Electric Power Plant Water Use in North Carolina: Forced Evaporation and Emission Controls

by

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May 2010

Masters project submitted in partial fulfillment of the
requirements for the Master of Environmental Management degree in
the Nicholas School of the Environment of
Duke University
2010

Abstract

The link between water use and electricity generation is very strong and largely omitted from the public policies aimed at sustainable generation of electricity. Electricity is required for treating and pumping water to its destination, and water is required for electricity generation at thermoelectric power plants for cooling purposes, and for the operation of environmental control devices that reduce air emissions.

North Carolina is ranked 9th in the United States for electricity total net production, according to the Energy Information Administration. Thermoelectric power freshwater withdrawals far outstrip all other water withdrawal categories; by the year 2000, thermoelectric power freshwater withdrawals were approaching 8,000 million gallons per day, and as the population continues to grow in North Carolina, that number can only be expected to increase. They make some of the largest water withdrawals in the state of North Carolina, but they only consume approximately 3% of the water they intake.

The consumptive use percentage of 3% is misleading because it doesn't take into account forced evaporation. As mentioned previously, power plants require intake water to use for cooling purposes in the electricity generation process. The withdrawn cooling waters, once run through the plant, are returned to rivers/lakes at a higher temperature than the ambient water temperature. This higher temperature water causes additional evaporation (forced evaporation) from the river/lake. Forced evaporation should be of particular concern to North Carolina due to the severe droughts that have occurred in the region in recent history which threaten energy production as well as other water uses (ex. drinking water supply).

In this project we find that forced evaporation represents an average 22% increase in power plant water consumption in North Carolina, when compared to water consumption occurring during electricity generation on-site.

We also look at the impact that air emission controls have on the plants water consumption. If carbon emissions are required to be controlled in the future, then water use at all power plants will increase, on average, approximately 5%.

The water lost to forced evaporation and emissions controls will add additional strain to power plants located in drought prone regions.

Acknowledgements

List of Figures

List of Tables

Table of Contents

Introduction

The link between water use and electricity production/use is very strong and largely omitted from the public policies aimed at sustainable generation of electricity. Energy is required for treating and pumping water to its destination, and water is required for electricity generation at thermoelectric power plants for cooling purposes, and for the operation of environmental control devices that reduce air emissions (1). Further examples of the link between water and electricity are shown in Figure 1 below.

Figure 1: Examples of links between water and energy (1)

In addition to the water evaporation occurring within the power plant (eg. cooling towers), there is another, often overlooked type of evaporation that occurs during electricity generation called "forced evaporation." As previously mentioned, power plants require intake water to use for cooling purposes in the electricity generation process. Forced evaporation occurs after the water withdrawn by power plants is returned to the water source of origin. The

withdrawn cooling waters, once run through the plant, are returned to rivers/lakes at a higher temperature than the ambient water temperature. This higher temperature water causes additional evaporation (forced evaporation) from the river/lake.

Fossil-fired power plants also require water for the operation of emissions control technologies. Emission control technologies include scrubbers, which remove sulfur dioxide (SO2) particles from exhaust fumes, and carbon capture and sequestration (CCS) equipment, which reduce carbon dioxide (CO2) emissions. As future regulations require or create incentives for the installation of emissions control equipment, the question of how much water is consumed per kilowatt hour (kWh) of electricity generated gains tremendous importance, particularly in regions like North Carolina where droughts are frequent and the demand for both water and electricity is projected to increase.

The main goal of this paper is to quantify the water use for electricity generation in North Carolina. Specifically, we will provide estimates for the amount of annual water lost due to electricity production 1) from forced evaporation, 2) scrubber use, 3) and from theoretical future carbon capture technology.

Section 1 begins with a background on North Carolina water and energy policies, followed by a discussion of the methods used to estimate forced evaporation and scrubber/carbon capture water use in Section 2. Section 3 discusses the analysis performed, and final estimates are included in Section 4, the results section. The implications of the water use estimates are included in Sections 5 and 6, the discussion and conclusion sections.

Section 1: Water and Energy Policies in North Carolina

Water Withdrawals by North Carolina Power Plants

North Carolina is ranked 9th in the United States for electricity total net production, according to the Energy Information Administration (2). Of this electricity, three-fifths is provided by coal-fired power plants, one-third by nuclear power, and hydroelectric and natural gas-fired power plants provide the rest (3). Duke Energy and Progress Energy are the two main utility companies in North Carolina that provide power to a state population of 9.4 million.

