The Water Energy-Nexus in the Southeastern United States

A Baseline Assessment of Regional Reliability and Documentation of Abatement Solutions



By:

Jack Besse

Michael Brendlinger

Matthew Cook

Elizabeth Kelley

ADVISOR: MR1
PROJECT NUMBER: 1207
DIVISION NUMBER: 42

The Water Energy-Nexus in the Southeastern United States

A Baseline Assessment of Regional Reliability and Documentation of Abatement Solutions

An Interactive Qualifying Project submitted to the faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the
Degree of Bachelor of Science

Sponsoring Agency: Department of Energy- Office of Policy and International Affairs

Submitted to
Dr. Diana Bauer and Dr. Jennifer Li: Department of Energy
Prof. Marsha Rolle and Prof. Creighton Peet: Worcester Polytechnic Institute

Submitted by

Jack Besse
_____

Michael Brendlinger
_____

Matthew Cook
_____

Elizabeth Kelley
_____

Date: December 14th, 2012

DISCLAIMER

Abstract

Increasing energy demand and unreliable water supplies due to drought threaten thermoelectric power generation, which required large amounts of water for cooling, in the Southeastern U.S. Our IQP addressed this issue by gathering data on power plants in the region, as well as interviewing plant experts, meeting with DOE water-energy experts, and reviewing water-energy reports to gain a broad perspective of the issues and potential solutions to the problem in order to provide recommendations to mitigate the problem.

Acknowledgements

This project was a team effort, but it would not have been possible without the support and guidance from many people and organizations. First, we would like to extend our utmost gratitude to our Department of Energy liaisons, Diana Bauer and Jennifer Li. Diana and Jennifer were willing to offer their advice and resources, and time to help further our knowledge on our subject and ultimately to complete our project. We would like to thank the Department of Energy for making us feel welcome and comfortable, and specifically to Brandon Knight who was our mentor and friend along the way. We also extend our deepest gratitude to Kevin Easley, who orchestrated our site visit to the North Anna Nuclear Generating Station, which was in invaluable educational experience that we will never forget. We would also like to thank all of the DOE offices that took the time to meet with us and share their knowledge on the water-energy nexus. To the many other individuals at the Department of Energy who took the time to talk to us and helped us with our project, we are exceptionally thankful. Finally, we would like to thank our WPI faculty advisors, Professors Marsha Rolle and Creighton Peet, who joined us in Washington, D.C. They offered feedback, direction and support throughout our project experience and without them we would not have had such an invaluable IQP experience.

Authorship

Although our whole group contributed to the writing of this report, writing was generally done by one or two people at a time, and many revisions were done to each section by all group members. The primary author or authors of each section are outlined below:

Table of Contents

Table of Figures

Table of Tables

Index of Abbreviations

DOE- Department of Energy

PI-Office of Policy of International Affairs

EIA-Energy Information Administration

OS-Office of Science

OE-Office of Electricity

NETL-National Energy Technology Laboratories

ARPA-E-Advanced Research Projects Association-Energy

NREL-National Renewable Energy Laboratory

EPA-Environmental Protection Agency

USGS-United States Geological Survey

NOAA-National Oceanic and Atmospheric Administration

SERC-Southeastern Reliability Corporation

TPP-Thermoelectric Power Plant

CWA-Clean Water Act

VACAR-Virginia-Carolinas

NPDES- National Pollutant Discharge Elimination System

OF-Once-through Cooling, Freshwater

OS-Once-through Cooling, Saline water

RF-Recirculating Cooling, Forced Draft Tower

RI-Recirculating Cooling, Induced Draft Tower

RN-Recirculating Cooling, Natural Draft Tower

RC-Recirculating Cooling, Cooling Pond

MWH-Megawatt Hour(s)

MGD-Million Gallons per Day

IQP-Interactive Qualifying Project

WPI-Worcester Polytechnic Institute

Executive Summary

Water shortages are becoming more prevalent in the southeastern United States. Climate change is increasing the risk of severe weather patterns such as droughts, making this a consistent threat for the future. In the southeastern U.S., above average population growth in recent decades has created the need for increased electricity production and capacity, as well as corresponding increases in water use. Although electricity is essential for today's society to function properly, providing a stable supply has been a challenge at times. Power generation uses massive amounts of water for cooling and steam generation; In the United States, 49% of all water withdrawals are for electricity generation. During times of drought, precipitation levels fall and water levels of surface water bodies begin to fall. This presents a massive threat to power generation; if water levels fall too low, some power plants may be forced to shut down, potentially creating energy production reliability problems.

The purpose of our project was to analyze the current state of the water-energy relationship in the Southeast and identify ways to improve the reliability of electricity in the region by determining ways to manage water more sustainably. We analyzed data available to us through the Energy Information Administration by creating visual representations of the data using computer tools such as Microsoft Excel. This allowed us to see any noteworthy trends or outlying data points. To gain a further understanding of vulnerability at a power plant level, we conducted interviews with plant operators and plant managers. We also had meetings with experts from various offices within the DOE and the Advanced Research Projects Administration. These meetings gave us different perspectives on the problem and provided information on different aspects of

the problem. We also used archival research on previous water-energy studies as a reference for the data we found, as well as to inform us about the work that is being done on the issue today. Using information gathered from these sources we assessed the water efficiency of 25 power plants in the Southeast, the vulnerability of certain plants to drought, and the technology options available to meet growing energy and water demand and decreasing water availability.

Through our research and analysis, we came across several key findings that led us to our conclusions. First, a study by the SERC Reliability Corporation reported that electricity generation in the Southeast was not threatened as a whole even in a severe drought scenario. Our data show that there is significant capacity in the system that could be called upon if a plant were to close down due to water shortage. Despite the overall positive regional situation it became clear that individual plants are still vulnerable to drought.

We found that manmade lakes were more at risk than natural water bodies in drought periods because these water bodies are often fed by a single river or stream rather than multiple streams and natural aquifers, which makes them more dependent on rainfall. The dams that support these reservoirs are also required to release a minimum volume of water per second for downstream uses. Therefore the water levels are more prone to rapid and significant water height fluctuation and power plants with intakes on these water bodies are more vulnerable to drought.

Another significant finding was that water use varies seasonally. Our data show a direct correlation between increased intake water temperatures and increased water usage per unit of electricity generation. When this finding is added to the fact that (46%)

of power plants still use once-through cooling systems, which require on average around 40,000 gallons of water to generate one megawatt hour of electricity, it is clear that they are vulnerable to water shortages and water temperature spikes. Recirculating systems withdraw on the order of 100 times less water, but consume 80-100% of the water they withdraw, meaning it is lost from the water body into the air. This leads to the slow depletion of water resources in drought periods. Water demand is increasing on an annual basis due to a rapidly growing regional population, which grew 11% from 2000 to 2010, much higher than the national average. Over stressed water resources increases the likelihood of this essential resource being depleted in times of reduced precipitation.

Knowing that there were cooling reliability risks to individual plants, we looked for ways to minimize the problems related to these risks both short-term to keep the plant operating, and long-term to prevent any future problems. We found that short-term plans include methods such as blocking off part of the river with sand bags or using floating pumps, which can help keep the cooling system running if the water levels significantly decrease. For the long term, however, there are many new alternatives to traditional cooling operations. We found many different cooling tower technologies that can significantly reduce water use, meaning they should be able to operate at high capacity in drought situations. We also found that there are alternative sources of water that can reduce the demand on freshwater bodies, such as mine pool water and treated municipal waste water.

Based on information gathered from our analysis, we were able to conclude that overall electricity reliability in the Southeast is not at risk, at least in the near term.

However, on an individual plant level, certain facilities have been at risk in times of drought, and there are many risk factors that may lead to cooling problems in the future. Because of this, we recommend that power plants develop short-term contingency plans in the event of a drought rather than allowing the plant to shut down. We concluded that there is technology available that reduces water use, and increases plant reliability in drought situations. We recommend that plants with a history of drought related problems shift towards these technologies. Recirculating systems are a step in the right direction, but there are more advanced, more water conservative technologies available. We also found that the industry has yet to adopt some of the more advanced technology because of the associated cost benefit risks. We therefore recommend that the DOE push investments in water conserving cooling technologies in order to make it financially reasonable for plants to invest in the new technologies. Finally, we can conclude that the EIA data are not consistent from year to year, making it hard to identify trends over time. We recommend that the EIA both standardize its forms, and standardize the questionnaires sent to power plants annually to allow the plants to provide more consistently accurate information. Our efforts contributed to the start of a long process of balancing the water and energy resources in the Southeast.

1. Introduction

Water shortages are becoming more frequent in the U.S. due to climate change and growing water demand (EPA, 2012e). At the same time, the nation's energy demand is rising, forcing power plants to generate electricity in large quantities (EIA, 2012a). Today, the vast majority of the nation's energy production comes from burning fossil fuels and nuclear fission. The cooling systems associated with these types of energy production require large amounts of water to drive the process. Cooling these thermoelectric power plants (TTPs) accounts for 49% of all water withdrawals in the United States (USGS, 2009). This growing need for water in the power industry is negatively affecting the natural and human environment by placing stress on watersheds that are used for many other purposes.

While energy demand has continued to rise, the water resources required to produce the energy have become less reliable (USGS, 2009). Ideally, the water levels of the sources utilized for power generation and other industries would remain high and stable so that a lack of water would not cause problems. Recently, however, uncharacteristic droughts have made water availability in the southeastern U.S. unreliable (Flatow & Peterson, 2012). Additionally, population growth in this region has increased water consumption and placed a strain on water availability (Vörösmarty, et al., 2000). With an increased likelihood of droughts, higher water temperatures, and a rising overall water demand in the Southeast, there are potential scenarios where there may not be enough cooling water available to keep the TPPs in operation. There are also environmental concerns because some cooling systems (e.g., once-through cooling)

withdraw water, then release it back into the environment at an elevated temperature. Elevated water temperatures can potentially cause algal blooms and lower the dissolved oxygen content of the water, killing fish and other aquatic species. Alternative energy sources and better cooling system technologies may be able to reduce water demand for electricity generation purposes, but thermoelectric power generation is still the primary source of energy in the U.S.; therefore, billions of gallons of cooling water will continue to be needed for the foreseeable future.

As noted by the World Nuclear Association (2011), certain cooling system designs are better at conserving water but have a greater impact on the environment, whereas other cooling systems that consume greater amounts of water are more environmentally friendly. Previous research has identified the water requirements associated with different cooling systems and types of thermoelectric power plants currently in use, as well as the high costs of building these cooling systems (Carney, 2012). Furthermore, previous studies from across the world, such as those conducted by Guseva (2000) and Henry (2006), have shown that cooling water discharge into the surrounding environment may have both beneficial and harmful effects.

While there have been many studies on the specific effects from a single power plant's cooling water systems (Guseva, 2000; Henry, 2006), the broader scope of the problem throughout the southeastern region of the U.S. is relatively unknown. It is difficult to create an informed policy for managing the energy-water connections in the region without an overall perspective on the current situation. An analysis on a plant by plant basis and comparison of the cooling operations will provide a better perspective. With all of the impacts of cooling water use along with the potential threat of droughts

associated with climate change, the DOE has recognized this as a legitimate concern for the energy industry.

The goal of our project was to inform the DOE's Office of Policy and International Affairs (PI) on the state of water and energy resources in the southeastern states of Virginia, North Carolina, South Carolina, and Georgia. We accomplished this by gathering technical and environmental data on twenty five power plants and their cooling systems. We also analyzed vulnerability to droughts, along with existing and proposed EPA regulations regarding cooling systems. We talked to experts with a broad range of focuses and viewpoints on the water-energy situation. After analyzing all of this information, we provided the DOE with our understanding of the water-energy situation in the southeastern United States along with recommendations on what further work can be done to assess and address the water-energy issues in the region.

2. Background

The massive use of water for cooling thermoelectric power plants is a global concern. It is necessary to look at the relationship between electricity generation and cooling water on both a regional and plant level. In this chapter we have provided the necessary background information needed to understand the context and research for our project. Sections on power plants, cooling systems, climate, energy demand, and regulations have been included.

2.1. Energy Demand and Rising Population

Over the past 10 years we have seen a steady increase in energy demand in the Southeast (U.S. EIA, 2012a). The main factors that attribute to the rising need for energy is population increase and a greater societal dependence on technology. The national population has increased nearly 10% from 2000 to 2010 (U.S. EIA, 2010). The population increase coupled with constant growth in technology use has caused the demand to rise accordingly. The major concern is operations during peak hours and months of the year (DOE, 2012b). The cooling of homes is important during the hot summer months, especially in the southeastern United States, where air conditioners consume a large percentage of the area's electricity and are mainly responsible for peaks in summer demand (U.S. EIA, 2012c). As populations increase, there will be increasing energy demand to heat and cool the growing number of homes.

2.2. Thermoelectric Power Plants

The most common fuel sources for thermoelectric power plants are coal, natural gas, and nuclear (EIA, 2012a). Coal is burned in a furnace, natural gas is burned in a combustion engine, while nuclear materials are consumed in a chain nuclear fission

reaction. Regardless of fuel source, the thermoelectric plant operations require massive amounts of cooling water to keep the processes operating.

2.2.1. Operation by Fuel Source

Coal has been the primary source of energy in America for over 100 years (EIA, 2012d). Currently, coal-fired plants generate 42% of the nation's energy because its domestic abundance makes it cheap and dependable. In the Southeast coal is the primary energy source for Georgia and North Carolina. Coal power plants work by creating a steam cycle (NETL, 2011). The heat from the coal vaporizes water in a boiler, where the water flows through pipes and is heated to the point of vaporization under pressure. This pressurized steam flows through a steam turbine which creates the rotational energy that spins the generator. The steam is then condensed and reused continuously. In recent years there has been construction of fewer coal power plants due to increased coal taxes and cheaper alternatives, such as natural gas.

Natural gas Power Plants have become more common in recent years due to both natural gas' greater availability and lesser environmental impact. With advances in hydraulic fracturing in the United States, there has been a significant drop in domestic natural gas prices, increasing its appeal as a fuel source (Roston, E., 2012). According to the U.S. Energy Information Administration (2012b), natural gas facilities now generate 25% of America's electricity, but this percentage has increased rapidly over the last 10 years. Natural gas electricity generation rose 47% between 2002 and 2011, despite energy demand only rising 6%. Natural gas plants mainly provide extra power at peak demand times because these facilities are easy to start and stop. Operations can easily be adjusted according to demand.

Nuclear power was developed 50 years ago and is an emissions free power source (Nuclear Energy Institute, 2012). Nuclear energy is produced by the fission of unstable atoms of Uranium, releasing large amounts of energy. Nuclear energy accounts for around 20% of U.S. power generation (US Energy information Administration, 2012b). This percentage has remained relatively stable for many years due to the lack of construction of new nuclear plants and increasing plant efficiency that has matched slowly increasing energy demand (U.S. Nuclear Regulatory Commission, 2012). Of the region addressed in this report, South Carolina and Virginia use nuclear power as their primary energy source (EIA, 2012d).

Nuclear plants work very similarly to coal fired plants with the exception that the water has to flow through a secondary fluid to transfer the heat to the working water (Nuclear Energy Institute, 2012). Because the cooling water cannot come in contact with the nuclear materials due to the risk of transmitting radioactive material, the nuclear material heats a body of water, which is at extreme pressure to prevent boiling. This water is raised to extreme temperature, and this pool of water heats the working water that runs through the turbine and heat exchanger.

2.2.2. Cooling Systems

Large amounts of water are needed to cool down the steam that is used to power the plant's turbines. The primary types of cooling systems in are once-through and recirculating. Both once-through and recirculating systems require additional cooling water to be withdrawn.

Once-through cooling systems operate by pumping water from a large water body such as a river, lake, ocean, reservoir, or groundwater source to a condenser

(World Nuclear Association, 2011). The water is run through a heat exchanger to remove heat from the steam and sent back into the water body at an elevated temperature. These systems withdraw large amounts of water, but consume little to no water in the process. Open loop systems are cheap to install and operate because operating cost is limited to pumping the water through the system, which is fairly small when compared to the alternatives.

A recirculating system reuses much of the same water after it has been cooled down, as opposed to dumping the warm water back into the water body. The evaporative systems work by running air past the water, and evaporating a portion of it to remove heat. The water lost to evaporation is consumed water, which means the cooling towers have to withdraw additional water to make up for this loss of water in the cooling system.

One type of recirculating system is the natural draft cooling tower. These towers take advantage of the natural air flow created by the temperature differential in a large hyperbolic tower, as shown in Figure 2.1. The air flows in through the open bottom section of the tower, and the natural updraft evaporates and cools the water. The large benefit of the natural draft tower is that it takes very little energy to operate because it has very few moving parts (Carney, 2011b). The routine maintenance done on this type of tower consists of the replacement of plastic spray heads and examination and repairs of the pumps. These types of maintenance are inexpensive which makes the operating costs low. However, natural draft towers require a huge capital investment in order to construct them because of their enormous size (Hensley, J. C., 2009).

Figure 2.1: Natural Draft Cooling Tower (Britton, I, 2002)

Another type of recirculating cooling system is the mechanical draft cooling tower. These towers are significantly smaller than the natural draft tower, but require a fan to create the airflow necessary to evaporate water (Carney, 2011b). Mechanical draft towers are much smaller than natural draft, and therefore have a much lower initial capital investment. These types of towers have a constant power requirement for the fan, which means the plant's net electricity production is lower. The maintenance costs for the fan are expensive because of the need to replace gearboxes, fan blades, motors, etc. These systems come in two forms, induced and forced draft towers.

Induced draft towers have a fan at the top of the tower, causing air to rise up through the tower. A forced draft tower has a fan at the base of the tower, and blows the air in through the bottom of the tower. Both systems require similar amounts of energy and achieve similar levels of cooling.

2.3. Water Ecosystems and the Affects of Power Plants

Thermoelectric power plant (TPP) cooling systems have large effects on the water ecosystems they rely on. Intake water generally contains large quantities of biomass, of which large percentages are killed from various cooling system factors (Henry, 2006). Discharge water contains a high amount of unnatural heat and potentially elevated nutrient levels. This leads to increased biological activity in the surrounding waters of the discharge zone, which can be beneficial but also harmful.

2.3.1. Water Intake for Power Plants

The cooling systems themselves kill large numbers of aquatic organisms. These organisms include algal species, phytoplankton, zooplankton, fish species, coral, sea grass, and periphyton (Guseva & Chebotina, 2000). When organisms get sucked into the intake pipes and pass through the cooling system, it is referred to as entrainment. On average around 50% of biomass passing through the system is killed. The largest influencing factor is the addition of biocides (typically chlorine) to the cooling water to reduce the formation of biofilms on pipe walls. Sharp temperature increases, as well as mechanical shearing stress are also responsible for the destruction of biomass.

Organisms can also get trapped on the intake screens that are design to keep solid objects from entering the cooling system. Often, the water is pumped into the cooling system at a high rate. The rate can be so high that some fish and other aquatic

organisms cannot swim away and are killed against the screens. This is referred to as impingement.

To address the problems of impingement and entrainment, the EPA (2012c) has proposed legislation to regulate the water intake systems of all power plants. The EPA Clean Water Act section 316(b) requires; "*that the location, design, construction and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impact*" (para. 1). This rule is designed to protect aquatic ecosystems from fish kill due to impingement and entrainment.

CWA 316(b) was written in three phases. The phase I rule applies to new facilities, the phase II rule applies to large existing facilities, and the phase III rule applies to certain existing facilities and new offshore and coastal oil and gas extraction facilities. For our project, the focus was on the phase II rule that applies to existing facilities.

The 316(b) rule applies to all existing steam-generation facilities that meet a given set of criteria. Plants that meet the criteria are referred to as in-scope facilities. In-scope facilities must first have a point source that uses, or proposes to use a cooling water intake structure (EPA, 2012c). They must have at least one cooling water intake structure that uses at least 25% of the water it withdraws for cooling purposes. They must also have a national pollutant discharge elimination system (NPDES) permit or are required to get one. Additionally they must have a design intake flow of at least 2 million gallons per day (MGD). Of these criteria, the intake flow of 2 MGD is the main factor concerning power plants.

The proposed phase II rule has three different implementation options. Option 1 requires all facilities withdrawing more than 2 MGD to install impingement controls to

reduce impingement kills by 80-95%. This can be accomplished either by the installation of advanced fish nets and return systems, or reducing intake flow speeds to 0.5 feet per second or less (EPA, 2012c). Option 2 includes the requirements of option 1 and additionally requires that all facilities withdrawing more than 125 MGD reduce the number of organisms withdrawn into the cooling system by 60-90%, depending on location, the amount of water withdrawn, and energy generation. They can do this by either installing a recirculating cooling system, or installing technology that achieves reductions equivalent to recirculating cooling system. Option 3 includes the requirements of option 1 and the same requirements of option 2, but for facilities that withdraw more than 50 MGD.

