1,177.86**	662
May	11,134,000	**$34,679.70**	148,839,931	698,000	**$1,660.90**	933
June	12,282,608	**$38,257.34**	164,194,586	1,187,000	**$2,824.48**	1,587
July	10,810,096	**$33,670.82**	144,509,964	1,219,000	**$2,900.63**	1,630
August	10,887,888	**$33,913.12**	145,549,892	1,382,000	**$3,288.49**	1,847
September	10,182,524	**$31,716.09**	136,120,547	1,308,000	**$3,112.40**	1,749
October	7,495,708	**$23,347.31**	100,203,041	893,000	**$2,124.91**	1,194
November	4,905,384	**$15,279.08**	65,575,446	537,000	**$1,277.80**	718
December	3,710,828	**$11,558.33**	49,606,555	371,000	**$882.80**	496
Total	92,538,324	**$288,234.39**		9,437,000	**$22,455.47**	

Chiller Plant 2: Reclaim			
Condensate Reclaim	**Price Saved/Month**	Blowdown	**Price Saved/Month**
Gallons		Gallons	
144,533	**$343.92**	152,800	**$363.59**
162,850	**$387.50**	114,387	**$272.19**
n/a	**n/a**	n/a	n/a
n/a	**n/a**	n/a	n/a
n/a	**n/a**	n/a	n/a
n/a	**n/a**	n/a	n/a
n/a	**n/a**	n/a	n/a
1,118,157	**$2,660.67**	n/a	n/a
1,132,259	**$2,694.23**	n/a	n/a
412,377	**$981.26**	n/a	n/a
155,939	**$371.06**	n/a	n/a
243,860	**$580.27**	n/a	n/a
3,062,592	**$8,018.90**	267,187	**$635.78**

Net Present Values for Each Alternative	
Interest Rate: 5.5%	Time period: 20 Years
Alternatives	**NPV**
NPV for Operations as Usual	**$9,462,575**
Direct Distribution Line	**$18,074,525**
MBR System	**$13,510,006**