A study by the U.S. Geological Survey identified the major water withdrawal categories in North Carolina and the amount of water withdrawn by these categories over the course of 30 years (4). The amount of water withdrawn by these categories is defined as the total volume removed from the water source (5). As can be seen in Figure 2 below, thermoelectric power freshwater withdrawals far outstrip all other water withdrawal categories. By the year 2000, thermoelectric power freshwater withdrawals were approaching 8,000 million gallons per day. Self reporting of water withdrawals by North Carolina electric utilities during 2004 to the Division of Water Resources resulted in a total average daily withdrawal of approximately 9,200 million gallons per day (6). This increase in daily water withdrawals by thermoelectric power plants from 2000 to 2004 helps to demonstrate that as the population continues to grow in North Carolina, water withdrawals by power plants can only be expected to increase.

Figure 2: Water withdrawals by category in North Carolina (4)

North Carolina power plants are required to report water withdrawals because they are one of the industries that withdraw over 100,000 gallons of water per day in the state. All water withdrawals made for cooling purposes in North Carolina come from surface water reserves (7). They make some of the largest water withdrawals in the state of North Carolina, but they only consume approximately 3% of the water they intake (8). Consumptive water use is defined as the amount of water removed for use (in this case by power plants) and not returned to its source (5).

Forced Evaporation at North Carolina Power Plants

The consumptive use percentage of 3% is misleading because it doesn't take into account forced evaporation. As discussed previously, power plants require intake water to use for cooling purposes in the electricity generation process. The withdrawn cooling waters, once run through the plant, are returned to rivers/lakes at a much higher temperature than the ambient water temperature. This higher temperature water causes additional evaporation (forced evaporation) from the river/lake.

Forced evaporation should be of particular concern to North Carolina due to the severe droughts that have occurred in the region in recent history which threaten energy production as well as other important water uses such as drinking water supply. Although it can be argued that water lost to forced evaporation is not truly lost because it returns to the water cycle and will eventually return to earth, this does not prevent the regional drought issues of North Carolina from being exacerbated by forced evaporation.

North Carolina Water Policies

Many regulations and policies monitor North Carolina's various regions and water resources. The North Carolina Capacity Use Act of 1967 applies to the Central Coastal Plain Capacity Use Area: 15 southeastern counties in NC (9). This region is suffering from declining ground water levels so this act requires reporting and measurement of water use in addition to incremental cutbacks in water use over time. The North Carolina Interbasin Transfer Act of 1993 (as amended in 2007), requires that any transfer of surface waters between the 17 major river basins and 21 sub-basins greater than two million gallons per day is approved by the Environmental Management Commission. The Federal Tennessee Valley Act regulates

structures in the tributaries of the Tennessee River (western North Carolina) including intake and discharge pipes or dams. The Tennessee Valley Authority keeps records of water withdrawals and use in these tributaries. The United States Army Corps of Engineers is responsible for building, operating, maintaining, and managing locks, dams, and lakes on the Yadkin, Cape Fear, Neuse, and Roanoke Rivers. The numerous regulators and variety of water sources they monitor add to the complexity of water management in the state. Although the various state and federal regulations in place provide much information and data to water managers, they don't provide a unified approach to state water management (10).

Response to Drought

In recent years, North Carolina has become increasingly concerned with the occurrence of drought in the state. Severe drought occurring from 1998 to 2002 prompted the North Carolina General Assembly to pass House Bill 1215: Conserve Water/Promote Green Energy. This legislation requires that water conservation measures implemented in North Carolina are evaluated and reported by the North Carolina Department of Environment and Natural Resources (DENR) (10). The concept of historically abundant water supply in North Carolina made educating citizens during the 1998 to 2002 drought on the limited amount of water supplies and the need for conservation measures difficult (11).

The most recent severe drought occurred from 2007 to 2008 and threatened to shut down operating power plants in the Catawba River Basin. This posed a major threat to overall electricity generation in North Carolina because plants located in this region account for approximately 50% of North Carolina's baseload generation capacity (7). One of the responses to this most recent drought was the introduction of Senate Bill 907, Water Resource Policy Act

of 2009, to the General Assembly (not yet passed). A key precedent set by this legislation would be the requirement for large water withdrawers in the state to pay initial application/renewal fees and annual fees to obtain a water withdrawal permit. However, the annual fee would assign a very small value to water, with the cost per gallon being a miniscule fraction of a penny. All water withdrawals over 100,000 gallons per day would require a paid permit, so the regulation would apply to power plants (12). Currently, most large water withdrawers (over 100,000 gallons per day) in North Carolina are required to report water withdrawals but do not need a permit.

To further examine the effect of electricity generation on water supply/availability, eighteen baseload and intermediate load water-intensive power plants in North Carolina with generation capacities above 250 megawatts were identified and are listed in Table 1 below.