Intake systems are also the most likely places where drought related issues will occur first. When water levels drop too close to intake points, intake pumps are faced with the issue of hydrodynamic cavitation. Hydrodynamic cavitation is the process of vaporization in a flowing liquid that results from a decrease in pressure. Vapor bubbles occur when the pressure gets below the saturated vapor pressure (McNally Institute, n.d.). All pumps have a required pressure at the suction end of the pump that is the limit before pumps experience suction cavitation. This requirement is set by the manufacturer of the pumps. If the pressure is too low, possibly due to low water levels, then as water passes through the low/high pressure gradient created by the pump it will turn into vapor at the eye of the pump impeller. The vapor will continue through the system until it reaches the other side of the pump where it no longer experiences the differential. At this point the vapor implodes violently and can cause significant damage to the pump (Pump World, 2012). To avoid damaging their pumps, power plants stop

withdrawing water. Without sufficient amount of cooling water the plants are then forced to shut down. In order to resume the use of their pumps, plants need to wait for water levels to rise back to safe levels.

2.3.2. Water Discharge from Power Plants

Warm water discharge, mainly from once-through systems, changes the ecological dynamic of the cooling source. The warm water lowers the dissolved oxygen content in the receiving body and may also raise nutrient levels. In Port Moody Arm (PMA) in British Columbia, Canada, home to a TPP, the average phytoplankton biomass was three times higher than in the adjacent waters of the Strait of Georgia (Henry, 2006). The PMA plant and others often discharge cooling water with elevated nutrient levels. This is due to the fact that intake cooling water is often drawn from a point around ten meters below the surface where nutrient levels are higher. The deep-water intake is more desirable because the colder water has a higher heat absorbing capacity, which increases the efficiency of the system. Water with elevated nutrient levels is discharged to the surface waters where phytoplankton biomass is more abundant; this leads to increased growth and biomass, especially in summer months when nutrient levels typically fall (Henry, 2006). It is possible that increased nutrient levels could lead to eutrophication and/or harmful algal blooms, causing fish deaths and poisoning.

The other concern about water discharge is the temperature of the water that exits from power plant cooling systems. According to the EPA (EPA, 2012a) this temperature can cause an imbalance in the natural ecosystem of an area. High water temperatures can allow some algae and deadly bacteria to grow in these water conditions. Additionally, high temperatures lower the dissolved oxygen content of the

water, because it is easier for oxygen to escape the water (USGS, 2012). The reduced oxygen levels can make it impossible for organisms to live in areas downstream, or in the general vicinity of cooling system effluent. Fish that swim into these areas can also be killed from lowered dissolved oxygen levels.

The EPA strictly monitors the discharged water from TPPs. As part of the EPA, the National Pollutant Discharge Elimination System (NPDES) characterizes warm water as a pollutant. Facilities discharging warm water are required to obtain permits from state environmental authorities as part of the NPDES system. The permits sometimes set a limit on effluent temperatures, but sometimes do not, depending on the location and other water body factors. When temperatures exceed permit limits it is noted in the NPDES system as a quarter year in non-compliance. Sometimes there are fines associated with non-compliance. For an example of a plant that was forced to make changes by the EPA because of water temperature, please see Appendix B.

2.3.3. Water Usage of Power Plants

Water usage for thermoelectric plant cooling purposes accounts for around 49% of all water withdrawals in the United States (USGS, 2009). This includes withdrawals for both once-through and recirculating systems. Once-through systems accounted for about 92% of thermoelectric plant withdrawals, as they generally do not reuse any of the cooling water. The USGS estimate for 2005 set the total water withdrawals for thermoelectric cooling systems at 201 Billion gallons per day (Bgal/day). This is a very slight increase since the 2000 estimate of around 195 Bgal/day. With a slowly rising energy demand, the slight increase in water use is to be expected.

While water use for power plants is significant, U.S. power plants have managed to improve water efficiency a great deal over past decades. However, efficiency improvements have not been able to keep up with growing demand, so water usage continues to grow. Water usage in 1950 was 63 gallons per kWh, whereas today it is around 25 gallons per kWh (Sovacool, 2009). For the same time period, electricity generation increased by a factor of fifteen. Additional methods are required to further reduce thermoelectric water usage before the problem becomes much more significant in the future, as additional power plants are constructed to meet rising energy demand.

Within 2-3 decades it is expected that many coal-fired plants may be required to use carbon capture technology to reduce greenhouse gas emissions. These advanced systems can reduce electricity output capacity by 20-30%, while increasing water usage by about 50% (Chandel, Pratson, & Jackson, 2011). Thus, in areas where water is scarce, fuels other than coal may become more practical.

Demand-side reductions and energy efficiency improvements would also go a long way toward reducing energy and thus water consumption. Renewable energies, which consume relatively tiny amounts of water compared to thermoelectric sources, could also be utilized to meet future energy demand without putting more strain on water resources. These strategies may all come into play in the relatively near future (5-10 years) and play an important role in reducing electricity generation related water consumption.

2.3.4. Competing Water Uses

While water use for thermoelectric power accounts for 49% of water withdrawals in the U.S., there are many other demands on water bodies for other uses (USGS, 2009).

The main competitor for water throughout the country is irrigation. Irrigation accounts for 31% of water withdrawals and 85% of water consumption (Torcellini, 2008). In the south where the sun tends to dry out the crop fields, irrigation is especially important to ensure the growth of the crops.

Another large competitor for water use is public supply water, which accounts for 11% of water withdrawals (USGS, 2009). The average American family uses 400 gallons of water every day, and some areas in the Southeast use much more than that for landscape irrigation (EPA, 2012e). This water is considered top priority because people need drinking water to survive, and thus even in times of drought, this supply is protected.

Other major water withdrawers are industry, aquaculture, mining, and livestock (USGS, 2009). All of these uses are crucial to the operation of our economy and to our daily lives, so any interruption of these sources could be disastrous to the country.

2.4. Climate in Southeastern United States

In recent years, the Southeast region has been affected by droughts and water shortages and these water-related issues will only escalate if changes are not made for water usage in thermoelectric power generation (U.S. Global Change Research Program, 2012).

Global climate change is a term that encompasses increases in air and water temperatures, shifts in weather patterns, increases in sea levels, and the melting of glaciers (EPA, 2012b). The rate and severity of climate change has spiked in the last century and even more drastically in the past forty years. Certain regions will become

warmer and drier, and areas by the coast will experience less frequent but more intense storms (Tel Aviv University, 2012). Regions, such as the Southeast, are experiencing uncharacteristic weather patterns for which they are not properly prepared.

The Southeast has experienced changes in precipitation patterns. Although the average amount of precipitation annually has not changed, the region experiences more periods of no rain followed by heavy rainstorms (Flatow, 2012). This inconsistency in precipitation allows for the air, land and plants to dry out. When heavy rains come the land does not have the ability to store the large quantity of rainfall and water systems are not fully replenished.

According to the U.S. Global Change Research Program (2009), the average annual temperature in the Southeast has gone up 2 °F in the last 40 years, whereas in the prior century the average temperature was relatively constant. With the rise in temperature, the land in the region has not adjusted and is uncharacteristically dry. Although the Southeast region of the U.S. is typically not a dry area, the change in climate has made it so the region is experiencing more frequent droughts and water shortages that could be socially and economically devastating.

Droughts, depending on their severity, can be economically, environmentally and socially traumatic (U.S. Drought Monitor, 2012). The majority of the droughts in the nation have been in the Southwest, but they are better prepared to handle their dry spells due to their naturally dry climate. In the Southeast, however, industries and society in general are not equipped for droughts. The 2007-2009 drought was responsible for over a billion dollars in crop losses and strained the water supply system. Because of water shortages, the local governments had to introduce and enforce water

restrictions, which ultimately have led to conflicts and lawsuits between cities and states fighting over water.

According to Corrigan (2009), the Drought of 2007-2009 was the longest, most intense drought of the decade with respect to the Southeast. The winter of 2007 was uncharacteristically dry, and the drought intensified the following summer. That summer, the average precipitation was down fifty percent and temperatures were at record highs. Droughts cause strain on water bodies, lowering water heights. By summer 2008, the Southeast was experiencing below average stream flows as shown by the red and orange in Figure 2.2.

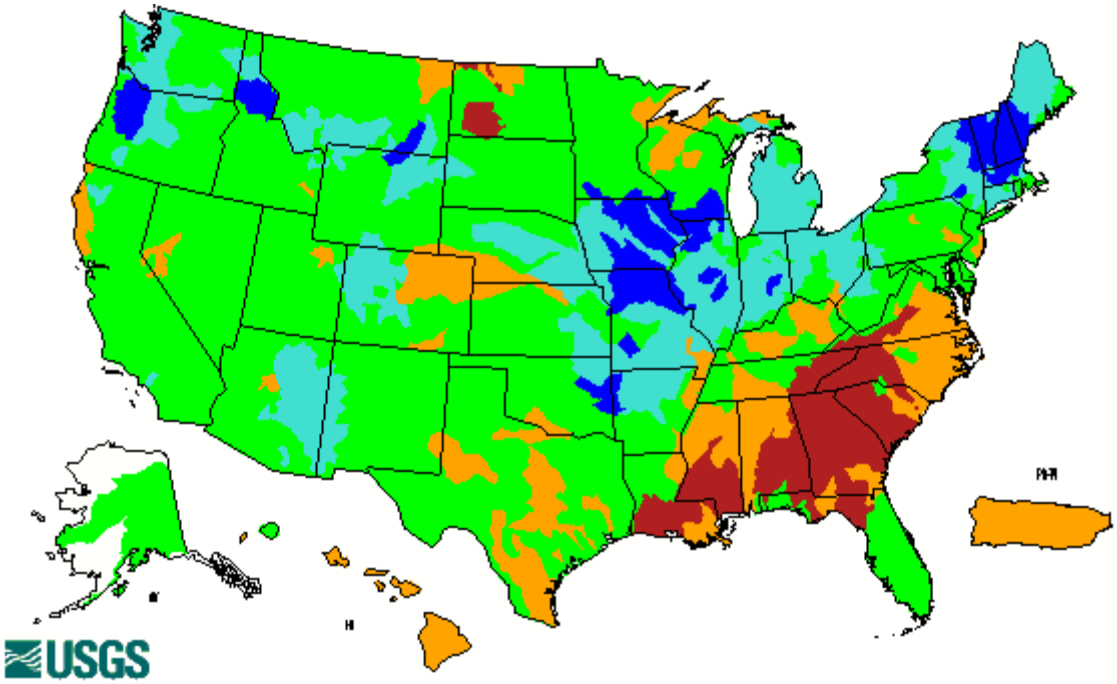

Figure 2.2: Stream Flows, July 2008 (Corrigan, 2009)

It is important to keep in mind how climate has and is continuing to affect the water bodies in the Southeast. Power plants require huge amounts of water for their cooling processes. Collectively Georgia, North Carolina, South Carolina, and Virginia

withdraw 22.5 billion gallons of freshwater daily, 39% of which is used in thermoelectric power (USGS, 2009). Limited water availability would pose serious threats to the region's power supply.

2.5. Summary

All of the topics covered in this chapter are necessary to understand the problems with the water-energy nexus in the Southeast. TPPs are large, complex systems, with many options for fuel sources and cooling systems, all of which affect the water needs for the plant. The power plants can have a very large effect on the surrounding aquatic ecosystems, and these impacts need to be addressed when considering the water usage of the power plants. Climate change may produce lower water levels; therefore, we need to ensure that energy producers will still have enough cooling water for electricity generation. Population growth strains water supplies both from the associated growth in electricity generation and increases in drinking water needs and occurs at a faster rate than climate change. Little is currently known about the profile of the water use by thermoelectric power plants in the region as a whole, which makes regulation and policy making to protect the water resources very difficult.

3. Methodology

The goal of our project was to inform policy makers in the U.S. Department of Energy on the connection between water and energy related to cooling systems for thermoelectric power plants in the southeastern U.S. We first met with DOE experts on water-energy issues in order to gain a broader perspective on the many issues surrounding the water-energy situation. Our group then compiled EIA data on a sample of 25 power plants in the region. We then analyzed this data to identify trends that best describe the state of thermoelectric power plant cooling in the Southeast. Finally, we interviewed several plant operation experts from our list of selected plants in order to gain a perspective of operations at a plant level. In this chapter, we outline the research methods we used to achieve our project goal and objectives.

3.1. Meetings with DOE water-energy experts

In order to expand our breadth of knowledge about water-energy as a whole, we met with many DOE offices that had done water-energy work related to their fields. We discussed issues related to our project that both parties felt would be useful and informative. These meetings provided a much broader view of the water-energy situation, because every person and organization had a different view of what is important about the situation. Many of the people we met with also provided us with many studies that had been done on water-energy issues that helped us with our understanding of the situation as a whole. For a summary of each meeting, please see Appendix C.

3.2. Data Collection on Power Plants

In order to get a base of knowledge about the plants in the region, specifically their cooling systems, we compiled case studies on 25 large thermoelectric power plants within the 4 states of Virginia, North Carolina, South Carolina, and Georgia. We investigated each plant to gain specific knowledge on the cooling processes utilized at the plant.

3.2.1. Power Plant Selection

We selected a set of power plants in the region based on various criteria: generation capacity, geographic location, cooling system types, fuel type, and water source. We attempted to have a balance of all factors on both a state and regional level. We also had our selection of plants match the general fuel type balance that the region employs. Another criteria we selected by was that the plants have a significant contribution to electricity generation in the state, so we attempted to select plants with a capacity of 500 or more megawatts. We also selected plants in different areas of the states to get a balance of water bodies. Finally, we selected based on cooling systems to get a balance systems that was representative of the regional averages.

3.2.2. EIA Data Collection

To gather the necessary quantitative information on the selected plants to develop a cooling system profile, we used archived data available through the Energy Information Administration (EIA). These databases have extensive data on water use and energy production for TPPs across the nation. We used data from EIA forms 767, 860, and 923. The 767 form is the precursor to the 923 and 860 forms and has not been in use since 2006, but it helped us obtain historical data back to 2002. The 767 form

provided a combination of static and operational data with yearly, rather than monthly data. The 860 form provided us with static plant data such as generation capacity and system specifications of the plants. The EIA 923 form contains monthly data collected from the power plants, and it provided us with electricity generation and cooling system data such as monthly plant water usage.

We gathered information from these spreadsheets on our selected 25 TPPs between 2002 and 2011. We compiled data on the energy produced, the amount of water withdrawn and consumed, the intake and discharge temperatures of the cooling water, and other relevant aspects of plant operations found in these databases. These data helped us develop a general profile of the water-energy nexus for thermoelectric power plants in the region.

3.2.3. Data Analysis

Once we had data on the 25 selected plants, our group looked to find interesting and telling trends or patterns in the data. Specifically, we investigated topics related to water consumption, water withdrawals, intake and discharge depth, water temperatures, type of cooling system, type and location of power plants, and electricity generated. We used Microsoft Excel and Access to organize and compile all of the data we collected. The use of these computer tools was extremely helpful for organizing, presenting, and analyzing these data. We created graphs and tables to display our findings in an easily understandable fashion and compare the different characteristics of power plants side by side in order to draw conclusions.

3.3. Archival Research

In order to further our knowledge or the water-energy issue as a whole, we gathered information from previous studies on the water-energy connection. Many of these studies were conducted by various DOE agencies, and the people we met with at the DOE were able to forward these studies to us for our reference. We read and analyzed many of these studies in order to provide reference and context for the analysis of the data we collected. They also informed us about many alternatives to traditional cooling practices that could be implemented at power plants throughout the Southeast.

3.4. Interviews with Plant Operation Experts

Analyzing archival data was useful, but in order to more fully understand the situation at each specific power plant, we conducted phone interviews with 3 plant operation experts, specifically experts in cooling systems. Interviewees were hard to come by so they were selected based on availability and willingness to talk about their plants. From the interviews, we were able to identify the unique situations at each plant, and we were able to gather qualitative data that was not available in the EIA spreadsheets. We tailored each interview specifically from our prior knowledge of the TPP from the EIA data and other research. The interviews were conducted over the phone, and were semi-structured interviews to allow for more conversation specifically about their plants. For a summary of the interviews, please reference Appendix C.

3.5. Site visit

We toured the North Anna nuclear power plant, one of the plants we studied, in order to directly observe their operations. The goal of our site visit to this plant was to

be able to better understand the size and scope of the power plant cooling systems, as well as to be able to better understand how energy generation actually works. This gave us a better sense of how unique features of the cooling systems affect the overall operations of a power plant. During our visit, we were also able to conduct informal interviews of plant employees, which allowed us to gain a further understanding of the plant's cooling operations, as well as the future plans for their proposed new cooling systems.

3.6. Summary

Our methods were completed using interviews with plant operations experts, meetings with DOE water-energy experts, and archival research on TPP cooling systems and the water bodies they affect. Many sides of the problem were considered in order to get a better sense of the overall scope of the water-energy issue. The data were compiled in such a way that made it clear what recommendations could be made to approach a more sustainable use of water in the region. In the next chapter, we will present the results of our research.

4. Results and Analysis

After completing our methods, we compiled qualitative and quantitative data to determine the following results and analysis. We looked at records, research and reports from as far back as 2000 that covered a range of topics including; cooling operations, new cooling technologies, electricity generation, regional population and energy demand. From this analysis, we were able to get an understanding of the water-energy nexus in the region.

4.1 Water Supply and Electricity Demand Stress Factors

In the development of our project we determined two major external factors that influence the supply and demand of water. Both factors present the most significant risks to water availability and power plant operations. These external factors are droughts and population growth. The findings we have gathered are presented below.

4.1.1 Droughts

According to our interview with the Office of Science we learned that, in general, droughts are increasing in frequency, severity, and duration in the Southeast. Of the four plants we interviewed, most of them have had to deal with drought situations and resort to their contingency plans in the last decade. We also learned of additional plants outside of our targeted list that have had drought related issues. The U.S. Drought monitor records drought conditions by land area. Figure 4.1 below, shows drought periods for our four states, plus Florida and Alabama, over the last twelve years. During the 2007-2009 drought, 30% of the region experienced exceptional drought conditions.

There have also been lingering drought conditions in recent months that may point to droughts becoming more frequent in the region.

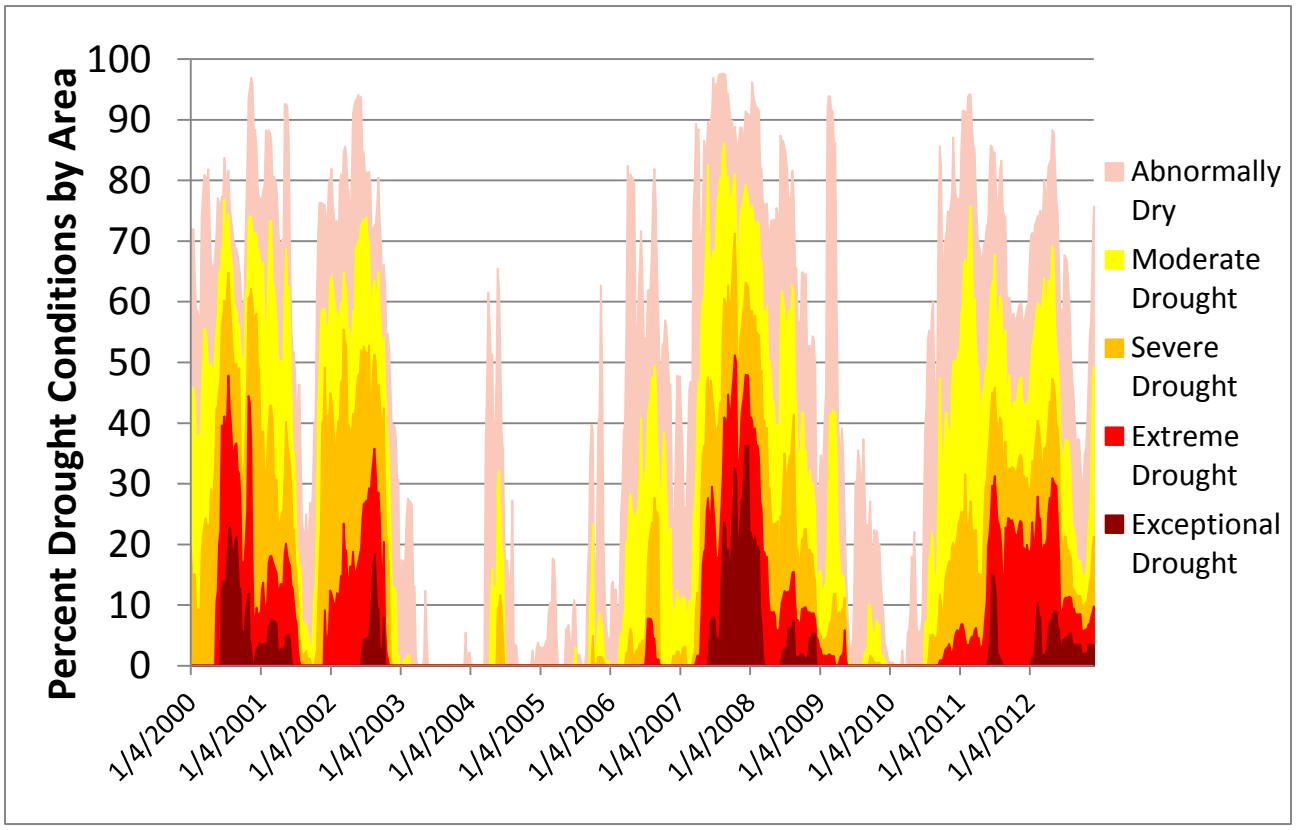

Figure 4.1: Drought Conditions in the Southeast

If drought conditions become more frequent and severe in the region, thermoelectric power plants will have to reevaluate their current cooling processes to avoid water related problems. Although the Southeast is not a traditionally dry area, the issue of water availability is not going away. Drought, however, is not the only major factor affecting water availability.