Table 1: Baseload/intermediate water-intensive power plants in North Carolina with generation capacity greater than 250 MW

Power Plant	Parent Company	Fuel Type	Capacity (MW)[1]	County
McGuire Nuclear Station	Duke Energy	Nuclear	2,200	Mecklenburg
Brunswick	Progress Energy	Nuclear	1,875	Brunswick
Shearon Harris	Progress Energy	Nuclear	900	Wake
Lincoln Combustion	Duke Energy	Oil/Gas	1,200	Lincoln
Rockingham Station	Duke Energy	Oil/Gas	825	Rockingham
Allen Steam Station	Duke Energy	Coal	1,140	Gaston
Belews Creek	Duke Energy	Coal	2,240	Stokes
Buck Steam Station	Duke Energy	Coal	369	Rowan
Cliffside	Duke Energy	Coal	760	Cleveland/Rutherford
Dan River	Duke Energy	Coal	276	Rockingham
Marshall Steam Station	Duke Energy	Coal	2,090	Catawba
Riverbend Steam Station	Duke Energy	Coal	454	Gaston
Asheville	Progress Energy	Coal	376	Buncombe
Cape Fear	Progress Energy	Coal	316	Chatham
Lee	Progress Energy	Coal	397	Wayne
Mayo	Progress Energy	Coal	742	Person
Roxboro	Progress Energy	Coal	2,424	Person
Sutton	Progress Energy	Coal	600	New Hanover

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[1] Duke Energy: http://www.duke-energy.com/power-plants/franchised.asp
Progress Energy: http://www.progress-energy.com/aboutenergy/powerplants/index.asp

Section 2: Methods

In this section we describe the methods used to estimate water consumption by selected electric power plants in North Carolina. The 18 baseload and intermediate load water-intensive power plants in North Carolina with generation capacities above 250 megawatts were identified and selected using the EPA's eGRID data base and the Duke Energy and Progress Energy websites. Electricity generation information and environmental factors were considered to calculate forced evaporation rates at the 18 baseload and intermediate load water-intensive power plants in North Carolina. This information was also used to calculate scrubber and carbon capture water use at these power plants using the Integrated Environmental Control Model (IECM) (13).

Forced Evaporation

The amount of forced evaporation that occurs at each power plant depends upon both environmental factors and plant-specific factors. In order to estimate the amount of forced evaporation occurring at individual power plants, data from each plant was used to generate an annual estimate.

To calculate an estimate of the amount of water consumed due to forced evaporation at major power plants, an equation developed by William Mills and Carrie Munill was used (14). This equation can be applied to power plants that utilize once-through cooling. Once-through cooling systems use water local to the plant, such as from a nearby river or lake, to cool the condenser water. As shown in Figure 3 below, the local river water is pumped through a heat exchanger to condense the steam, and is then returned to the river at a much higher temperature (15).

Figure 3: Diagram of once-through cooling system (15)

The Mills/Munill forced evaporation equation used to evaluate the 18 selected power plants is listed below. The values used for each of the equation's variables to calculate the forced evaporation rate at each power plant are included in Table 2.

Forced Evaporation Equation:

$$E_f = \frac{\alpha_\Delta}{\rho\lambda}(1 - e_s - e_p)\frac{H_e}{e_p}$$

E_f = Forced evaporation rate
α_Δ = Ratio of evaporation perturbed energy flux components
e_s = Fraction of total input energy dissipated by stack emissions
e_p = Fraction of total input energy that generates electricity (net)
H_e = Power plant electricity generation flux
λ = Latent heat for evaporation
ρ = Water density

9

Table 2: Variable values for forced evaporation calculation

Variable	Value
α_Δ	0.4 [2]
e_s	0.0 (nuclear), 0.1 (steam cycle)
e_p	0.33 (nuclear), 0.38 (steam cycle)
H_e	eGRID annual net generation of each power plant [3] [MWh/yr]
λ	4184 [597.3 – (0.564 x T(C°))] [J/kg] T(C°) = ambient temperature in Celsius
ρ	1000 [kg/m^3]

To illustrate how forced evaporation has been estimated we provide a sample calculation of the Asheville plant:

Sample Calculation: Asheville Plant

$$E_f = \frac{\alpha_\Delta}{\rho\lambda}(1 - e_s - e_p)\frac{H_e}{e_p}$$

Step 1: The latent heat of evaporation (λ) varies with water temperature. It was assumed that the average water temperature was 21° Celsius (T(C°) = 21°C). Using the equation below, the latent heat of evaporation (in J/kg) was calculated, and will be used for all power plant calculations.

λ = 4184 [597.3 – (0.564 x 21°C] = 2,449,547.904 [J/kg]

Step 2: The annual net generation for the Asheville plant available in eGRID (He) is provided in the units: MWh/yr. In order to correctly utilize the equation, the annual net generation must be converted to J/year.

H_e = (2370895 MWh/yr)(3,600,000,000 J/MWh) = 8.5 x 10^15 [J/year]

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[2] Estimates of Forced Evaporation from Thermoelectric Power Plants that Utilize Once-Through Cooling Systems
[3] U.S. EPA eGRID2007: http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html

Step 3: Using the information provided by eGRID and the constants listed in Table 2, forced evaporation can be calculated for the Asheville plant.

$$E_f = \frac{0.4}{(1000\,\text{kg/m\textasciicircum3})(2449547.904\,\text{J/kg})}(1-0.1-0.38)\frac{8.5\text{x}10\text{\textasciicircum}15\,\text{J/year}}{0.38}$$

$$E_f = 1{,}907{,}254.388 \text{ m\textasciicircum3/year}$$

Step 4: In order for the forced evaporation rate to be in a more accessible format, the rate needs to be converted to million gallons per year.

E_f = 1907254.388 m^3/day (264.17 U.S. gallons/m^3)/1,000,000

E_f = 503.84 million gallons per year

Scrubber and Carbon Capture Water Use from Coal-Fired Power Plants

Water use by coal-fired power plants is likely to increase if they are retrofitted with scrubbers and carbon capture and sequestration (CCS) equipment to reduce air emissions. Flue gas desulfurization (FGD) technology is typically used to remove sulfur dioxide from the exhaust flue gases. Wet scrubbing is the most common method of FGD that uses lime or limestone to remove sulfur dioxide (16). Although only the Asheville plant was identified by eGRID to have installed WFGD technology it is very likely that in the future the rising cost of SO2 emissions allowances will create the need for retrofits with WFGD. In this analysis we calculate the water use of plants assuming a scenario in which all are retrofitted with WFGD.

Recent proposals for federal climate-energy policy like the Waxman-Markey Bill (American Clean Energy and Security Act of 2009) indicate that in the future several coal-fired power plants are likely to be equipped with carbon capture and sequestration technology (CCS). This technology would be used to capture carbon dioxide released in power plant emissions, compress it, and transport it to a site where it will be stored at a geological formation. Existing power plants will likely be retrofitted with amine-based or chilled ammonia post-combustion

CCS systems. Both technologies are water intensive and there are no current commercial scale applications, but they are expected to come online within the next 10 years.

Although the future performance and costs of post-combustion CCS systems is uncertain, current knowledge indicates that for power plants with access to cold water, chilled-ammonia systems might be a better option than amine based. However, for other plants amine-based would be the technology of choice. Plants with amine-based systems require the installation of FGD equipment; otherwise the operation and maintenance costs become prohibitive (17). Given the conditions in North Carolina, we have to assume that the plants in the state would be retrofitted with amine-based systems. The water consumed during scrubber use and carbon capture (amine-based) is estimated by the IECM (13).

Water consumed by nitrogen oxide (NOx) scrubbers was not included in the analysis because, according to eGRID, North Carolina power plants do not have selective catalytic reduction equipment (SCRs) installed, but in-furnace controls which do not use water. The high price of nitrogen oxide allowances might encourage the installation of SCRs, so future analysis should consider the possibility of North Carolina plants being retrofitted with SCRs and the associated water use. To demonstrate that the amount of water used for the removal of nitrous oxides will likely be small using SCR equipment, the IECM was used to calculate NOx capture water use by the Asheville plant, resulting in 4.55 million gallons of water consumed per year.

The computer model developed at Carnegie Mellon University (IECM) allows the user to input the characteristics of the specific power plant being analyzed and based on the provided information, the model outputs various information including water use. The IECM allows users to specify information including the type of cooling system (Once-Through), the fuel type (Medium Sulfur Appalachian Coal), and the presence of emission controls (SO2 control, CO2

capture). Additional plant specific data can be input into the model such as gross electrical output and steam cycle heat rate (obtained from eGRID). Many factors of the IECM were kept constant across all of the power plants analyzed due to the lack of availability of highly detailed individual power plant data. To demonstrate the process followed, please refer to Appendix A for IECM instructions and diagrams associated with the Asheville power plant.

Section 3: Analysis

Forced Evaporation Calculation

Of the 18 power plants listed in Table 1, 16 have annual net generation data available through the U.S. EPA eGRID for 2005. According to eGRID data from both 2004 and 2005, Lincoln Combustion and Rockingham Station were offline, and will not be considered in further forced evaporation calculations.

Scrubber and Carbon Capture Water Use Calculations

In order to estimate the water consumed during scrubber use and carbon capture, eGRID data and the Integrated Environmental Control Model (IECM) were used (13). Of the 18 power plants listed in Table 1, 13 will be analyzed for scrubber and carbon capture water use. Of the five plants not included in the analysis, three are nuclear plants which don't require scrubber or carbon capture equipment, and the other two are Lincoln Combustion and Rockingham, which were offline during 2005.