4.1.2 Population Growth

The main driver of water demand stress is population growth, due directly to higher domestic water use and indirectly to higher electricity use and

commercial/industrial water uses. The 2007-2009 drought, centered in Georgia, caused serious water shortages in the Southeast region and threatened Atlanta's drinking water supply as well as some power plant operations. However, this drought was no more severe than other recent droughts, even one as recent as 1998-2002 (Seager, R. et al, 2009). The fact that this drought was a normal occurrence and that water supplies were so heavily strained, indicates that the water shortage crisis was largely driven by rapid population growth in the region and the resulting increases in water demand.

In 1990, Georgia had 6.5 million people. By 2007 this figure had grown to 9.5 million, a rise of almost 50% in only 17 years (Environment News Service, 2008). Similar trends are occurring in the other three states under study. Across our four states, the population grew 17% from 2000 to 2010. This was much higher than the national population growth over this same period, at 10%. We applied the national growth to the population of our four states in 2000 to get a sense of the relative differences in growth, shown in Figure 4.2.

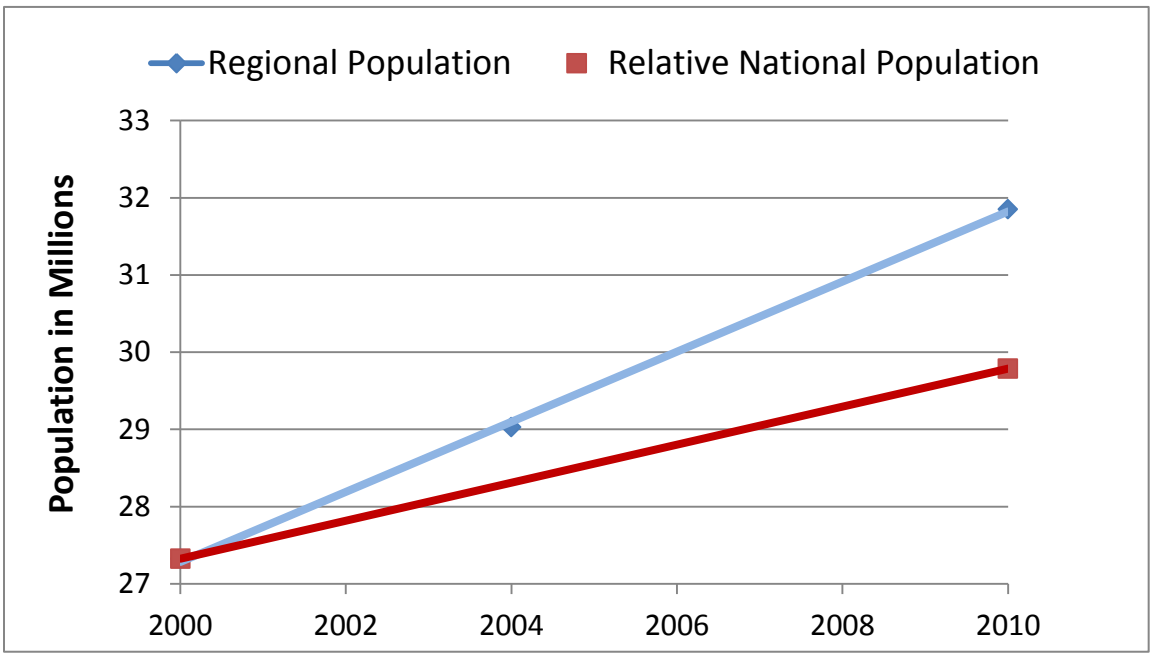

Figure 4.2: Regional Population vs. Adjusted National Population Growth

If regional population continues to grow at an accelerated rate, it will make the regional water supply much more sensitive to drought conditions. Both droughts and population growth pose a threat to the regional electricity supply. Water-related problems will only become more likely and severe in the future.

4.2 The State of Electricity Generation and Capacity in the Southeast

Power generation facilities are interconnected by transmission lines. Therefore different power plants have the ability to supply power to different regions. This creates a stable overall supply of electricity, even when a small number of facilities are forced to reduce their generation during times of drought.

4.2.1 Regional Drought Reliability

The Southeastern Reliability Corporation (SERC) publishes annual reliability reports. The SERC (2012) report noted that the energy reliability in the region is not at

risk for the next decade. Using historic generation growth, SERC projected a future growth rate and compared it to the net capacity of the plants. Figure 4.3 shows that the capacity is much higher than the projected energy requirement, meaning the energy reliability in the region should not be affected. The figure shows data for the VACAR sub region of SERC, which consists of Virginia, North Carolina and South Carolina.

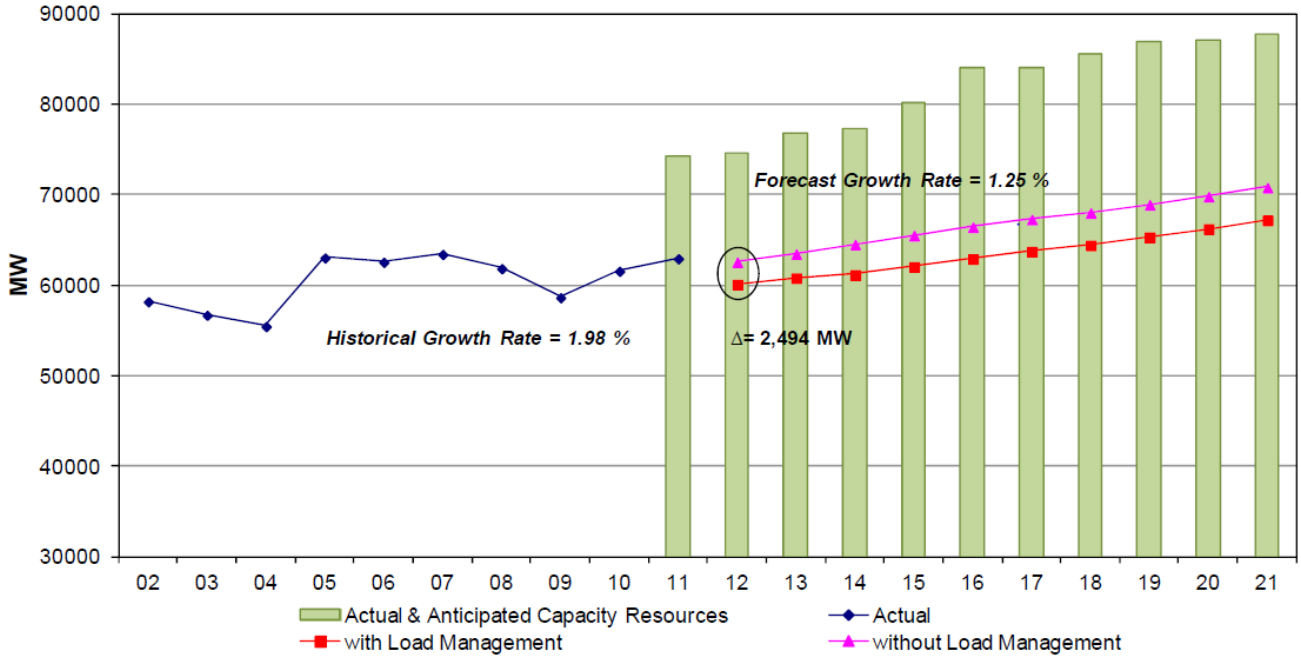

Figure 4.3: VACAR Sub region of SERC Summer Peak Demand-Actual vs. Projections (SERC, 2012)

In 2008, SERC produced a special report that focused on the impacts of droughts (Cauley, 2008). This report was published after a year of severe regional droughts, where many power plants were forced into using contingency plans and conservation methods. The report discussed three case studies representing various intensities of drought and determined that the regional reliability would remain unthreatened even in the most severe cases. SERC identified various effects that the droughts have on the region such as decreased water levels and higher intake temperature of cooling water.

Reliability, as defined by SERC, is continuous operation despite obstacles, typically with a 15% reserve margin. According to this definition, SERC determined that the reliability was not a concern mainly because of the large gap between overall capacity and actual electricity generation and the ability to transport large quantities of electricity throughout the region with high capacity transmission lines.

We were able to validate SERC's power generation findings using electricity generation data from our 25 plants in the VACAR states and Georgia, shown in Figure 4.4. The two graphs show a very similar curve with a maximum generation in 2007 and a minimum in 2002 with an overall dip in 2009 back to 2003 levels. Annual generation was determined from EIA data using the total generation from our selected power plants. Figure 4.4 shows that our data closely match data reported by SERC and that our data analysis can be used to make regional assumptions.

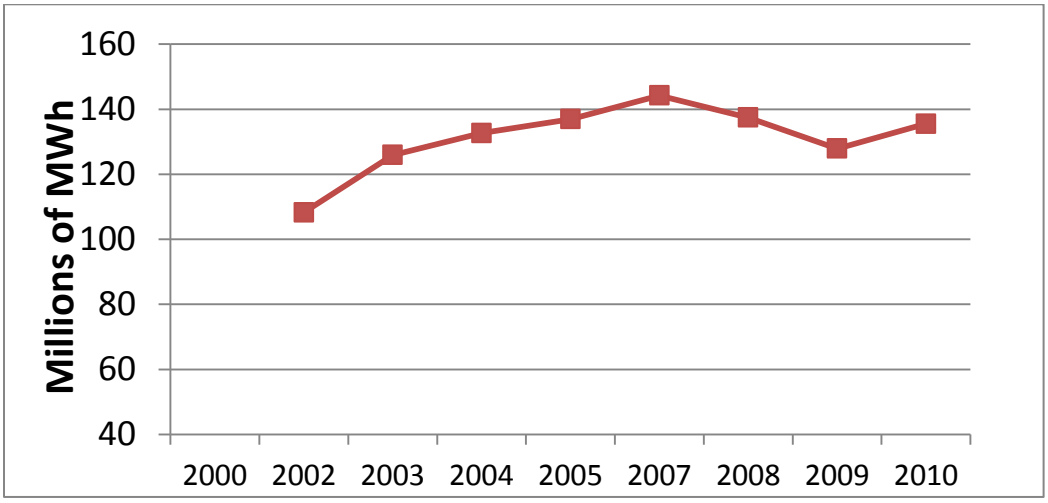

Figure 4.4: Regional Electricity Generation for Selected Plants

We can see from Figure 4.4 that the overall generation in the region is increasing; however we were curious to see how the energy profile has shifted in the last decade. It is important to understand how the different fuel types make up the

regional generation because generation needs to keep pace with rising energy demand. Figure 4.5 shows that natural gas and nuclear plants have provided a higher percentage of electricity in recent years, but coal is continues to provide less power.

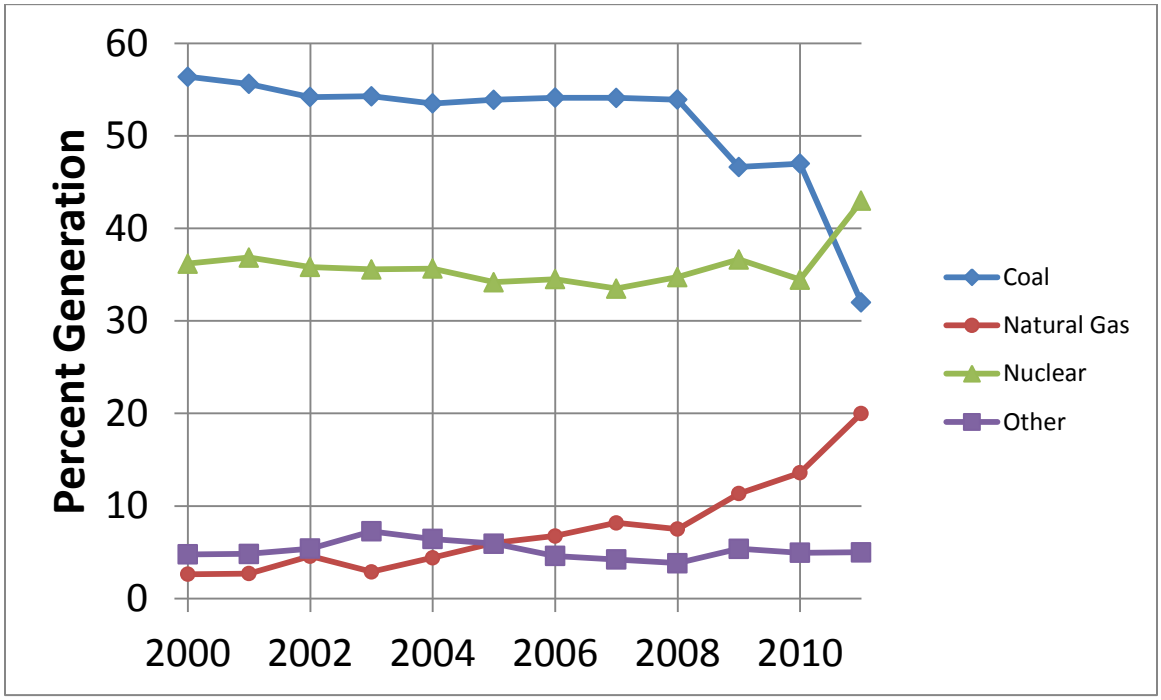

Figure 4.5: Percent Generation in the Southeast by Fuel Source

As shown in Figure 4.5, nuclear power has surpassed coal and become the largest contributor to the region's electricity generation in 2011. We expect that nuclear power will play and even larger role in the Southeast in the future because two of our selected plants, Vogtle and North Anna, both have plans to build new nuclear reactors. Hydraulic fracturing in the United States has lowered natural gas prices, making it a more popular and cheaper option for power generation. This has led to the construction of new natural gas plants, and natural gas plants now generate 20% of the region's electricity.

We also confirmed SERC's assessment of the overall reliability in the region. Although SERC encompasses a much larger region than our four states, we were able to show the significant difference between generation and full capacity in our region, seen in Figure 4.6.

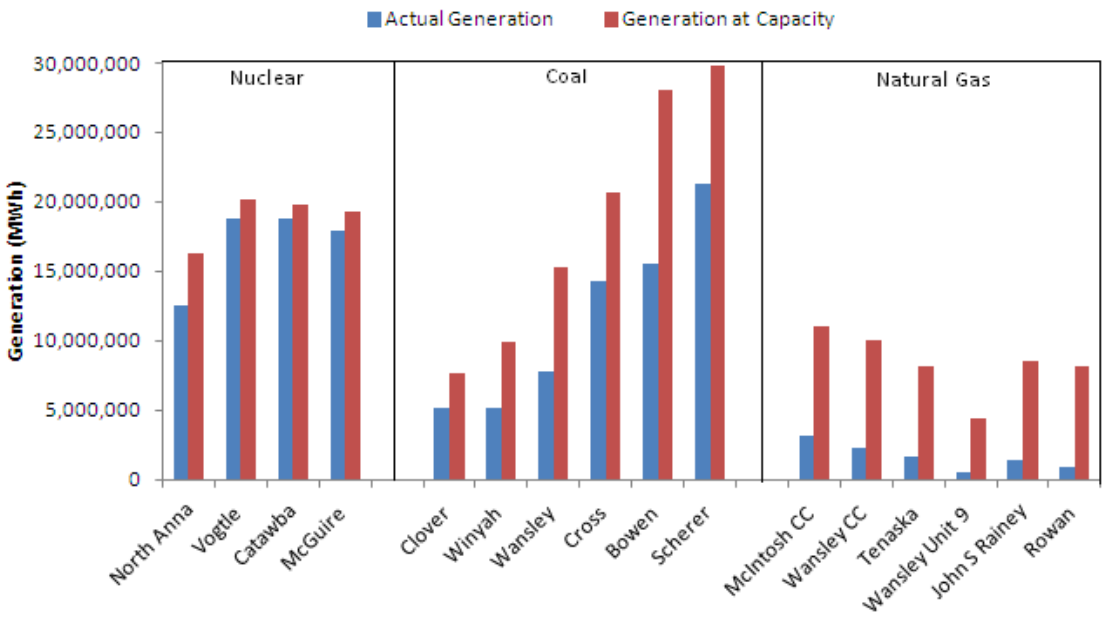

Figure 4.6: Generation and Capacity of Selected Power Plants-2011

Nuclear plants operate at the highest percentage of capacity, followed by coal plants, with natural gas plants at the lowest percentage of capacity. From Figure 4.6, we can infer that both coal and natural gas plants are underutilized and have the potential to generate much more electricity, although utilities are required to keep a specific percent reserve margin. These plants could make up for potential capacity losses or total shutdowns of other power plants during a period of drought. This shows that overall electric reliability is not an immediate concern, meaning water shortages will not cause any blackouts to the grid.

4.2.2 Water Usage by Cooling Type

Although overall regional reliability would not be affected by a moderate to severe drought, there are still individual plants that may be affected by severe droughts such as the drought of 2007-2009. Basic plant features such as cooling type, water body type, and regional characteristics can influence the vulnerability of certain power plants to water shortage.

Cooling system type is the main factor affecting the water usage of power plants. In order to compare the relative water requirements of each type of cooling system, we calculated water withdrawals per electricity generation and separated these numbers by cooling system (shown in Figure 4.7). You can clearly see that once-through cooling systems require up to 150 times more water to generate the same amount of electricity. In times of low water availability, once-through systems are impractical.

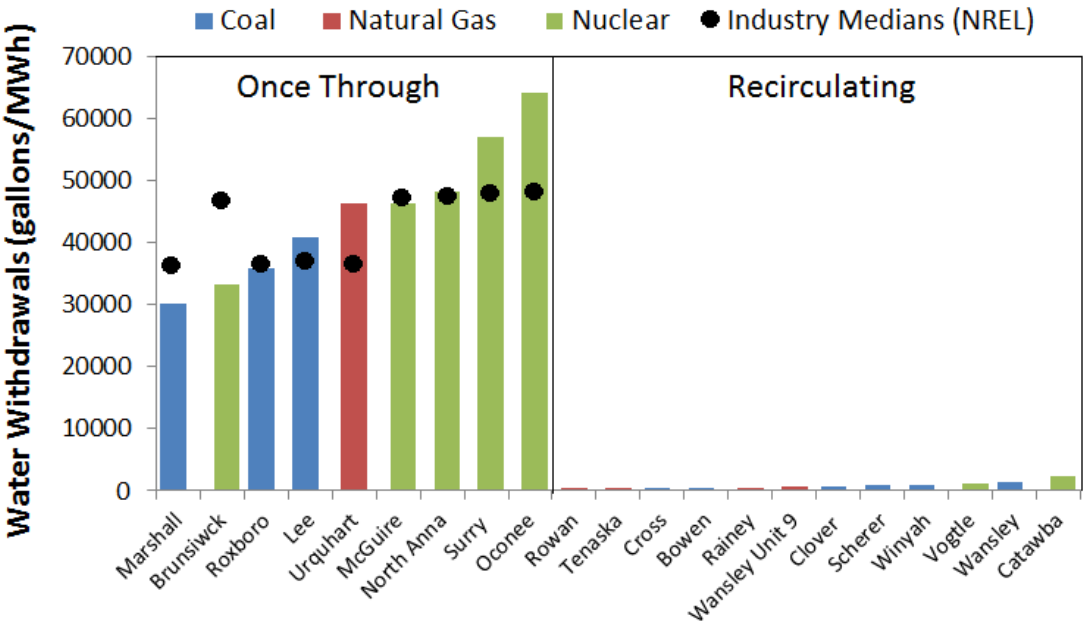

Figure 4.7: Water Withdrawals for All Cooling System Types

Recirculating systems are much more efficient users of water, but they do have high consumption rates compared to once-through systems. We calculated water consumption (gallons) per electricity generated (MWh) for plants with recirculating system (shown in Figure 4.8). The average efficiencies for each fuel source according to the National Renewable Energies Laboratory (NREL) are included as black dots on the graph. We found no clear difference in the water consumption of natural draft and mechanical draft towers. The consumption of McGuire's once-through system is shown to compare the consumption of once-through and recirculating systems.