Section 4: Results

Forced Evaporation

      Calculating forced evaporation occurring over the course of the year (2005) resulted in a total of 28,388 million gallons of forced evaporation for the 16 power plants included in the calculation. McGuire Nuclear Station had the highest annual level of forced evaporation (5522 million gallons), followed by Brunswick (4583 million gallons), and Marshall Steam Station (3293 million gallons). The three nuclear power plants had the highest forced evaporation rate per megawatt hour (315.3 gal/MWh) and all but one of the fossil-fired power plants had a forced evaporation rate of 212.5 gal/MWh.

Table 3: Average forced evaporation averaged over a year

Power Plant	Million Gallons Per Year	Gallons/MWh
McGuire Nuclear Station	5522.18	315.3
Brunswick	4583.40	315.3
Shearon Harris	2500.57	315.3
Allen Steam Station	1363.36	212.5
Belews Creek	3261.27	212.5
Buck Steam Station	350.01	212.5
Cliffside	793.35	212.5
Dan River	137.99	212.5
Marshall Steam Station	3293.75	212.5
Riverbend Steam Station	390.12	212.5
Asheville	503.84	212.5
Cape Fear	398.71	207.7
Lee	435.55	212.5
Mayo	1052.84	212.5
Roxboro	3145.13	212.5
Sutton	655.73	212.5

The observation that nuclear plants cause more forced evaporation than fossil-fired is consistent with an EPRI report on Water and Sustainability; however the EPRI report estimates are higher for river evaporation, with estimates of 400 gal/MWh for nuclear and 300 gal/MWh for fossil-fired power plants (18).

A report by the World Resources Institute estimates that for every 4 kWh produced, power plants consume about 1 gallon of water (19). This estimate does not consider forced evaporation, which helps demonstrates that water consumption by power plants is underestimated (if forced evaporation is considered). Nuclear plants cause about 1 gallon of forced evaporation loss for every 3 kWh produced, and fossil-fired power plants cause about 1 gallon of forced evaporation loss for every 5 kWh produced. This water loss is in addition to the general estimate of 1 gallon of water consumed during the generation of 4 kWh.

To address the uncertainty associated with the forced evaporation calculation, a sensitivity analysis was performed to see which variables had the most impact on the final product. The variable that impacted the forced evaporation equation the most was the fraction of total input energy that generates electricity, i.e. the efficiency of the plant (e_p). A change in ambient water temperature (used to calculate latent heat of evaporation) and the fraction of total input energy dissipated by stack emissions (e_s) had very little impact on the resulting forced evaporation value. As expected, when the annual net generation (H_e) is increased, for example, by 10%, the forced evaporation rate also increases by 10%.

In order to evaluate the impact electricity generation could have on drought conditions during the summer months, the generation at each power plant during ozone season was used to calculate forced evaporation rates during the ozone season of 2005. The data used previously from eGRID provides data for one year (2005), and assuming that 2005 is a typical year (no

severe weather conditions), data from eGRID in 2005 was used to evaluate and compare forced evaporation rates during ozone season. Ozone season starts on April 1st and ends October 31st every year (20). As shown in Table 4 below, ozone season power plant electricity generation varied from 38 percent to 58 percent of yearly electricity generation. One possible explanation for this variation is that some plants are responsible for baseload power production and run year round, lowering their fraction of electricity generated during ozone season. The other power plants are for intermediate loading needs, and only run when electricity demand requires them, for example, during very hot days, giving them a higher fraction of electricity generation during ozone season. Overall, approximately 44 percent of electricity generation occurred during ozone season of 2005, which corresponds to approximately 44 percent of annual forced evaporation occurring during ozone season of 2005.

Table 4: Average forced evaporation during ozone season of 2005

Power Plant	Fraction of Electricity Generation Occurring in Ozone Season 2005	Million gallons/ozone season
McGuire Nuclear Station	0.45	2483.9
Brunswick	0.44	2013.9
Shearon Harris	0.41	1017.1
Allen Steam Station	0.46	621.3
Belews Creek	0.46	1499.3
Buck Steam Station	0.50	175.7
Cliffside	0.54	429.6
Dan River	0.58	80.1
Marshall Steam Station	0.42	1390.7
Riverbend Steam Station	0.53	205.6
Asheville	0.41	207.6
Cape Fear	0.38	152.3
Lee	0.38	166.9
Mayo	0.44	465.5
Roxboro	0.45	1417.2
Sutton	0.39	254.3

Scrubber and Carbon Capture Water Use

Wet scrubbing uses water to recirculate an aqueous slurry of lime or limestone in an absorber vessel to increase contact with the flue gas and remove sulfur dioxide (16). Calculating scrubber water use occurring over the course of the year (2005) for 13 of the major power plants resulted in a total of 517 million gallons of water used. Amine-based carbon capture uses water in an aqueous amine solution to remove carbon dioxide from the flue gas by dissolving CO_2 in the water, which then reacts with the amine in an exothermic process (21). Calculating carbon capture water use occurring over the course of the year (2005) for the same 13 plants resulted in a total of 1919 million gallons of water used.

Table 5: Annual scrubber and carbon capture water use

Power Plant	Scrubber Water Use (Million gallons per year)	Scrubber Water Use (Gallons/MWh)	Carbon Capture Water Use (Million gallons per year)	Carbon Capture Water Use (Gallons/MWh)
Allen Steam Station	44.54	6.9	158.74	24.7
Belews Creek	83.3	5.4	283.50	18.5
Buck Steam Station	18.29	11.1	72.18	43.8
Cliffside	30.12	8.1	116.41	31.2
Dan River	14.95	23.0	69.60	107.2
Marshall Steam Station	76.97	5.0	243.11	15.7
Riverbend Steam Station	23.18	12.6	92.96	50.6
Asheville	32.28	13.6	127.77	53.9
Cape Fear	16.6	8.8	63.94	34.1
Lee	19.6	9.6	89.10	43.5
Mayo	28.38	5.7	110.68	22.3
Roxboro	99.32	6.7	367.38	24.8
Sutton	29.42	9.5	123.5	40.0

Emission control results show much more variability in water use by each power plant (refer to Figure 4). Scrubber water use varies from 15 to 99 million gallons per year and (theoretical) carbon capture varies from 64 to 367 million gallons per year. These values help

illuminate that carbon capture would use much more water than scrubbers do in the same power plant; carbon capture requires approximately three times the water of sulfur dioxide scrubbers.
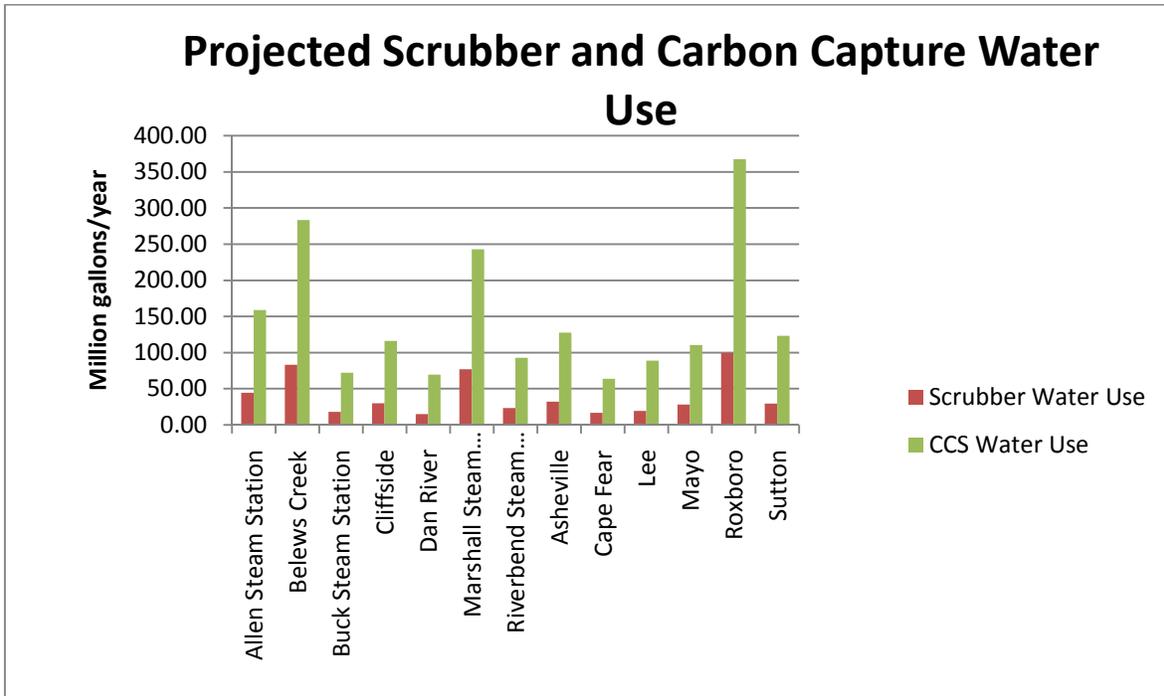

Figure 4: Projected Scrubber and Carbon Capture Water Use

There is more uncertainty associated with the IECM calculation, because many factors of the IECM were kept constant across all power plants analyzed. It would be inappropriate to change some of the initial input data (once-through cooling system, fuel type, etc.) because these inputs are not expected to vary over the short term for the plants analyzed. Electricity generation over the course of the year (eGRID data) varies each year so it's expected that output values would vary moderately if a different year's eGRID data was used. The factors that were kept constant across all power plants analyzed, due to the lack of availability of highly detailed individual power plant data, could affect the outcome of the model the most. Refer to Appendix A to view the data that was changed in the model for analysis.