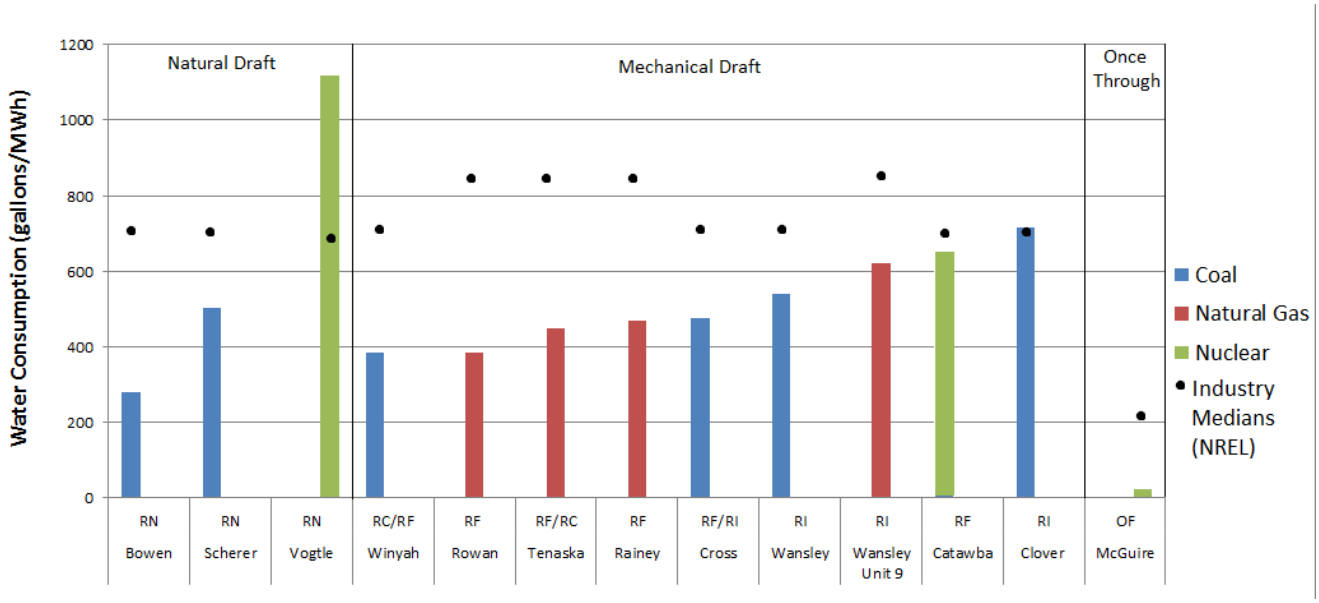

Figure 4.8: Water Consumption per Generation-2011

Although once-through systems use much more water in their cooling processes, the high water consumption of recirculating systems may also pose a problem during times of water shortage. For example, a recirculating system on a manmade lake would slowly evaporate the lake water until there is not enough left to use, assuming that the lake would not be replenished in a drought period.

Overall, there is not much of a difference between the vulnerability of once through versus recirculating systems. Argonne National Laboratories compiled a report for NETL about the water vulnerabilities of existing coal fired power plants (Argonne National Laboratories, 2010). The report identified 307 vulnerable plants. Of these, 53% use once-through systems and 47% use recirculating systems. Since cooling system type is not dependent on fuel type and differences in water use by fuel type are minor, these figures are likely similar for the Southeast.

4.2.3. Vulnerability of Reservoirs

Based on our interviews with ARPA-E and the Office of Electricity, we have also been able to judge that reservoir water levels are more susceptible to droughts because they are not naturally occurring. James Klausner of ARPA-E informed us that during the drought of 2007-2009 Georgia attempted to conserve water by decreasing water releases from Lake Sidney Lanier, a reservoir that supplies the majority of Atlanta's drinking water. This decision was fought in court by Florida and Alabama who needed more water downstream for various purposes. The court ruled that Georgia was required to maintain a certain volume of water releases. In a drought scenario, the water inlet flow to the reservoir could easily be less than the outlet flow. This would result in falling water levels. The rate at which water levels would fall depends on the severity of the drought, and how far water levels would fall would depend on its duration. Because of this court ruling and similar rules for other reservoirs, power plants with intakes on manmade water bodies are at a higher risk of experiencing water related problems.

Certain plants with low intake depths are more vulnerable to reduced water levels and temperature spikes than those with deeper intakes. We compiled data on the depths of the cooling water intakes at all of the plants we looked at in the Southeast, shown in Figure 4.9. Plant McIntosh, which had a listed intake depth of 0, was left off of this graph, because we confirmed in an interview with a plant manager that this data point was incorrect. In general, intakes on lakes/reservoirs are deeper than those on rivers. This is likely because lakes are, in general, deeper than rivers and thus intakes can be built deeper. Deeper intakes are desirable because cold water leads to more efficient cooling.

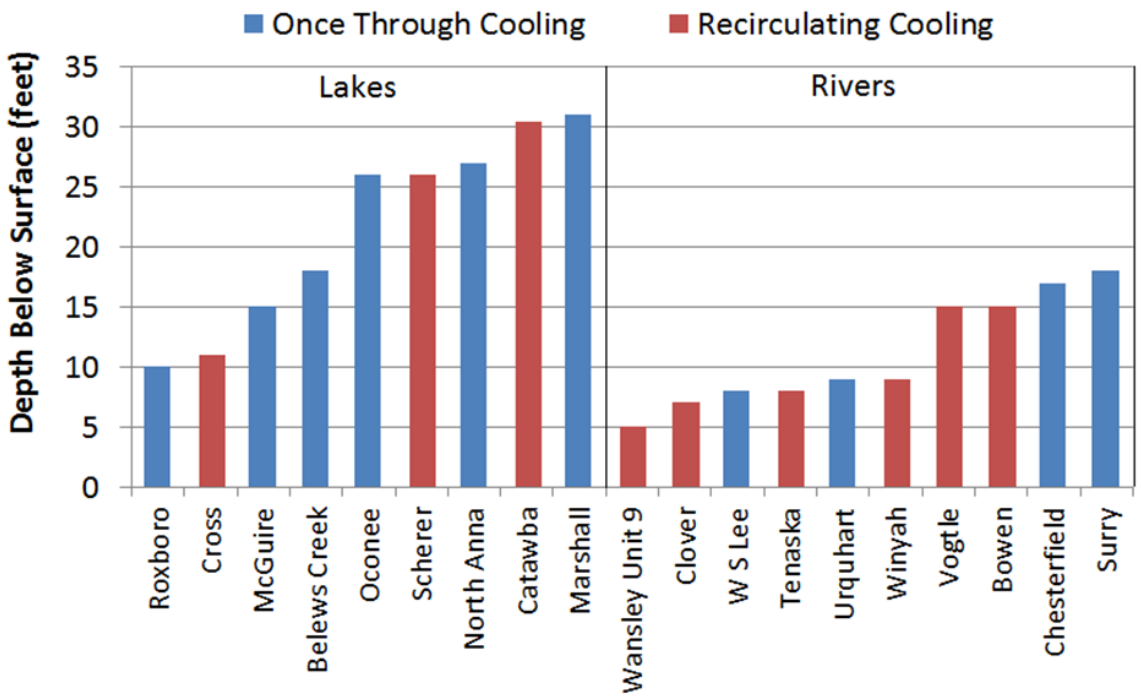

Figure 4.9: Intake Depth by Water Source

Although the intake depths listed in Figure 4.9 are multiple feet below the surface, water levels would need to drop only a fraction of this depth to force a shutdown of the intake pumps due to suction cavitation (see background section 2.3.1)

or other regulatory issues. Both rivers and lakes have the possibility of dropping to the point where plants cannot operate. During our visit to the North Anna nuclear plant, we were informed that lake levels would need to drop only eight feet before the plant would have to shut down, but North Anna's intake depth was reported at 27 feet, thus leaving a 19 foot difference between water level and intake depth. This proves that even plants with seemingly deep intakes may still be vulnerable to relatively shallow decreases in water height.

4.2.4. Seasonal Effects on Water Use and Generation

Electricity generation is least reliable in the summer months due to a confluence of factors that include higher electricity demand, higher water temperatures, and lower water availability. Initially, we hypothesized that increasing water temperatures due to climate change would have an impact on cooling systems in the Southeast. To get a sense of the water requirements for power plants during different seasons of the year, we compared year round EIA water intake temperature data to year round water withdrawals per generation data for the Catawba and Surry nuclear plants, which use a recirculating and once-through cooling system, respectively. Nuclear plants were chosen because they generally run at a high capacity, and we could thus control for this factor.

Figure 4.10 shows the relationship between increasing water temperatures and water usage for a plant with a once-through system. It is clear that increased water intake temperatures lead to an increase in water required per MWh of electricity generated.

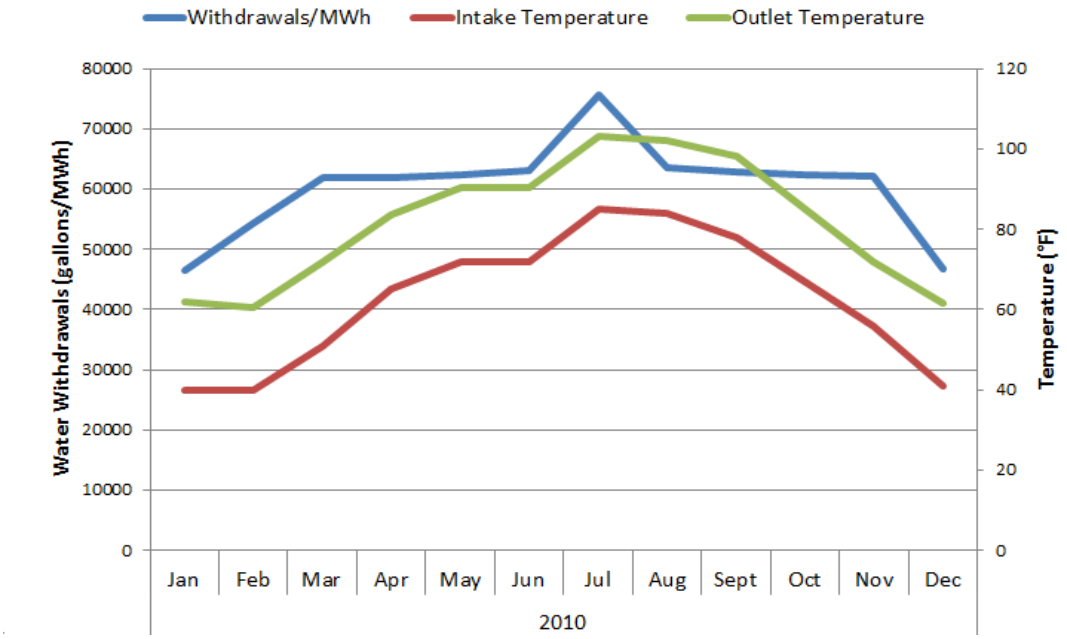

Figure 4.10: Relationship of Water Use, Intake and Discharge Temperatures for Surry

In July 2010, the temperature of the intake cooling water for Surry Nuclear was nearly 87 °F. The ratio in July of water withdrawn per unit generation went up to 7500 gallons/MWh, nearly 40% larger than January's ratio.

The temperature change between inlet and outlet water appears to be constant, but there are slightly greater changes in the winter months of January and December. Presumably, this larger temperature difference leads to more efficient cooling, power generation, and water usage as seen in the low withdrawals to generation ratio.

This result was seen for almost all of the plants that used once through cooling in the plants studied. This result means that increasing water temperatures due to climate change could force more water use per MWh produced in plants that use once through cooling. Since high electricity demand, high water temperatures, and low water

availability all occur in the summer, it is likely that water availability could pose a serious problem for electricity generation in the summer months.

Figure 4.11 shows that recirculating cooling systems are also affected by increased water temperatures. Recirculating cooling systems recycle the water within the system and only withdraw enough to make up for the water lost to evaporation. This means that the increased withdrawals seen in the summer months also lead to increased evaporative consumption. These efficiency trends are similar to those of once-through meaning that increased temperatures lead to decreased efficiencies; however, the recirculating cooling is only effected by a small percentage of the warm water, so the effect should be less.

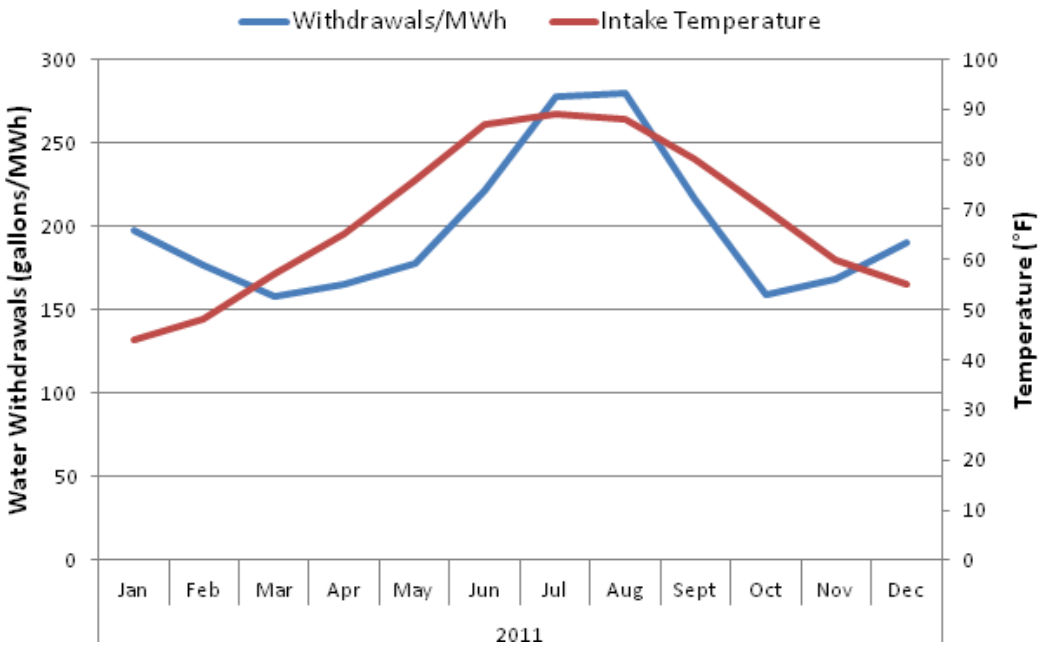

Figure 4.11: Intake and Water Withdrawals for Catawba-2011 (Recirculating)

Figure 4.10 also shows that spikes in intake temperatures for once-through systems lead to equivalent spikes in discharge temperatures. Warm water discharge is

regulated by the NPDES system (see background section 2.3.2) and many plants are required to keep their discharges below a certain temperature. Violations of these limits are noted in the NPDES national data base and may lead to fines or even closings. We attempted to find temperature discharge limits and compare them to the actual discharge temperatures for the once-through cooling systems we studied. However these permits were extremely difficult to find and the permits that we were able to obtain did not match up to the available EIA data. Tenaska had discharge limits, but no EIA data, where Chesterfield did not have discharge limits, but the EIA data was available. The temperature increase of the cooling water is still interesting to note. The temperature increase of the effluent ranges from 11-27°F, as shown in Figure 4.6.

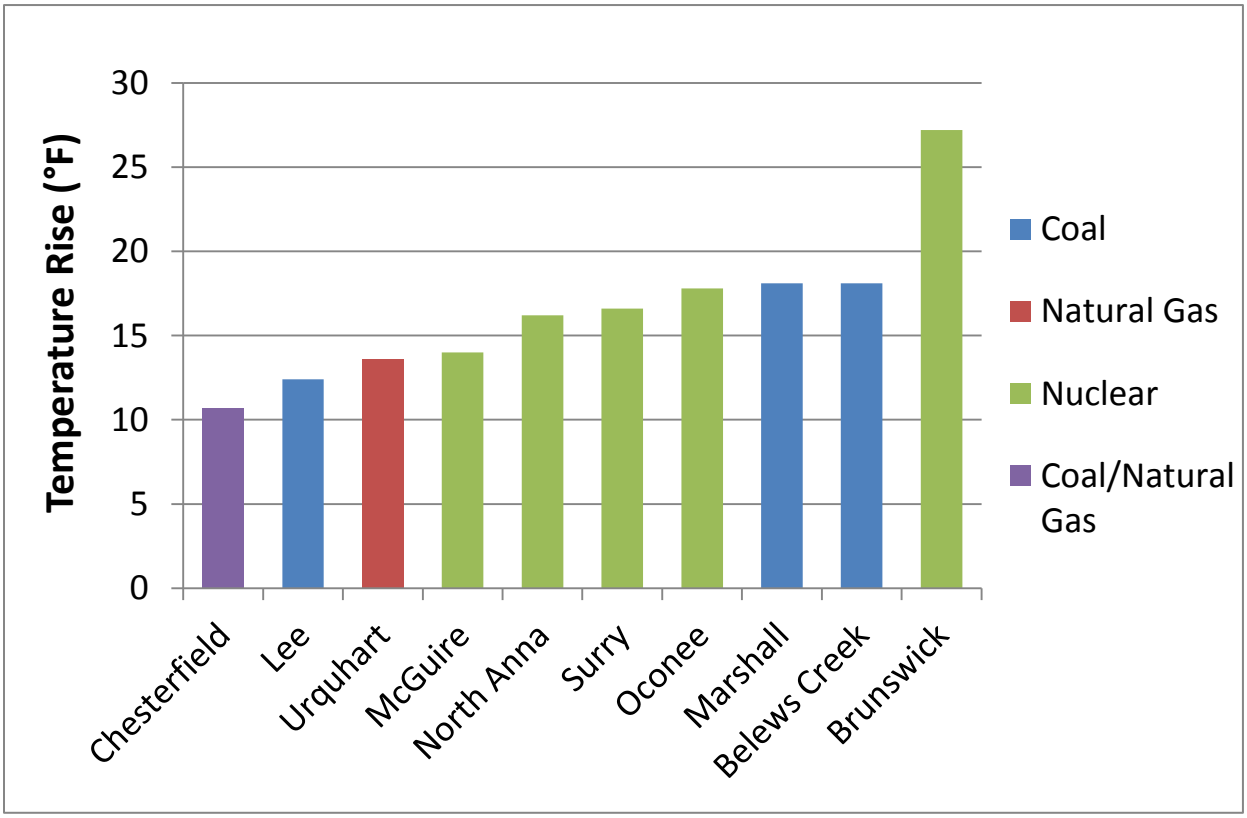

Figure 4.12: Temperature Increase of Water for Once-Through Cooling

4.3. Water Use Regulations

According to the EPA Economic and Benefits Analysis report the SERC region has 912 generating facilities, representing 16.9% of all nationwide facilities and 26.5% of the nationwide capacity at 288,625 MW, the most of any NERC region. Of these, 147 or 16.1% of all SERC facilities, fall within the scope of the proposed phase II rule (see Background 2.3.1). These in-scope facilities represent 54.3% of total SERC capacity. According to Figure 4.13, 42% use once-through cooling and will likely be affected by 316(b) regulations, which deal with cooling system intakes (see background section 2.3.1).

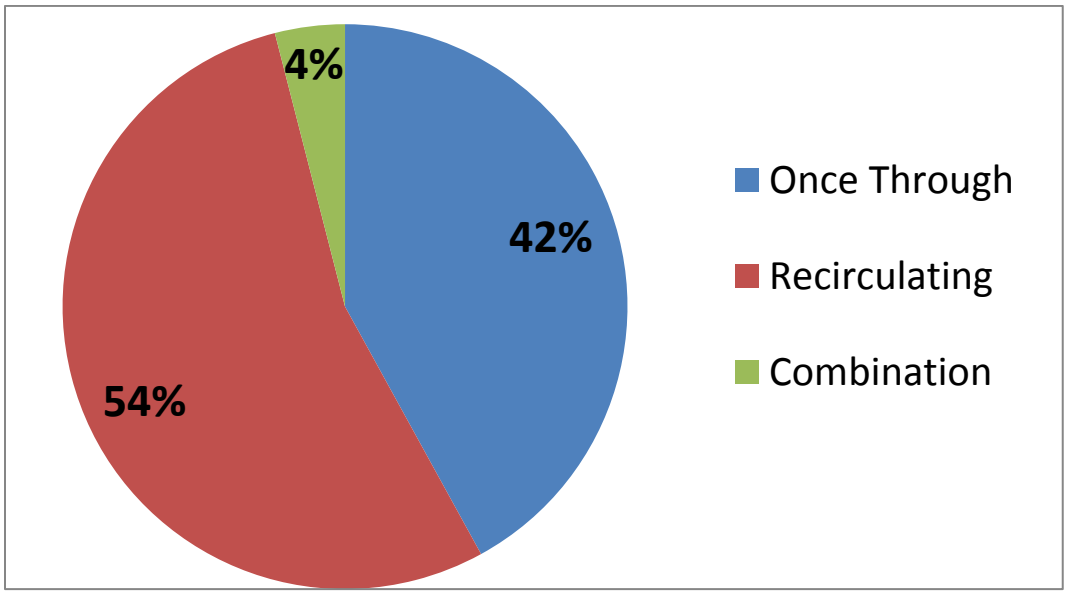

Figure 4.13: Percentage of cooling system types used in our selected plants.

A significant point to note about the study is the fact that the implementation of 316(b) will be more costly in the SERC region, second only to the Reliability *First* Corporation (RFC) region. This is mainly because facilities within the SERC region that are covered by the new rule account for over 54% of the regional capacity, second highest among NERC regions. This means that the down time that power plants require

to install new equipment will also be second highest and result in lost production. Additionally, the high percentage of in-scope facilities means that more upgrades will have to be made in this region compared to others. However, the EPA report does note that the percentage and regional capacity of in-scope facilities may be overstated because not all facilities will experience down time and some of the necessary downtime will occur during routine downtime for scheduled maintenance.