Section 5: Discussion

Previous analysis has shown that the Central and Southern Piedmont regions (shown in Figure 5) of the state are the most susceptible to drought (7). Within these regions are located McGuire Nuclear Station, Marshall Steam Station, Riverbend, and Shearon Harris (and one hydroelectric plant: Cowans Ford Hydro). This is a major concern because McGuire Nuclear Station has the largest annual forced evaporation rate and Marshall Steam Station has the third largest annual forced evaporation rate, and both of these power plants are located in drought prone areas. Marshall Steam Station also had one of the highest water use values for scrubber use and carbon capture. In the summer months, this additional water use could exacerbate drought issues experienced in North Carolina.
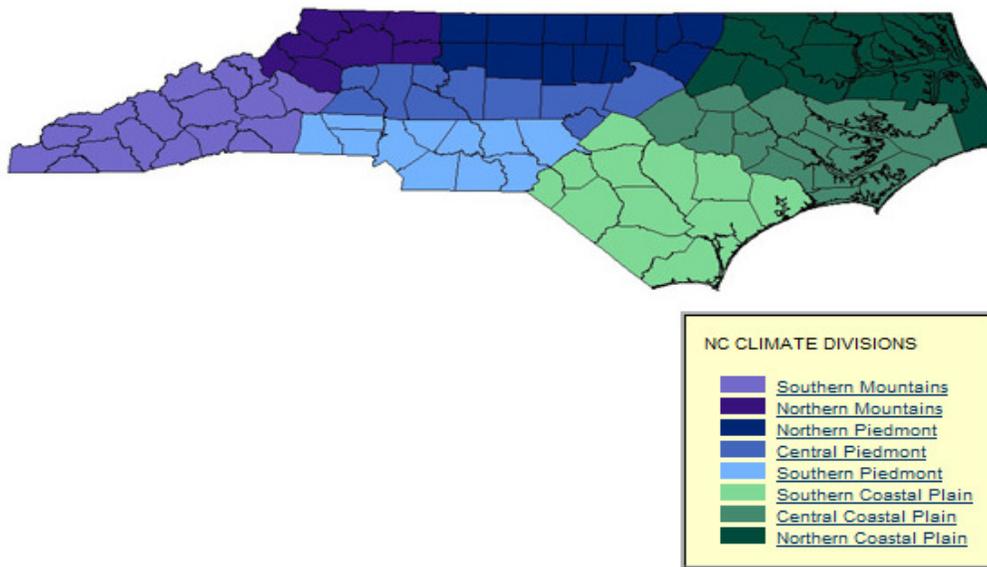

Figure 5: North Carolina Climate Divisions (22)

As shown in Figure 6 below, there is great natural variation in the amount of rainfall that occurs in North Carolina, according to the Palmer Index (23). The Palmer Index ranges from

negative 6 to positive 6, negative 6 representing the most severe drought, and 0 being normal
(24). In terms of the Palmer Index, power plant electricity generation is at risk when a drought of
negative 3.5 severity or less occurs (7). The unpredictable nature of statewide rainfall helps
support the conclusion that water withdrawals made by power plants should be monitored more
closely, especially since the social and economic side effects of drought can be very high. For
example, during the 1998 to 2002 drought, the J.H. Kerr Reservoir (on North Carolina – Virginia
State line) was unable to support regular hydroelectric power production. Replacement power
had to be purchased at a cost of approximately $1.3 million, a cost that was ultimately borne by
customers (11). This replacement power had to be purchased near the end of the drought, and
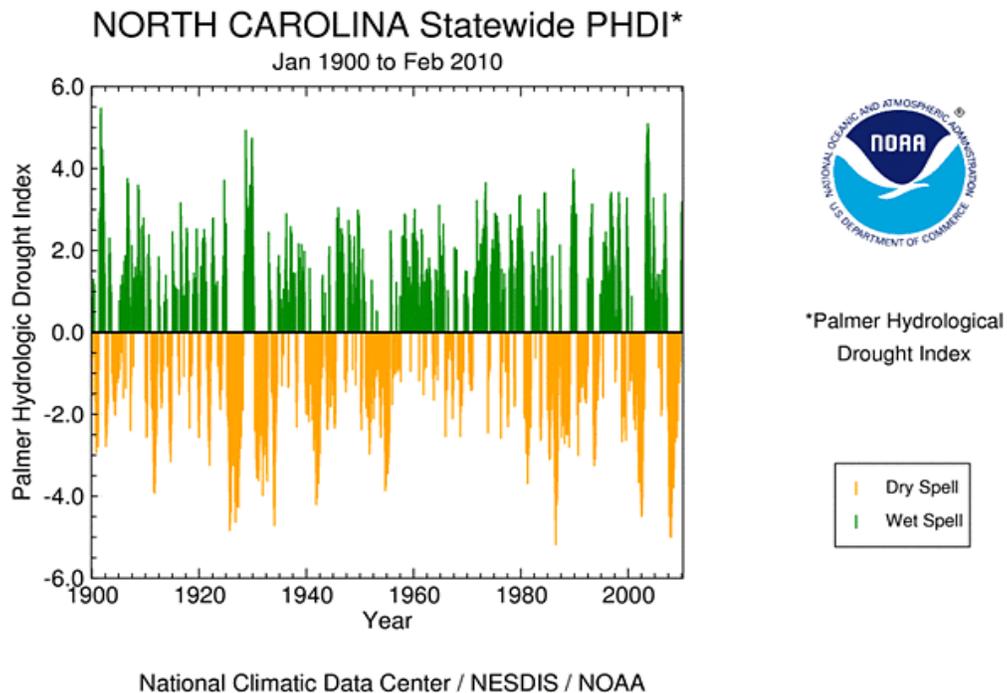had the drought lasted longer, the costs could have greatly increased.