According to our interview with an operator from the McIntosh plant, the implementation of 316(b) would require the plant to install fish friendly intake screens and a fish return system to the river. They would also need to modify their intake system to reduce the flow to <0.5 feet per second in order to comply with the flow limits set forth in 316(b). McIntosh uses once-through cooling for its older, 163 MW coal fired generator and uses recirculating cooling for its newer 1,240 MW combined cycle natural gas facility it uses. Both of these systems will have to make modifications to their intake speeds. This shows that although 54% of the cooling systems we studied are recirculating cooling, some of these may also need to make modifications such as new cooling towers, more intake pipes, or wider intake pipes.

As mentioned in background section 2.3.1, the main costs for the implementation of 316(b) are up front capital costs, annually recurring operation and maintenance costs, the energy penalty that results from the parasitic energy demand of new cooling towers, and lost production/capital from down time required for installations. The options the EPA considered for facilities to meet compliance were based off of the existing technology at the facility and any new technology the facility

would need to meet compliance. The McIntosh plant, for example, would need to implement option 7. The options are summarized below:

1. Cooling tower
2. Add fish handling and return system
3. Add new larger intake structure with fine mesh, handling and return
4. Relocate intake to submerged near-shore with passive fine mesh screen
5. Add fish barrier net
6. Add velocity cap at inlet
7. Combination of options 3 and 5
8. Combination of options 2 and 5

While we were unable to obtain sensitive cost information from plants and utility companies, the EPA estimated total costs for compliance in dollars, as well as cents per KWh, and the annual costs per household. Under option 1, the estimated pre-tax compliance costs in 2015 assuming 2009 currency values, and annualized for a period of 30 years, which is the assumed "compliance life" of any installed equipment, is $99,360,633. Also under option 1, the compliance cost in ¢/KWh is 0.011 and the annual cost per residential household is $1.64. Under option 2, the total annualized pre-tax compliance cost is $1,643,059,866, the cost in ¢/KWh is 0.185, and the annual cost per household is $27.11. Under option 3, these values are $1,689,520,164, 0.190 ¢/KWh, and $27.88.

Figure 4.14 below shows the estimated costs of each option. Options 2 and 3 are significantly more expensive than option 1. Also, there is not much difference between the costs of options 2 and 3.

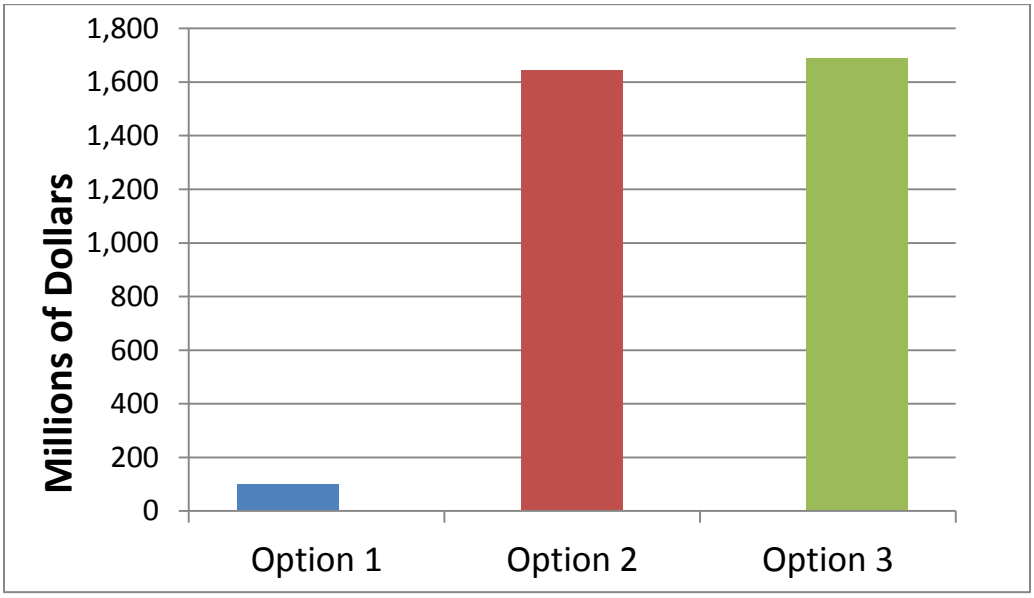

Figure 4.14: Relative costs of options 1-3 in proportion to option 3 for SERC region.

These costs are for the entire SERC region and must be extrapolated to the four states we studied, but it is clear that options 2 and 3 will be very costly, mostly due to the construction of new cooling towers. These costs will largely be passed on to the consumer and thus electricity prices will rise in the Southeast. However, the construction of new cooling towers will make it easier for power plants to cope with drought scenarios in the future because of decreased water requirements. Meeting CWA 316 (b) requirements is also an opportunity for plants to invest in new cooling technologies that conserve more water than traditional technologies.

4.4 Contingency Plans

From our interviews with various plants, we have found that each plant has unique methods for dealing with low water levels as a result of drought. Many plants have had to put these plans into effect during a drought. Others have made post-drought modifications to their intake systems. Some plants have had to do both. In 2007, the McIntosh Plant was forced to resort to its contingency plan due to severely low water levels. The threat of suction cavitation forced the plant to rent barges that held auxiliary pumps and intake pipes, which allowed the plant to withdraw cooler water from the bottom of the river where it was more readily available. As it turned, out the auxiliary pumps were not needed because water levels began to rise, however this situation caused the plant to install a permanent auxiliary pump at a lower depth in the river should the water level of the Savannah River decrease to these low depths again. This shows that the McIntosh plant is planning ahead for the possibility of another severe drought and has made necessary modifications.

In our interview with plant Vogtle, we discovered another type of contingency plan that was used during a drought in the mid-80's when the Edwin Hatch nuclear plant experienced very low water levels at its water source. In order to keep the plant running, they built a sandbag wall in the river that diverted water and caused it to pool next to the intake pumps, allowing the plant to continue normal operations. Plant Vogtle said they would likely resort to a similar plan if the water on the Savannah were to drop significantly as a result of a severe drought. While this plan is not very high-tech, the plant employee we interviewed said that Vogtle did not expect the Savannah River

to drop significantly even in a severe drought, so the plant does not feel the need to create a more advanced plan.

Information from the Vogtle and McIntosh plants seems to tell two different stories. On the one hand Vogtle said they do not expect Savannah River water levels to fall to a point where their power production is threatened, but McIntosh almost had to resort to its contingency plan because of this exact problem. Perhaps the difference in vulnerability can be attributed to intake depths. Vogtle has a listed intake depth of 16 feet. McIntosh has a listed intake depth of 0 feet, but we confirmed that this is a mistake in the reported data, thus we cannot draw conclusions from this data.

Contingency plans vary from plant to plant and reflect the unique conditions of the cooling water source as well as the intake design. The North Anna nuclear plant withdraws from Lake Anna, which is a manmade lake. Under normal operating conditions the North Anna Dam releases a minimum of 40 cubic feet per second (cfs) of water downstream to the North Anna River. When the plant experiences drought conditions, meaning the lake level falls from 250 to 248 feet or less (above sea level), the dam reduces the water release rate in increments of 5 cfs down to 20 cfs, which is the absolute minimum. The dam will continue to release water at this rate until they see the water levels rise again.

The North Anna plant experienced such a drought in 2001, where lake levels fell as low as 245 feet, one foot above the shutdown threshold for the plant. After the drought, the plant added two extra feet of depth to their intake pipes to lower their minimum operating depth from 244 to 242 feet. We learned that this was relatively cheap and easy to do because the company that built the intake structures already had

a kit available to make such modifications. Additionally, the intake pipes were constructed vertically from the surface, which made it easy to add depth. On a side note, it is interesting that North Anna's intake depth is reported at 27 feet, but only an eight foot drop in water levels forces the plant to shutdown, according to plant officials.

Some plants, however, do not have a contingency plan that would allow them to continue operation through a drought. Plant Scherer said that if the water level of Lake Juliette were to decrease, they would simply reduce electricity output and water withdrawals until the water level was too low to for the plant to operate at all. Plant Scherer did not seem overly concerned about lower water levels and seemed to have no real contingency plans to avoid capacity losses.

4.5 Long Term Drought Preparations

In order to prepare for extreme drought situations and other water availability concerns, it is important that power plants consider new, water conservative technologies when will building new units. Many plants lack a long term plan for significantly reducing water usage. Listed below are technologies that could help plants operate more effectively in drought periods and regions of high water demand and low water supply.

4.5.1 New Cooling Technologies

There are newly developed systems that have been proven to significantly reduce consumed and withdrawn water. Some of these technologies can be used to retrofit plants, while others will require capital investment in order to build new infrastructure.

Indirect dry cooling is a technology that is being used all over the world at power plants and chemical plants. This type of cooling system has major advantages because it requires no water besides the amount needed to fill the system's pipes. This is because the system does not allow for evaporation. It first uses water to cool steam in the heat exchanger, then sends this water to a large tower where it is cooled by air before recirculation. The tower works by sending the plant flue gases up the tower, which causes an updraft of warm air that draws in cool air through openings in the base of the tower. This allows power plants to have better site locations that are not dependent on water bodies.

The National Energy Technology Laboratories (NETL) has done a project to change the design of induced draft systems to capture more of the evaporated water that leaves the cooling system in the form of a steam plume. Traditional towers have one location where cool ambient air meets warm moist air, and the water evaporates out as seen in Figure 4.15. This system does not collect all of the water present in the steam, and a lot of water is lost in the steam plume leaving the tower.

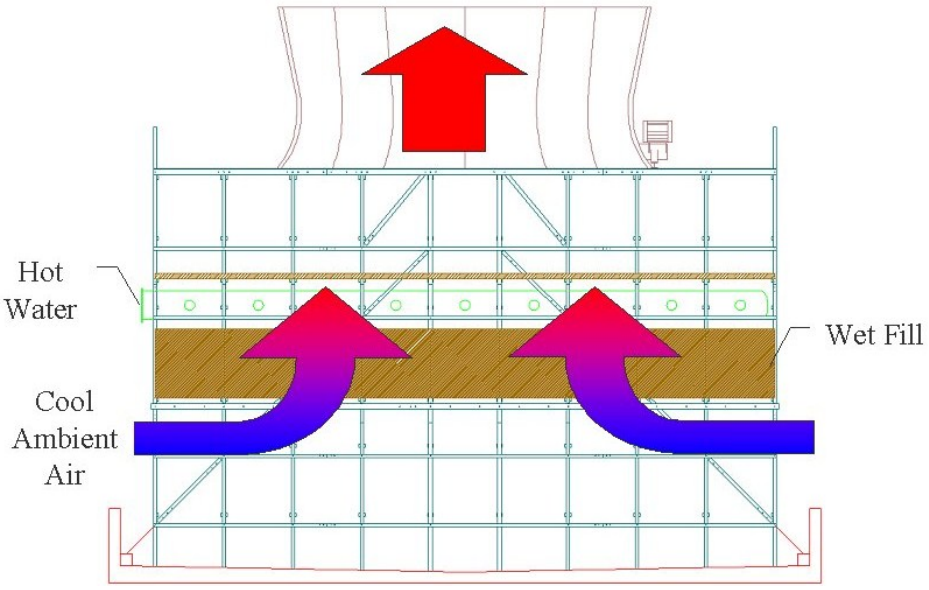

Figure 4.15: Traditional Cooling Tower (NETL, 2009, p. 3)

The new system, known as the SPX Air2Air water conservation cooling tower, provides several locations for heat exchangers to condense out the water from the steam and keep it from being lost into the air. This set up can be seen in Figure 4.16.

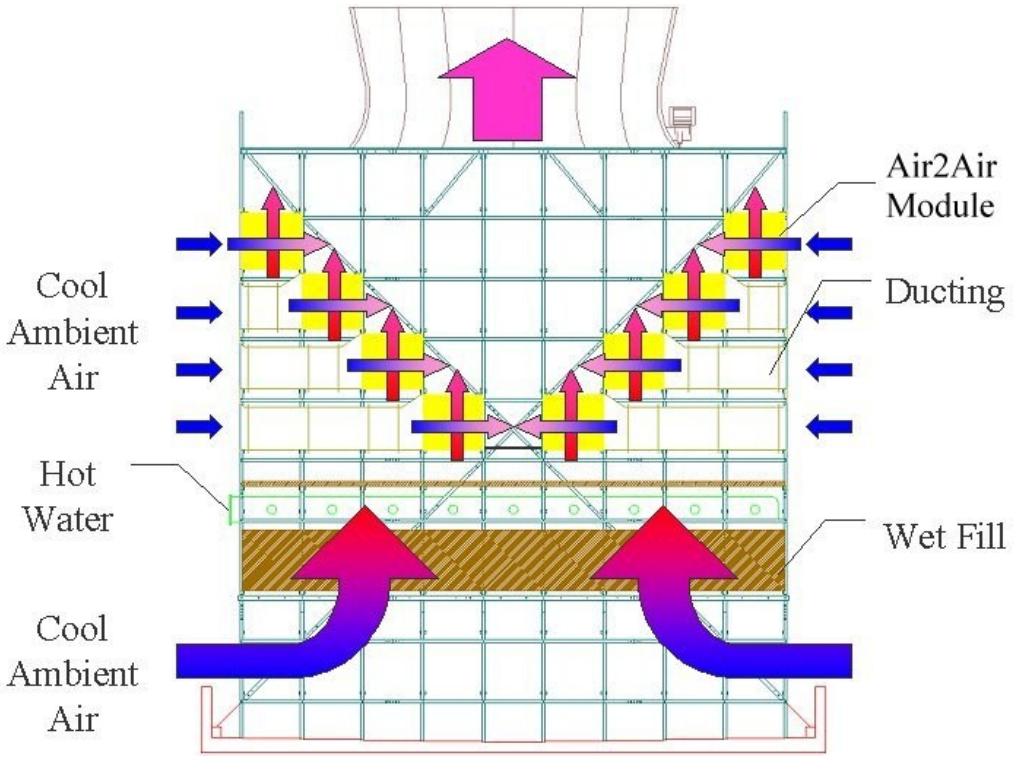

Figure 4.16: SPX Air2Air Cooling Tower (NETL, 2009, p. 4)

The SPX Air2Air system allows for 10-25 % less water loss due to evaporation, with the average being 20 % less. If power plants in the Southeast were to adopt this system, the energy sector could see significant water savings. For example, the Clover power plant, which consumes 370 million gallons of water a year, could save almost 75 million gallons of water that is normally lost. The down side of this approach is that the Air2Air cooling tower has higher capital cost because it is a larger, more complicated structure and cannot be retrofitted to existing towers. The NETL project manager informed us that power plants may be reluctant to take a risk with a new technology like the Air2Air system until they have clear evidence that it will be beneficial and cost effective.

In addition to indirect dry cooling technology, which does not require water, and water conservative wet cooling technology, mentioned above, there is an emerging

hybrid cooling system, which is a combination of both wet and dry cooling. The cooling water can be pumped to either the dry cooling or wet cooling systems separately, or both systems in tandem, by using valves to control the water flow. Hybrid systems can save energy by running their wet cooling system during normal times and save water by running their dry or combined systems during dry times. Additionally, the hybrid system can send hot air produced from the dry cooling system to the top of the wet cooling tower. The hot air mixes with saturated air from the wet tower and absorbs some of its moisture, which almost completely reduces the visible plume. The hybrid system allows for more cooling capacity and reduces the amount of water consumed by the system. Also, this technology can be retrofitted to plants in the Southeast that are currently, or primarily using wet cooling towers.

According to the Early Site Permit (ESP) for the construction of a new nuclear reactor at North Anna power plant, the reactor will be cooled by a wet cooling tower and a dry cooling tower (Nuclear Regulatory Commission, 2011). This hybrid system will have the ability to operate in water conservation mode, energy conservation mode, and a combination of the two. Water conservative mode will run the dry cooling tower, which will allow for no additional water to be withdrawn, but require a constant supply of electricity to run the fans. The energy conservative mode will only use the wet cooling tower, which is a natural draft tower that does not require any additional energy. This combination system can also operate using both towers to allow for maximum water cooling.

From plant experts we have learned that they do not intend to build additional intake infrastructures to accommodate for the hybrid system. They will use the once

through intake system for units 1 and 2 to supply make-up water to the wet cooling system. However, Dominion is going to add an additional 3 inches of water to Lake Anna in order to account for the additional water needed for their new system. We also learned that they will not use the new cooling tower system to provide water to units one and two. Systems like this can be used at plants that already have a wet cooling system and will allow for continuous operation in times of droughts.

4.5.2 Alternative Cooling Water Sources

As an alternative to using surface water in recirculating cooling systems, it is possible to use unconventional water sources. The most successful example of alternative cooling water is treated municipal wastewater. Wastewater has already been used as a source of cooling water for some power plants in the Western U.S. This source requires little tertiary treatment before being used in the cooling system, and it is available around the country. The amount of available wastewater is also proportional to the size of the regional population and the regional energy demand, which makes for a good match for power plants.

Another alternative water source is mine pool water. After mines have been depleted and closed, they collect large amounts of water. This water can be pumped to a power plant and used in a recirculating cooling system. The limitations to this method are that the water may require a substantial amount of treatment prior to being used in a cooling system, and this water can only be found where there are old mines.

A third alternative source of water is recycled industrial water. This water comes from mining and gas extraction activities such as natural gas hydraulic fracturing. This water also needs a substantial amount of treatment before it can be run through a

cooling system and may also have high transportation costs unless the power plant is located next to the mining operation. All of these options require the installation of pipes and pumping equipment as initial capital cost that varies with a plant's proximity to the water source. The water may also require additional pretreatment, but these alternative sources do not require any additional surface or ground water to be used, and therefore they avoid the rules of CWA 316(b) and could provide a constant source of cooling water in dry areas.

4.5.3 Waste heat/water Uses

According to NETL's Barbara Carney, there are a number of ways to utilize the waste heat from cooling systems. Specifically for coal-fired plants, she mentioned coal drying. In this process, you would use the waste heat from the boiler to dry the coal, which in turn would allow the coal to burn much more efficiently. This process also allows for the use of waste heat and, potentially, the capture of water from the coal, which can be used in the cooling processes. Some low quality coals can be as much as 40% water by mass. Coal drying increases the overall efficiency of a plant and can be retrofitted to existing cooling systems.

Cooling water effluent may also be used for desalination. In a meeting with ARPA-E's James Klausner, he explained a great deal about desalination as an alternative use for waste heat. He mentioned two different types of processes to accomplish desalination: thermal evaporation and reverse osmosis membranes. Reverse osmosis membranes filter out salt and other dissolved solids, but let some dissolved minerals pass through. This produces water of drinking quality. Also, the warm water is less viscous so it travels through the membrane more easily than cold water and therefore

requires less energy to pump through the membranes. In the thermal processes water is evaporated, leaving behind all suspended and dissolved solids, including minerals. This water is not suitable for drinking, but its high level of purity is valuable for industrial purposes. These desalination processes are driven by heat that would normally be expelled into the air or receiving water. In addition to providing fresh water, desalination processes benefit the environment because hot water is not released into the environment.

These alternate uses of waste heat and discharge water allow for the system as a whole to be more efficient. With increasing energy demands it is important that our power generation systems are operating at the maximum possible efficiency.

4.6 Summary

In our studies we have found that certain plants are vulnerable to droughts and EPA regulations. Above average population growth is straining water resources at an unsustainable level that is threatening power generation, among other things. Most power plants seem to have short term contingency plans in place to deal with water shortages, but more robust and water conservative long term plans need to be considered in a region where water supply appears to be decreasing and demand increasing. Many of these technology options are currently available, but have not yet been commercialized in the United States. In our next section we present our conclusions and recommendations for the thermoelectric power industry in the Southeast.

5. Conclusions and Recommendations

Based on the results of our research we have identified several conclusions that could help better manage the water-energy situation in the southeastern U.S. From these conclusions we developed recommendations for addressing the water-energy situation in the region. We recommend the following:

- Power plants need to develop short term contingency plans and look into long term investments to abate impacts future droughts
- The industry should shift away from the traditional once though cooling system towards recirculating systems
- The Department of Energy should invest more in research and development of water conservative technologies because power plants are afraid of investments of new technologies because of the high risk involved
- The EIA forms should be more specific and consistent with their questions and should be reviewed for accuracy and completion

Our conclusions and recommendations are organized into three sections of discussion: reliability, cooling technology, and data.

5.1 Reliability: Generation is threatened at a plant level

The SERC Summer 2008 Reliability Report on the electric reliability of the region in times of droughts concluded that even in the most severe droughts, there would be no energy production issues, although electricity price increases would be likely (Cauley, 2008). This, however, reported on the regional system as a whole, not on a plant by plant basis. Our report has analyzed the thermoelectric power plants of the region at a

plant level. We concluded that energy production in drought scenarios is a threat on an individual plant basis even though the region's overall energy production would not be in danger. In talking with a few of the plants' managers, we realized that they had to resort to their contingency plans in the 2007-2009 drought in order to be able to continue to provide electricity to their region.

Global climate change models predict that the severity of droughts in the future will increase (see background section 2.4 for more on climate change). This would mean that if the plants have already been experiencing water related problems in past drought years, then they will continue to experience similar and more extreme problems in the future. In Figure 4.2, you can see the upward growth in population for the Southeast region from 2000-2010. If the population continues to increase, electricity generation and water use will grow accordingly. We can conclude, therefore, that the water-energy problem from the demand side will continue to become worse in the future. Thus it is important that plants develop short term contingency plans in case a severe drought should occur, but they also should consider long term options that will help increase the reliability of the plants' operation.

Of the 25 plants we investigated, a substantial portion, 38%, have once-through cooling systems. These plants are the most affected by climate change and droughts because of water temperatures and water availability. Figure 4.7 shows how much more water is needed for once-through compared to recirculating systems. Also, the higher the temperature of the cooling water, the less effective it is; thus more water is needed to achieve the same amount of cooling. From this, we can conclude that the once-through systems will be the most affected in drought situations. Accordingly, we

recommend that the once-through systems be phased out on smaller water bodies such as smaller rivers and reservoirs. The use of sea water for once-through cooling is still feasible, especially when paired with the use of desalination technologies, but plants will need to account for the large increases in discharge temperatures as well as the effects on the natural marine life.

5.2 Technology: Lower water use by enhancing technology

The vulnerability of power plants is highly related to their cooling system technology. Each cooling system has different benefits and drawbacks. On average, the once-through cooling systems in the region withdraw 46,000 gallons per MWh. Even if the plant is located on a large lake or river, the fresh water is likely used in other industries as well. Technologies are available to reduce the water usage with either wet cooling towers or dry cooling. While dry cooling requires large amounts of electricity to run, the potential to save water is enormous, and in a drought situation, an advanced dry cooling system would see fewer problems. New wet cooling technology also can significantly reduce water use, especially in comparison to traditional wet cooling, and can protect plants from EPA regulation restrictions and drought situations. Because we have determined that the Southeast is at risk of future drought related problems with power generation, we recommend that policies be enacted to influence a switch to cooling systems that will be able to operate even in extreme weather situations. We also recommend that despite the advances in technology through investment and work by agencies such as ARPA-E and NETL, there should be more investment and research done to continue developing more efficient cooling systems. Power plants are afraid of investing in new technologies because of the high costs and high risks that are involved.

With more technologies available, the plants will have more options to choose from that work both financially and operationally in their favor.

5.3 Data: Improving data collection for more accurate analysis

Originally we had wanted to look at trends in water usage, electricity generation, and water temperatures by looking at EIA data for the selected power plants over a 10 year time period. This was rather difficult because the types of data collected changed from year to year and some plants left sections blank. The EIA data contained sufficient information to enable us to generate ample graphs and perform sufficient analysis; however our group has identified some recommendations to make the public databases more user-friendly.

The EIA data forms that are sent out to the power plants should be more specific in their questions so that the numbers and units are standard, making the data more reliable. During our meeting with EIA statistician, Cha-Chi Fan, she warned us that some of the data is hard to compare between plants because the answers are up to the interpretation of the plant employee. As a result of such problems, we recommend that the DOE review the submissions for accuracy as well as completeness. If they were able to fact-check the forms, it would make the data more credible and ultimately more useful for research. It is also important that the EIA keep the questions they ask consistent through the years so that analysis over extended periods of time is possible. At this time, some organizations in the DOE do not trust EIA data enough to conduct analyses with it. If the forms could be standardized, and the data were known to be more accurate, then in future years the data could be used to provide more accurate profiles of plants across the United States over long time periods.

References

Argonne National Laboratories. (2010). Water vulnerabilities for existing coal-fired power plants. Retrieved from http://www.evs.anl.gov/pub/dsp_detail.cfm?PubID=2547

Carney, B. (2011a). Institutional impediments to using alternative water sources in thermoelectric power plants. *National Energy Technology Laboratory.* Retrieved from http://www.ipd.anl.gov/anlpubs/2011/08/70656.pdf

Carney, B. (2011b). Reducing water freshwater consumption at coal-fired power plants: approaches used outside the United States. *National Energy Technology Laboratory.* Retrieved from http://www.netl.doe.gov/technologies/coalpower/ewr/water/pdfs/Outside_US_Approaches%20NETL%201493.pdf

Carney, B., Feeley, T., & McNemar, A. (2009) Power plant-water R&D program. *National Energy Technology Laboratory.* Retrieved from http://www.netl.doe.gov/technologies/coalpower/ewr/water/pdfs/NETL%20Paper%20Unesco%20Conference.pdf

Cauley, G. (2008). Summer 2008 drought impact in SERC region. *SERC Reliability Corporation.* Retrieved from http://www.serc1.org/Documents/Regional%20Entity%20Documents1/Regional%20Entity%20Documents%20%28All%29/P6-10%20SERC%20Summer%202008%20Special%20Reliability%20Assessment%20of%20Drought%20Impacts%20BREC%20markup-mbh.pdf

Chandel, M. K., Pratson, L. F., & Jackson, R. B. (2011). The potential impacts of climate-change policy on freshwater use in thermoelectric power generation. *Energy Policy, 39*(10), 6234-6242. doi: 10.1016/j.enpol.2011.07.022

Christian, D. (2003, September 25). North Anna early site permit application. Retrieved from http://pbadupws.nrc.gov/docs/ML0625/ML062580102.pdf

Cooperman, A., Dieckmann, J., & Brodrick, J. (2012). Power plant water use. (Water/Electricity trade-offs in evaporative cooling, part 2). *ASHRAE Journal, 54*(1), 65.

Corrigan, P. (2009). The 2007-2009 drought. Retrieved from http://www.erh.noaa.gov/rnk/Newsletter/Spring_2009/drought/drought_07_09.html

Department of Energy. (2012a). A Brief History of the Department of Energy. Retrieved 9/10/2012, from http://energy.gov/management/history/brief-history-department-energy

Department of Energy. (2012b). Estimating Appliance and Home Electronic Energy Use. Retrieved from http://energy.gov/energysaver/articles/estimating-appliance-and-home-electronic-energy-use

Department of Energy. (2012c). Leadership. Retrieved 9/13/2012, from http://energy.gov/leadership

Department of Energy. (2012d). Mission. Retrieved 9/12/2012, from http://energy.gov/mission

Department of Energy. (2012e). Office of Policy and International Affairs. Retrieved 9/11/2012, from http://energy.gov/pi/office-policy-and-international-affairs

Department of Energy. (2012f). Offices. Retrieved 9/10/2012, from http://energy.gov/offices

Department of Energy. (2012g). Organization Chart. Retrieved 9/13/2012, from http://energy.gov/about-us/organization-chart

Department of Energy. (2012h). Prices and Trends. Retrieved from http://energy.gov/public-services/energy-economy/prices-trends

Department of Energy. (2012i). Science Innovation. Retrieved 9/11/2012, from http://energy.gov/science-innovation

Department of Energy Office of Chief Financial Officer. (2012, February). FY 2013 Congressional Budget Request. Retrieved 9/11/2012, from http://www.cfo.doe.gov/budget/13budget/ content/volume3.pdf

Dominion Energy. (2012). Brayton Point Power Station. Retrieved from https://www.dom.com/about/stations/fossil/brayton-point-power-station.jsp

Environment News Service. (2008). Southeast water scarcity blamed on overpopulation. Retrieved from http://www.alternet.org/story/143493/southeast_water_scarcity_blamed_on_overpopulation?page=0%2C1

Environmental Protection Agency. (2008). Technology characterization: steam turbines. Retrieved from http://www.epa.gov/chp/documents/catalog_chptech_steam_turbines.pdf

Environmental Protection Agency. (2012a). Brayton Point Station: Final NPDES Permit. Retrieved from http://www.epa.gov/region1/braytonpoint/index.html.

Environmental Protection Agency. (2012b). Climate change basics. Retrieved from http://www.epa.gov/climatechange/basics/

Environmental Protection Agency. (2012c). Cooling Water Intake Structures- CWA Section 316(b). Retrieved from http://water.epa.gov/lawsregs/lawsguidance/cwa/316b/

Environmental Protection Agency. (2012d). Water resource use | clean energy. Retrieved 9/9/2012, from http://www.epa.gov/cleanenergy/energy-and-you/affect/water-resource.html

Environmental Protection Agency. (2012e). Water supply in the U.S. Retrieved from http://www.epa.gov/WaterSense/pubs/supply.html

Feeley, T. J., Skone, T. J., Stiegel, G. J., McNemar, A., Nemeth, M., Schimmoller, B., . . . Manfredo, L. (2008). Water: A critical resource in the thermoelectric power industry. *Energy, 33*(1), 1-11. doi: 10.1016/j.energy.2007.08.007

Filippini, M., & Hunt, L. C. (2012). US residential energy demand and energy efficiency: A stochastic demand frontier approach. *Energy Economics, 34*(5), 1484-1491. doi: 10.1016/j.eneco.2012.06.013

Finlayson, Jock. (2011). Global energy demand and supply. *Fraser Forum.* Retrieved from http://www.fraserinstitute.org/uploadedFiles/fraser-ca/Content/research-news/research/articles/global-energy-demand-and-supply.pdf

Flatow, I. (Interviewer) & Peterson, T. (Interviewee). (2012). Climate change ups odds of heat waves, drought [Interview Transcript]. Retrieved from http://www.npr.org/2012/07/13/156731302/climate-change-ups-odds-of-heat-waves-drought

Guseva, V. P., & Chebotina, M. Y. (2000). Changes in plankton abundance, biomass, and chemical composition under the influence of the cooling system of the Beloyarsk nuclear power plant. *Russian Journal of Ecology, 31*(1), 24-31. doi: 10.1007/BF02799722

Hendrick, S. (2010). State restrictions on new nuclear power facility construction. *National Conference of State Legislatures.* Retrieved from http://www.ncsl.org/issues-research/env-res/states-restrictions-on-new-nuclear-power-facility.aspx

Hensley, J. C. (2009). Cooling tower fundamentals. *SPX Cooling Technologies, Inc.* Retrieved from http://spxcooling.com/pdf/Cooling-Tower-Fundamentals.pdf

Henry, M. F. (2006). *Effects of cooling water discharge from a thermoelectric power plant on the nutrient and phytoplankton dynamics in Port Moody Arm, British Columbia, Canada. Retrieved from https://circle.ubc.ca/handle/2429/18541*

International Energy Agency. (2012). World Energy Outlook. Retrieved from the DOE database

Lindzen, R. S. (1997). Can increasing carbon dioxide cause climate change? *Proceedings of the National Academy of Sciences of the United States of America*, 94(16), 8335-8342. doi: 10.1073/pnas.94.16.8335

McNally Institute. Cavitation. Retrieved from http://www.mcnallyinstitute.com/01-html/1-3.html

National Energy Technology Laboratory. (2008). Water Requirements for Existing and Emerging Thermoelectric Plant Technologies. *National Energy Technology Laboratory.* Retrieved from http://www.netl.doe.gov/energy-analyses/pubs/WaterRequirements.pdf

National Energy Technology Laboratory. (2009). Use of Air2AirTM technology to recover fresh-water from the normal evaporative cooling loss at coal-based thermoelectric power plants. Retrieved from http://www.netl.doe.gov/technologies/coalpower/ewr/water/pp-mgmt/pubs/42725%20%20Final.pdf

Nuclear Energy Institute. (2012). Electric power generation. Retrieved from http://www.nei.org/howitworks/electricpowergeneration/

PCI Northeast. (2010). Dominion Energy Brayton Point Power Station. Retrieved from http://www.pcine.org/projects/project.cfm?articleID=549D43DE-E0A6-A96A-B51FEE77363DCB5E

Pump World. (2012). Suction Cavitation. Retrieved from http://www.pumpworld.com/Cavitation_suction_cavitation.htm

Richmond, William. (2011, December 19th). First Brayton Point Cooling Tower Starts Operating. Retrieved from http://www.heraldnews.com/news/x2019337778/First-Brayton-Point-cooling-tower-starts-operating#ixzz272UKMP4B.

Roston, E. (2012). Shale fracking makes U.S. natural gas super power. *Bloomberg.* Retrieved from http://www.bloomberg.com/news/2012-09-26/shale-fracking-makes-u-s-natural-gas-superpower-now-what-.html

Seager, R., Tzanova, A. & Nakamura, J. (2009). Drought in the southeastern United States. *Lamont-Doherty Earth Observatory.* Retrieved from http://www.biologicaldiversity.org/campaigns/overpopulation/pdfs/Seager_etal_SE_2009.pdf

Sehlke, G., & Wichlacz, P. (2009). U.S. Department of Energy's role in the energy-water nexus. *Journal of Contemporary Water Research & Education, 143*(1), 56-62. doi: 10.1111/j.1936-704X.2009.00066.x

Singham, J.R. (2011). ACHE. *Thermopedia.* Retrieved from http://www.thermopedia.com/content/663/

Sovacool, K.S. & Sovacool K.E. (2009, July). Identifying future electricity – water tradeoffs in the United States. *Energy Law Journal, 30*(1), 11.

Tel Aviv University. (2012). Climate change may lead to fewer – but more violent – thunderstorms. Retrieved from http://www.aftau.org/site/News2?page=NewsArticle&id=16927

Tonn, B., & Eisenberg, J. (2007). The aging US population and residential energy demand. *Energy Policy, 35*(1), 743-745. doi: 10.1016/j.enpol. 005.12.011

Torcellini, P., Long, N., & Judkoff, R. (2008). *Consumptive water use for U.S. power production.* Retrieved from http://www.nrel.gov/docs/fy04osti/33905.pdf

U.S. Drought Monitor. (2012). Drought monitor archives. Retrieved from http://droughtmonitor.unl.edu/archive.html

U.S. Energy Information Administration. (2006). 767 data form. Retrieved from http://www.eia.gov/cneaf/electricity/page/eia767/

U.S. Energy Information Administration. (2010). International Energy Statistics. Retrieved from http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=93&pid=44&aid=33&cid=regions&syid=2000&eyid=2010&unit=MM

U.S. Energy Information Administration. (2012a). Annual Energy Review. Retrieved from http://www.eia.gov/totalenergy/data/annual/showtext.cfm?t=ptb0801

U.S. Energy Information Administration. (2012b). Electric Power Monthly. Retrieved from http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_1_1

U.S. Energy Information Administration. (2012c). Petroleum and Other Liquids. Retrieved from http://www.eia.gov/petroleum/supply/annual/volume1/

U.S. Energy Information Administration. (2012d). US States. Retrieved from http://www.eia.gov/state/

U.S. Energy Information Administration. (2012e). 860 data form. Retrieved from http://www.eia.gov/electricity/data/eia860/index.html

U.S. Energy Information Administration. (2012f). 923 data form. Retrieved from http://www.eia.gov/electricity/data/eia923/index.html

U.S. Global Change Research Program. (2009). *Global climate change impacts in the United States: A state of knowledge report from the U.S. global change research program*. New York: Cambridge University Press.

U.S. Global Change Research Program. (2012). Southeast region. Retrieved from http://globalchange.gov/publications/reports/scientific-assessments/us-impacts/full-report/regional-climate-change-impacts/southeast

U.S. Nuclear Regulatory Commission. (2012). New Reactors. Retrieved from http://www.nrc.gov/reactors/new-reactors.html

Union of Concerned Scientists. (2007). Rising temperatures undermine nuclear power's promise. Retrieved from http://www.nirs.org/climate/background/ucsrisingtemps82307.pdf

USGS. (2009). Estimated use of water in the United States in 2005. Reston, Va: U.S. Geological Survey.

USGS. (2012). Water properties: dissolved oxygen. Retrieved from http://ga.water.usgs.gov/edu/dissolvedoxygen.html

Vörösmarty, C.J., Green, P., Salisbury, J., & Lammers, R.B. (2000). Global water resources: vulnerability from climate change and population growth. Retrieved from http://www.spar.msstate.edu/class/EPP-2008/Chapter%201/Reading%20material/Chapter%201%20-%20Water/Global%20Water%20Resources-Vulnerability%20from%20climate%20change%20and%20population%20growth.%20Science_2000.pdf

Wilbanks, T. Et. Al. (2012). Climate change and energy supply and use. *U.S. Department of Energy.* Retrieved from http://www.esd.ornl.gov/eess/EnergySupplyUse.pdf

Wilbanks, T. & Fernandez, S., et al. (2012). Climate change and infrastructure, urban systems, and vulnerabilities. *U.S. Department of Energy.* Retrieved from http://www.esd.ornl.gov/eess/Infrastructure.pdf

World Nuclear Association. (2011). Cooling power plants. Retrieved from http://www.world-nuclear.org/info/cooling_power_plants_inf121.html

WPI. (2012). The Interactive Qualifying Project (IQP). Retrieved from http://www.wpi.edu/academics/catalogs/ugrad/iqp.html

Appendix A: The Department of Energy

The Department of Energy (DOE, 2012a) is a department of the United States federal government with multiple purposes ranging from research on current and future energy sources to the protection and oversight of the nation's nuclear facilities. The DOE was created with the Department of Energy organization act of 1977 under Jimmy Carter in response to the 1973 oil crisis. The agency receives budget approval from the president, and it is funded by tax-payer dollars. In the past decade, the DOE's budget has grown on a scale of billions of dollars and for fiscal year 2013 is requested to be $27.2 billion (DOE Office of Chief Financial Officer, 2012). The budget points out areas where money is being saved and how the department is saving money in one area or with a certain process. According to their website, the Department of Energy (2012d) has a very straight-forward mission statement: "*to ensure America's security and prosperity by addressing its energy, environmental and nuclear challenges through transformative science and technology solutions*". Despite being a short mission statement, it covers a great deal of ground by encompassing energy, environmental and nuclear challenges.

The DOE (2012c) is run by the U.S. Secretary of Energy who is appointed by the president. Currently, this position is held by Dr. Steven Chu. Directly under Secretary Chu are three undersecretaries and eight assistant secretaries, where the undersecretaries are responsible for overseeing the major areas of the department's work, and the assistant secretaries are given management positions of major organizational elements of the department (DOE, 2012g). The rest of the agency is set

up as shown below in Figure A.1. There are many different program offices within the DOE, including Office of Electricity Delivery and Energy Reliability, Office of Environmental Management, Office of Fossil Energy, Office of Indian Energy Policy and Programs, Office of Legacy Management, Office of Nuclear Energy, and Office of Science.

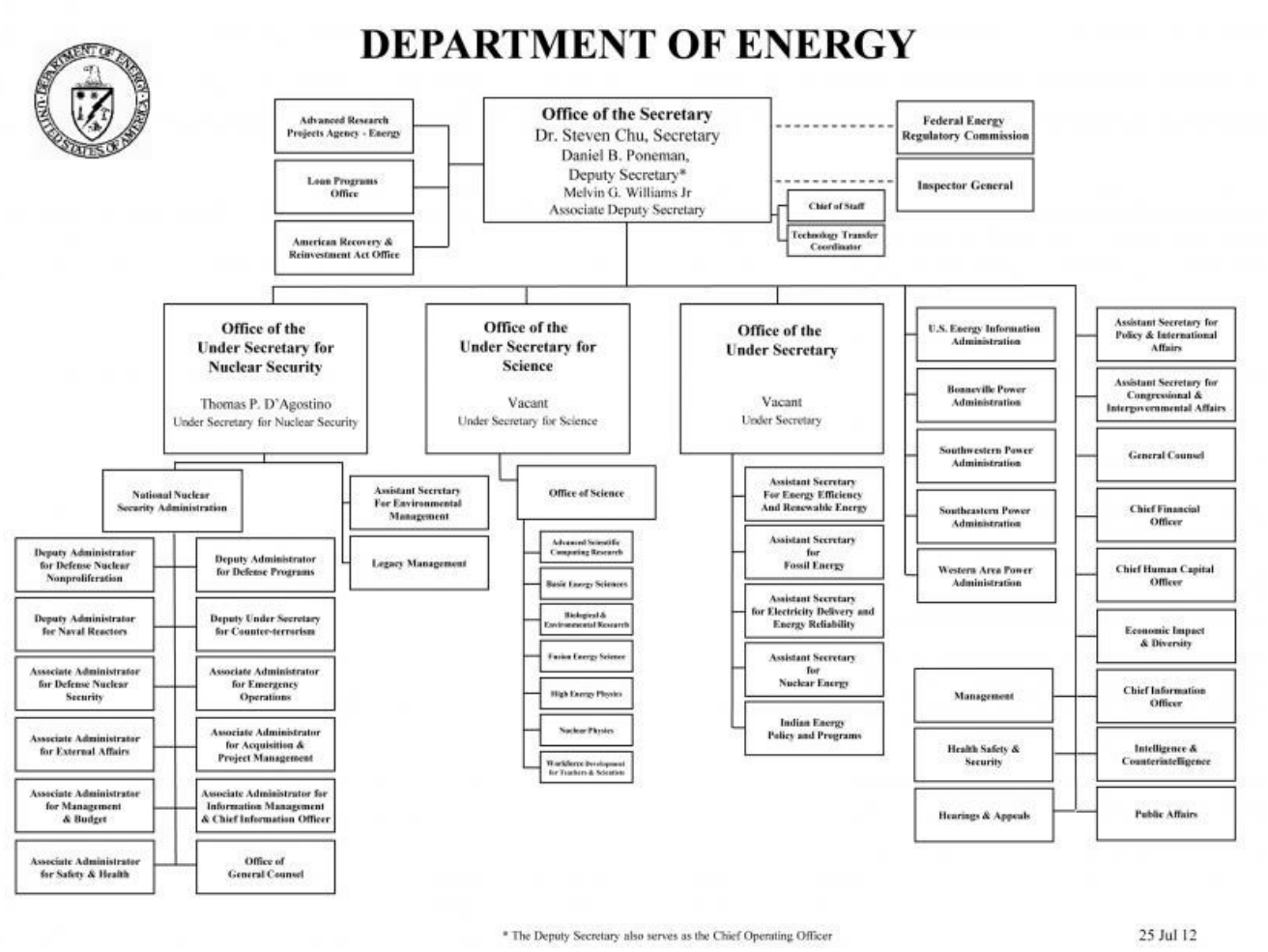

Figure A.1: Structure of Department of Energy (DOE, 2012g)

Our DOE liaisons described a wide variety of projects and departments that they have each worked on or with. Their total experience includes economic systems analysis, environmental systems analysis, economic modeling, extraction of oil and

natural gas, critical materials, rare earth metals, oil analysis, biofuel standards, nuclear waste cleanup, public administrations, and environmental policy and analysis.

A major aspect of the DOE's mission is to solve problems which are not yet major issues through research and strategic planning/policy (DOE, 2012e). This is where our project falls. They are not looking for a "quick fix" to the energy crisis, but instead an environmentally safe, economically sound, and politically approved solution. There is no perfect solution, but the Department of Energy will utilize their vast resources to develop and implement the best methods for solving real and impending problems.

The DOE had a massive 2012 budget of over $26 billion (DOE Office of Chief Financial Officer, 2012). More specifically, the Office of Policy and International Affairs, our sponsoring office, has a 2012 budget of $26,961,000. The DOE also has multiple offices, laboratories, technology centers, and field sites. These various resources have different responsibilities such as ensuring the country's ability to rely on traditional fossil fuel resources, cleaning up the environmental legacy of past nuclear energy research, and researching new technologies to improve existing energy sources (DOE, 2012i). The Office of Policy and International Affairs' mission is to advise the Secretary, Deputy Secretary, and Under Secretary within the DOE on domestic and international policy development and implementation as well as DOE policy analysis and activities (DOE, 2012e).

Under the freedom of information act, almost all data, research, and published documents are available either upfront or via request to the DOE. This allows access to any information needed to benefit or facilitate our project.

There are many supporting agencies and offices within the DOE that may be of assistance (Bauer, D., Easley, K., & Li, J., personal communication, September 6, 2012). Two of the main departments relating to our project are the National Energy Technology Laboratory (NETL) and the Energy Information Association (EIA). Relating to the environmental impact area of the project, the supporting agency will be the EPA, which controls and regulates all environmental factors. Whereas the EPA focuses solely on environmental management, the DOE works on the economic and technological aspect of U.S. energy in addition to environmental stewardship. The DOE, however, is not responsible for environmental regulation and must follow EPA regulations. The EPA, therefore, has a major influence on the DOE's policies. The main resources that will be invaluable to our project's research are Energy Information Administration (information on water use in TPPs), United States Geological Survey (possible water census data), National Energy Technology Laboratory (research on energy technology), and the National Oceanic and Atmospheric Administration (climate change data).

Appendix B: EPA Regulation of Brayton Point Power Plant

Brayton Point Station is the largest fossil-fuel burning power plant in New England with 306 acres of land (Dominion Energy, 2012). The plant provides power to about 1.5 million homes and is considered an important contributor to reliable electric service in the region. This is accomplished by their 3 coal-fired units and 1 natural gas generator as well as 3 back-up diesel generators. The plant is located on Mount Hope Bay, which is at the head of Narragansett Bay. This area has native fisheries that were being negatively affected by the elevated temperature of the water being discharged by the Brayton Point station (PCI Northeast, 2010). This is when regulation by the EPA came into play in order to protect the environment.

The EPA issued a permit to the Brayton Point Power Plant (BPPP), which forced the company to reduce the amount of water used and to lower the temperature of water that was being discharged into the Mount Hope Bay (PCI Northeast, 2010). This permit is considered a National Pollutant Discharge Elimination System (NPDES) permit, and to reach an agreement with the EPA the Power Station had switched to a "closed-cycle" cooling system, which replaced their prior "open-cycle" cooling system (EPA, 2012a). In order to accomplish this, Dominion Energy has built two 500 ft. tall cooling towers that cool the water for reuse (PCI Northeast, 2010). Dominion Energy (2012) has invested in a closed-loop system as well as an ash recovery system that will offset 170,000 tons of carbon dioxide emissions each year. This project has cost six hundred and twenty million dollars and will reduce the plant's water intake from about 1 billion gallons per day to only 5 percent of that (Richmond, 2011).

Appendix C: Summary of Meetings, Interviews, and Phone Calls

To gain knowledge on the water-energy nexus, we conducted a series of meetings and interviews with various industry experts and plant operators. The meetings with various individuals and offices of the DOE were instrumental in giving us a sense of how relevant water-energy is. In meeting with DOE personnel, we were provided with a wealth of research and reports that were crucial in the completion of our project. The interviews with plant experts came later in the timeline of the project. After most of the research and data was compiled, we talked to plant experts to get a sense of the story behind the hard data. Following are summaries from these meetings and interviews.

Table C.1: Table of Interviewees

Interviewee	Company/Agency	Title/division
Cha Chi Fan	DOE-EIA	Statistician
Robert Vallario	DOE-OS	Program Manager for Integrated Assessment Research Program (IARP)
Thomas Wilbanks	ORNL	Environmental Sciences
Caitlin Callaghan	DOE-OE	Chemical Engineer
Brittany Westlake	DOE-OE	American Association for the Advancement of Science (AAAS) Fellow
Darren Mollot	DOE-FE	Director of the Office of Clean Energy Systems-Coal
Barbara Carney	DOE-NETL	General Engineer, Environmental Projects Division
Jay Caspery	DOE-OE	Senior Policy Advisor
Vincent Tidwell	Sandia National Labs	Principle Member of Technical Staff
James Klausner	DOE-ARPA-E	Program Director
Matthew Crozat	DOE-NE	Senior Policy Advisor
Plant Representative	Georgia Power	Scherer Plant Expert
Plant Representative	Georgia Power	McIntosh Plant Expert
Plant Representative	Georgia Power	Vogtle Plant Expert
Plant Representatives	Dominion	North Anna and Surry Plant Experts

Meeting with the Energy Information Administration

Cha Chi Fan, 10/23/12

Energy Information Administration – Department of Energy

Cha Chi Fan works as a statistician in the Energy Information Administration (EIA) at the Department of Energy. She works specifically with the 923 data form which tracks monthly data from power plants. We met with the EIA in order to help us understand the workings and uses of the vast EIA data sheets.

Cha Chi told us about the differences between the various data forms that would be useful to our study. The 923 form would be able to give us operational, monthly data from most power plants in the region, but nuclear plants would only have data from 2010-2011. The sheet itself only began being created in 2007, and for the first few years, the data was incomplete. The 860 form would provide static data about the plants such as capacity and intake structure location. The 767 form would provide us with data similar to the 923, but with less detail, from 2005 back to 1985 if we needed it.

Cha Chi recommended that if we wanted more specific data about cooling systems themselves, we should contact the companies that build the systems, as they will be by far the most knowledgeable about them. She also said that It might be pertinent to contact regional authorities or regulators who will likely have more knowledge about the individual plants and their cooling operations.

Meeting with the Office of Science

Bob Vallario, Tom Wilbanks 11/7/12

Office of Science – Department of Energy

Bob Vallario and Tom Wilbanks both work for the Office of Science. They were able to give us some useful leads during our conversation with them. Bob is involved with biological and environmental research and has specifically dealt with climate and environmental sciences using integrated assessment models. Tom works at the Oakridge National Laboratory and deals with climate change consequences and their effects on energy systems. He has authored two papers on the effects of climate change, one on energy supply and demand and the other on urban infrastructure and connected infrastructure.

Bob and Tom were able to inform us that the general trend for air and water temperatures is a slow increase over time. They have been working with integrated assessment models that predict water precipitation patterns and climate change. The model has not yet been developed for the Southeast or any specific region. Tom is now working on a model that predicts changes in water temperatures due to climate change.

Bob and Tom also concluded that, in general, droughts are also increasing in frequency, severity, and duration. Heat waves are also becoming more frequent. They were also able to inform us that climate change is more intense inland. This seemed to be consistent with the drought that occurred in 2007-2009, which was concentrated in Northwest Georgia. They informed us of a drought situation in Texas in which one or more power plants were forced to shut down, leading to rolling blackouts in the state.

After this meeting Tom sent us the two ORNL reports he had authored, as well as a Union of Concerned Scientists report on the water-energy nexus.

Meeting with Office of Electricity Delivery and Energy Reliability

Caitlin Callaghan, Britney Westlake 11/7/12

Office of Electricity Delivery and Energy Reliability – Department of Energy

Caitlin Callaghan works with the Office of Electricity in collaboration with Sandia National Laboratories on a project developing a data model for electricity reliability in the Western +Texas interconnections. Britney Westlake is an AAAS fellow who is working with the DOE on the same project. We met with them to see if any of the work being done for the Sandia study could relate to the region we are focusing on.

In our discussion, we learned about what kind of demands and situations are arising that could force reductions in generation because the issues are more prevalent in the west where water is more scarce, and there are huge demands on the water for irrigation. Britney was able to talk about our region because she grew up in Georgia, and described how the water bodies are positively fed because the water tables are typically higher than the water bodies themselves, and that water has not been very much of an issue except in severe drought situations such as the 2007 drought.

They recommended that we look at some historical drought data to compare population changes, water uses, and energy demand to understand the changing profile of the south. They also gave us several people to contact, including Jay Caspary who could talk to us about electricity transmission and Vince Tidwell who could talk more in depth about the project being done by Sandia, and talk more about water use and cooling.

Meeting with Fossil Energy

Darren Mollot, Barbara Carney, 11/9/12

Fossil Energy + National Energy Technology Laboratory – Department of Energy

Darren Mollot works with the office of Fossil Energy (FE) on clean energy programs related to coal energy. Barbara Carney is a chemical engineer who works with the National Energy Technology Laboratory (NETL) on water-energy technologies, and has written many reports on new technologies or options for cooling systems at power plants.

The meeting mostly consisted mostly of Barbara giving a presentation on water-energy technology upgrades that could significantly decrease water use. She first gave us a brief description of the purpose of the cooling system in creating a vacuum of pressure which drives the cycle, which means the cooling system plays a key role in the efficiency of the plant. She then went on to describe some alternative water sources that could provide water without putting demand on clean water sources, such as treated waste water, mine pool water, and fracking wastewater. She also talked about using the used cooling water as a source of heat for other operations such as coal drying or water desalination.

Barbara then talked about several new cooling systems that were either in use or in development that have the potential to significantly reduce water use and loss. The first was the SPX air2air cooling tower, which is an induced draft cooling tower with an additional section that has extra air flow through the wet air from the evaporation which condenses more of the water out of the air, which reduces water loss, and thus water use. Other technologies include hybrid cooling which combines the best of

various types of cooling, and indirect dry cooling, which uses dry natural draft towers to cool the water. She also summarized why the US lags behind other countries in cooling technology as because we have generally ample water supplies, and the government does not require higher water use efficiency.

Meeting with the Office of Electricity Delivery and Energy Reliability

Jay Caspary, 11/16/12

Office of Electricity Delivery and Energy Reliability – Department of Energy

Jay Caspary is a consultant for the Office of Electricity Delivery and Energy Reliability (OE) who works on electricity grid modeling analytics. He mainly works with analyzing grid reliability and efficiency. He met with us after a recommendation from Caitlin Callaghan who also works in OE, and he told us about the electric grid in the southeastern region we are focusing on, as well as the state of the grid for the country as a whole.

He first informed us about the vertically integrated grid in the region, which means that the same company operates the power plants and the electric grid for a region. He told us that in a situation where a few power plants went down (e.g. severe drought scenario), one particular utility could possibly not have the generation capacity to provide for their distribution zone. He wasn't sure what kind of transmission capacities there were between utilities, but this would be a very important issue to look into if there is a significant possibility of power production reductions.

He also said that the relatively small impact of hydro power in the region is crucial to ensuring reliability of water supplies to other areas in drought scenarios because the dams don't have to hold back significant water resources.

Conference Call with Sandia National Laboratory

Vince Tidwell, 11/20/12

Sandia National Laboratory- Department of Energy

Dr. Tidwell works in Sandia National Laboratories in Sandia, NM. His recent projects have focused on the water-energy nexus in the west. He has developed projections for future weather patterns, water levels and temperatures in order to assess the water availability for power plants. Dr. Tidwell uses models to determine future effluent temperature s and then compares them to EPA regulations and NPDES permits. He mentioned in our phone call about alternative cooling technologies and alternative water sources. In the west, an issue is not having water sources so the plants must resort to using alternative cooling technologies such as dry cooling or alternative water sources such as municipal waste water. This conference call was very interesting to see the technologies and research that the Sandia Labs are performing on the water-energy nexus.

Meeting with ARPA-E

Dr. James Klausner 11/20/12

Advanced Research Projects Agency-Energy

Dr. James Klausner is a former Professor at the University of Florida who is currently working with ARPA-E. His expertise is in thermo chemistry.

Dr. Klausner was able to give us valuable insight on some of the recent drought related water issues in the Southeast. Lake Lanier, the primary drinking water source for the city of Atlanta, is a manmade lake that feeds the Chattahoochee River, which runs through Florida and Alabama and supplies cooling water to many thermoelectric power plants along the way. During the drought, water levels in Lake Lanier began to fall and Georgia decided to curtail water releases to maintain normal lake water levels. But the lower river levels had environmental consequences and more water was needed downstream for many other purposes. The states went to court and the court ruled that Georgia had to release a certain flow rate of water from the lake so that the other states would have enough water.

When asked if manmade lakes were more susceptible to droughts, Dr. Klausner said that water levels would probably fall faster because manmade lakes are not fed by natural streams and thus are not replenished easily in droughts. He mentioned that Georgia has a high dependence on agriculture, which uses massive amounts of water for irrigation. If a longer drought were to strike the area again, He fears that Atlanta and other communities may run short of drinking water.

Dr. Klausner mentioned a power plant in New York that withdrew water from the East River, but had to switch to a dry cooling system due to water related issues. He

acknowledged that dry cooling has a lower efficiency and thus more fuel is needed to produce the same amount of electricity, which in turn increases emissions. But they are significant because they use no water. He said that in order to make dry cooling more common, the technology would have to be made much more efficient.

We talked about using the waste heat from cooling system effluent to desalinate water. Dr. Klausner explained that there were two primary methods to treat the saline water, evaporation and reverse osmosis. The evaporative method uses waste heat to evaporate water and produces highly pure water that is unsuitable for drinking, but valuable for industrial uses. The reverse osmosis method, which is much more popular in the United States, produces mineralized water that is suitable for drinking. Dr. Klausner explained that it works more effectively with warm water because the warm water is less viscous and therefore can pass through the membrane with less effort. This leads to reduced pumping costs.

We learned that there are very few examples of power plant desalination in the U.S., but Dr. Klausner referred to one example in Tampa, FL. The Tampa plant was the first to use reverse osmosis desalination. The plant suffered a setback when the membranes were destroyed by mussel shells that were withdrawn by the intake system because of a lack of pre-filtration screens. The membranes cost $300 million to replace and the parent company went out of business. The power plant now has a new owner and has replaced the membranes and added pre-filtration. The system is now operating correctly.

We also discussed the potential use of waste heat for municipal heating, sometimes referred to as combined heat and power (CHP). Dr. Klausner explained that

it is harder to distribute the heat in U.S. cities because buildings are more spread out than they are in European cities where CHP is more common. There are also high pumping costs associated with this idea and the infrastructure to distribute the heat does not exist. He estimated that buildings receiving heating water from power plants would have to fall within a five mile radius of the plant for the idea to work effectively, again referring to high pumping costs. However, in the 90's and 00's there was a boom in the construction of cogeneration facilities in the U.S. where buildings would generate their own electricity and use the waste heat to heat the building. This method was internally cheaper.

Meeting with Office of Nuclear Energy

Matthew Crozat, 11/28/12

Office of Nuclear Energy – Department of Energy

Matthew Crozat works as a Senior Policy Analyst for Nuclear Energy Office at the DOE Headquarters. He explained how the nuclear industry works and identified possible resources that could pertain to our project.

He directed us to the NRC website and ADAMS search engine to gain information such as contingency plans specific to our nuclear power plants. He said that collectively nuclear plants operate well especially in heat waves at full capacity; however on a plant level there are various extreme conditions that have resulted in reduction or stop to operations. He also mentioned that the CWA as written seems unrealistic for existing nuclear plants as they are already such a large investment. Nuclear plants are a $10 billion +/- 20% capital investment without cooling towers. He noted that currently the nuclear industry is looking into building smaller reactors, which would mean a smaller investment and would be more appropriate to replace old and outdated coal plants. These smaller units could even use air cooling, but this idea is still years away from being implemented. He explained how plants need approval from the NRC and the cutting-edge technologies are more risky and harder to gain the necessary approval.

His final remarks were that industry has been heavily impacted by the policy and economics. Five years ago the NRC had lots of proposals for new nuclear plants, mostly with cooling towers, but some once-through. Because of the recession and lack of carbon tax, the development of these plants and the nuclear industry is moving slower than anticipated.

Phone Call with Plant Scherer

11/26/12

This phone call was aimed at discussing specific technical operations of the power plant. Some information that we found out was about the modifications of the cooling system. Scherer has been in the process of changing the material of their towers fill from cement to plastic because of issues related to the cement fill. We were also able to get information about the operations of the plant during the 2007 drought. From what we were told there were no reductions in plant generation but lake Juliette, the manmade lake it draws water from, was close to the point where the pumps would begin experiencing suction cavitation. If it had reached this point the pumps would have had to shut down, because such caviation can damage the pumps, effecting plant operations.

Phone Call with Plant McIntosh

11/26/12

This phone call was aimed at discussing specific technical operations of the power plant. There are two McIntosh plants located on the same site, an older 163 MW plant that uses the traditional once-through cooling and a two-unit, 1,240 MW natural gas combined cycle plant that uses closed loop mechanical draft cooling towers that are 8 years old. The primary make-up water supply to the combined cycle units is sourced from the discharge of the once-through cooling from the older plant. These towers were chosen because Georgia Power Company has installed closed cycle cooling towers on every one of its plants constructed since the clean water act was implemented. The plant indicated that the intake depth according to EIA data (which was 0) may be incorrect, depending on interpretation, because the pumps are located underwater. Some information that we found out was about the effects of the 2007-2009 drought. During this period Georgia Power participated in regular stakeholder calls facilitated by the J. Strom Thurmond dam and the Army Corps of Engineers to make sure that sufficient water was being released to meet all stakeholder needs. During the worst of the drought the plant rented temporary pumps and put them on a barge at low depths. These were a back up, but never needed, to feed the coal plant's once-through cooling system sufficiently to keep the combined cycle units operational. A modification made after the drought was the installation of a permanent auxiliary pump at a lower intake depth to increase the reliability of water supply to the two combined cycle units. With the currently proposed law 316 (b) the plant will have to make the following

modifications: add fish friendly intake screens as well as a fish return system, and modify the intake system so that it complies with the maximum intake rate.

Phone Call with Plant Vogtle

11/27/12

This phone call was aimed at discussing specific technical operations of the power plant. The two current 548 foot hyperboloid natural draft towers in use at Vogtle cools water from 120 degrees to 89 degrees at the basin. Each tower evaporates water out of the top at a rate of roughly 15,000 gallons per minute and they withdraw from the Savannah River to make up for this lost water. These towers undergo routine maintenance every 18 months when the reactors are shut down. This maintenance consists of replacing plastic spray heads, and inspection of pumps with necessary repairs. With the addition of two new nuclear reactors the plant is also installing two new natural draft towers these towers will be close to 600 feet tall to allow for more efficient cooling and more water capture. They chose to use the natural draft over the mechanical draft for two reasons. The first reason is that the natural draft towers are more inexpensive to operate compared to mechanical draft. The second reason is that mechanical draft towers have higher maintenance costs because of repairs that have to be made to the fan, i.e. fan blades, gears, etc. During the 2007-2009 drought the Vogtle plant was not affected and did not reduce generation because the Savannah River never got to the point where their pumps would begin to experience cavitation. A different plant, Plant Hatch, was affected by a drought in the 1980's and built a sandbag weir on the Altamaha River in order to have enough water around the pumps to keep them running.

Site Visit and Interviews with North Anna Generating Station

12/4/12

During our site visit to North Anna Generating Station, we were able to have multiple side conversations with Dominion staff including experts from both North Anna and Surry nuclear plants. These experts told us of the contingency plans at North Anna, and that the plant almost had to shut down in 2001 because of drought. We learned about Lake Anna's waste heat treatment system, which cools the effluent water from its once-through cooling system. After the drought, they added a 2 foot pipe section to their intake structure to lower its depth. To avoid having negative effects on the lake from elevated discharge temperatures, the plant uses a series of creeks next to the lake to cool the water over time. The dike system allows the warm outlet water to run through the dark blue areas of the lake as shown in Figure D.1. These are sectioned off from the rest of Lake Anna and it takes around a month for the warm water to be released into the lake, at which point, its temperature is less than one degree above average lake temperature. In talking to the plant experts, they said that their plant would not be affected by CWA 316(b) because it is a man-made lake so there are not any natural species.

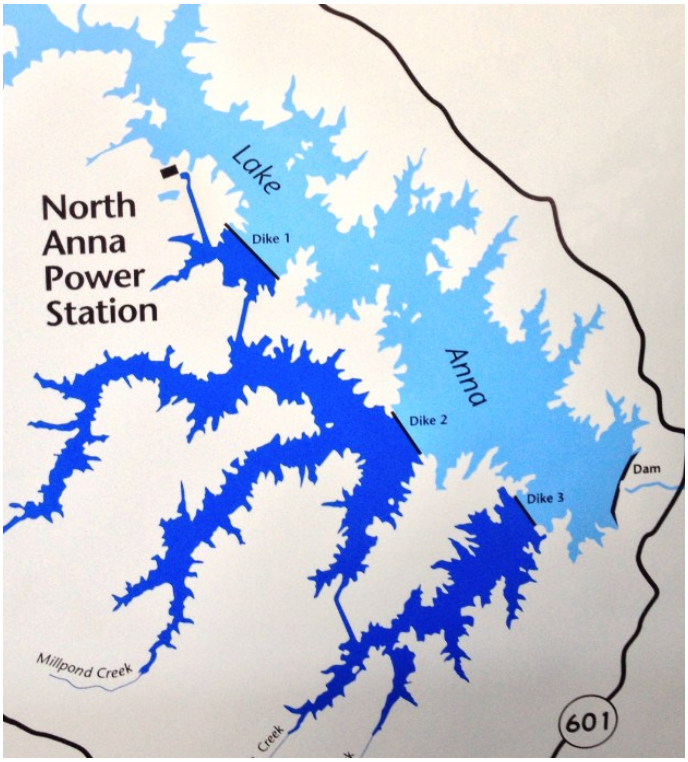

Figure C.1: Map of Lake Anna and North Anna Water Treatment (Photo by Elizabeth Kelley)

Appendix D: Selected Power Plants

The following plants were selected on the following criteria: generation capacity, location, cooling system, cooling water source, and fuel source. We plan on reducing the number of plants to twenty five for the final analysis, but for now we will look at these plants more closely and select the final twenty five based on data availability, relevance to our project, and input from our project sponsors.

Table D.1: Table of Selected Power Plants

Selected Plants	Utility ID	Plant ID	Fuel	Capacity (EIA'12)	2011 Cooling		Water Source Type	Water Source	Location
North Anna	19876	6168	Nuclear	1863	OF		Fresh Water River	North Anna River	Louisa County,VA
Surry	19876	3806	Nuclear	1638	OS		Brackish Water River	James River	Surry County, VA
Chesterfield	19876	3797	Coal/NG	1242/397	OF		Fresh Water River	James River	Chester, VA
Clover	19876	7213	Coal	865	RI		Fresh Water River	Staunton River	Halifax County, VA
Tenaska Virginia	18569	55439	NG	927	RF	RC	Fresh Water River	James River	Scottsville, VA
Scherer	7140	6257	Coal	3399.7	RN		Fresh Water River	Lake Juliette	Juliette, GA
Bowen	7140	703	Coal	3202	RN		Fresh Water River	Etowah River	Euharlee, GA
Hal B. Wansley	7140	6052	Coal	1744	RI		Fresh Water River	Chattahoochee River	Heard County, GA
Hal B. Wansley CC	17650	55965	NG	1143.1	RI		Fresh Water River	Chattahoochee River	Heard County, GA
Hal B. Wansley Unit 9	13100	7946	NG	503.3	RI		Fresh Water River	Chattahoochee River	Heard County, GA
Alvin W. Vogtle	7140	649	Nuclear	2302	RN		Fresh Water River	Savannah River	Waynesboro, GA
McIntosh CC	7140	56150	NG	1256.8	RF		Fresh Water River	Savannah River	Rincon, GA
Urquhart	17539	3295	NG	653	OF		Fresh Water River	Savannah River	Beech Island, SC
Oconee	5416	3265	Nuclear	2,538	OF		Fresh Water River	Lake Keowee	Oconee County, SC
Catawba	5416	6036	Nuclear	2,258	RF		Fresh Water River	Lake Wylie	York, SC
Cross	17543	130	Coal	2,350	RF	RI	Fresh Water River	Diversion Canal	Pineville, SC
Winyah Gen	17543	6249	Coal	1,130	RC	RF	Fresh Water River	Wadmacon Creek	Georgetown, SC
W.S. Lee	5416	3264	Coal	452	OF	RF	Fresh Water River	Saluda River	Pelzer, SC
John S. Rainey	17543	7834	NG	977	RF		Fresh Water River	Lake Russell	Anderson County, SC
Roxboro	3046	2712	Coal	2417	RC/RF	OF	Fresh Water River	Lake Hyco	Semora, NC
Brunswick	3046	6014	Nuclear	1875	OS		Salt	Cape Fear, Atlantic Ocean	Southport, NC
Marshall	5416	2727	Coal	2078	OF		Fresh Water River	Lake Norman	Terrell, NC
Belews Creek	5416	8042	Coal	2220	OF		Fresh Water River	Belews Lake	Belews Creek, NC
McGuire	5416	6038	Nuclear	2200	OF		Fresh Water River	Lake Norman	Huntersville, NC
Rowan	17650	7826	NG	924.6	RF		Other Types	City Water	Salisbury, NC

Appendix E: Maps of Selected Plants

Legend: Coal Natural Gas Nuclear

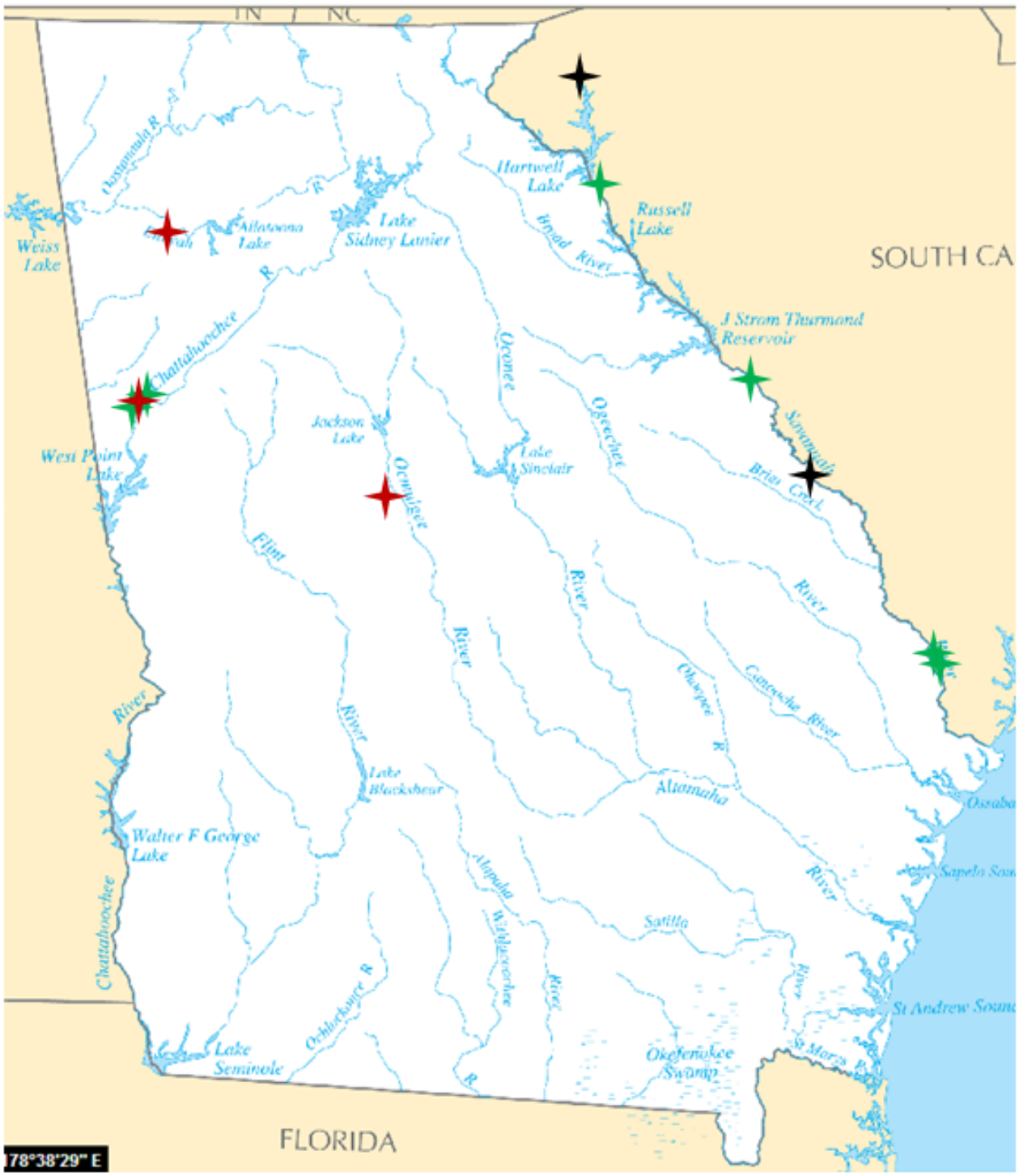

Figure E.1: Map of Selected Georgia Power Plants

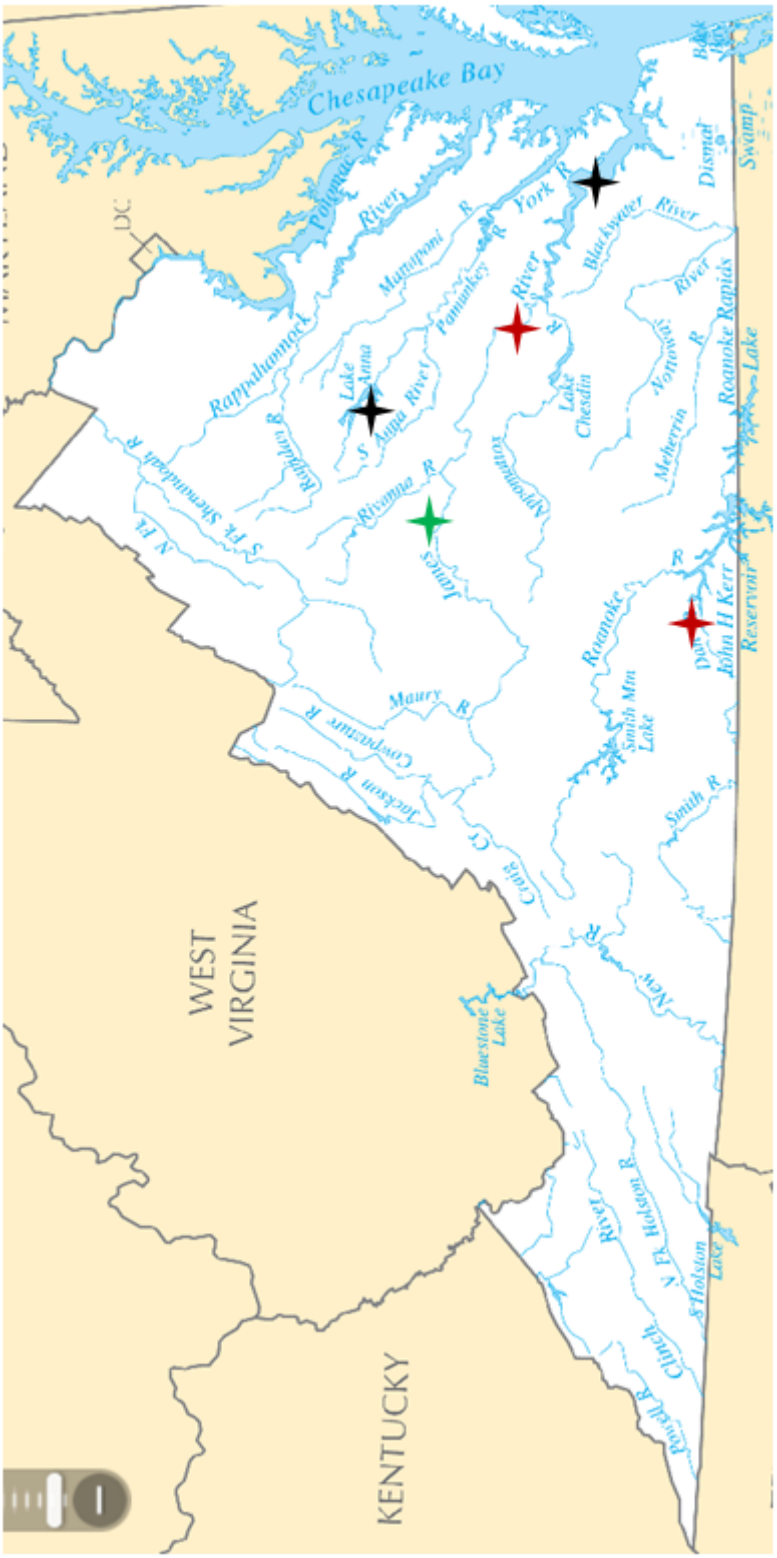

Figure E.2: Map of Selected Virginia Power Plants

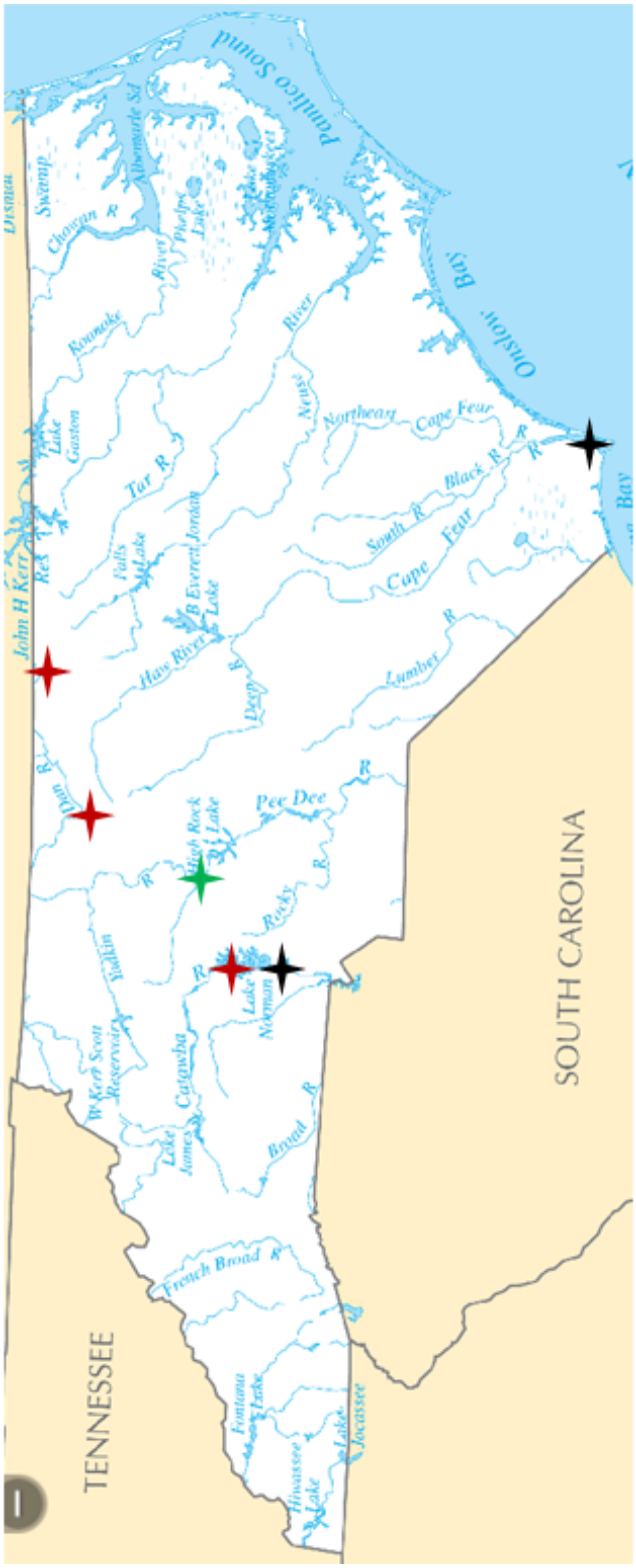

Figure E.3: Map of Selected North Carolina Power Plants

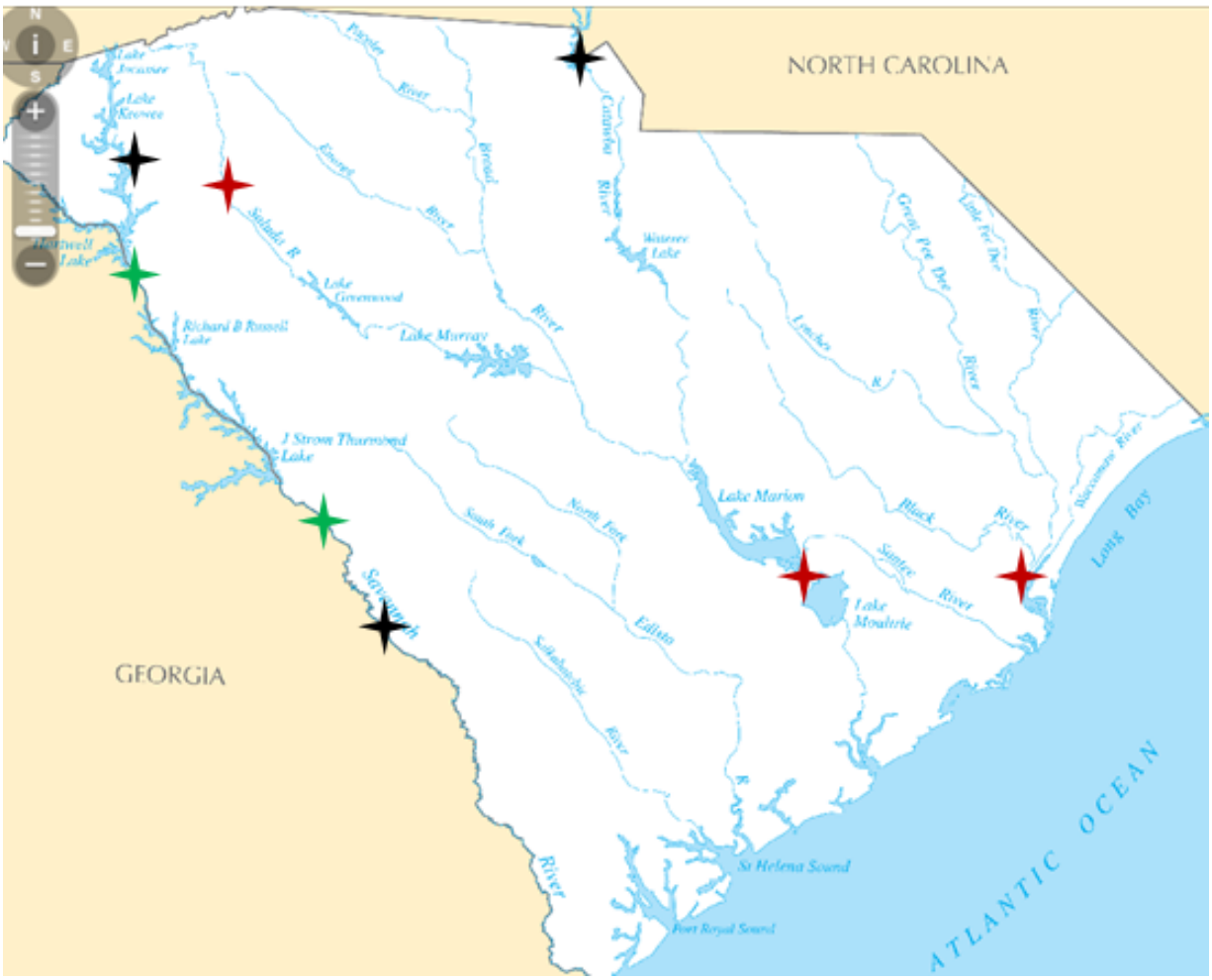

Figure E.4: Map of Selected South Carolina Power Plants