Figure 6: North Carolina Palmer Hydrological Drought Index (23)

In addition to more monitoring of water withdrawals and water consumption occurring at power plants, another way to prevent drought exacerbation from electricity generation is to reduce demand for electricity. Consumers can reduce their demand for electricity in many ways (efficiency, conservation, and demand side management) such as purchasing energy efficient appliances, installing compact fluorescent light bulbs, reducing air conditioner/heater use, and weatherizing their homes. Another way to reduce electricity demand which is often overlooked is to reduce water consumption, because energy is required to treat and transport water. Such reductions in electricity demand, especially in the summer months, could help reduce the water consumption by power plants.

A possible additional strain on water supply in the future will emerge if carbon emissions are required to be controlled, which will increase water use at all fossil-fired power plants. As can be seen from the results of above calculations, post-combustion amine-based carbon capture can use up to three times more water than sulfur dioxide scrubbers. This water strain would be in addition to sulfur dioxide scrubber water use, because sulfur dioxide scrubber installation is a pre-requisite for amine-based carbon capture equipment. This increase in water use as more emission controls are added to power plants helps demonstrate the need to consider all the ways water is consumed during electricity generation.

To further evaluate the impact forced evaporation and scrubber/carbon capture technologies have on water consumption at power plants, these water uses are listed in Table 6 below. The "Cooling" water use term refers to the water loss that occurs during electricity generation within the power plant. The minimum and maximum values for "Cooling" are based on the assumption that 3% of intake water is consumed during electricity production. As can be seen from the increase in water use column, forced evaporation causes a large increase (22%) in

water use when compared to the average cooling water consumption of 1200 gal/MWh. The water use increase associated with scrubber and carbon capture are much lower, so emission control water use may only be a concern in drought prone regions.

Table 6: Comparing power plant water uses

Water Use	Minimum [gal/MWh]	Maximum [gal/MWh]	Average [gal/MWh]	Increase in water use
Cooling	600	1800	1200	-
Forced Evaporation	208	315	262	22 %
WFGD	5	23	14	1 %
CCS (amine-based)	16	107	62	5 %

As shown in Table 7 below, nine of the 16 plants evaluated lose over two million gallons per day of water to forced evaporation. The North Carolina Interbasin Transfer Act of 1993 requires that any transfer of surface waters greater than two million gallons per day be approved by the Environmental Management Commission. If transfers of surface water greater than two million gallons per day are regulated, then forced evaporation water consumption/loss should be regulated as well, because the amount of forced evaporation occurring is above two million gallons per day at many power plants.

Table 7: Average forced evaporation: comparing yearly and daily rate

Power Plant	Million Gallons Per Year	Million Gallons Per Day
McGuire Nuclear Station	5522.18	15.1
Brunswick	4583.40	12.6
Shearon Harris	2500.57	6.9
Allen Steam Station	1363.36	3.7
Belews Creek	3261.27	8.9
Buck Steam Station	350.01	0.96
Cliffside	793.35	2.2
Dan River	137.99	0.4
Marshall Steam Station	3293.75	9.0
Riverbend Steam Station	390.12	1.1
Asheville	503.84	1.4
Cape Fear	398.71	1.1
Lee	435.55	1.2
Mayo	1052.84	2.9
Roxboro	3145.13	8.6
Sutton	655.73	1.8

Section 6: Conclusions

The percentage increase in water use associated with forced evaporation and the rates of

forced evaporation being highest at the plants located in drought prone regions demonstrates that

forced evaporation needs to be considered in North Carolina water policies. The recent

occurrence of powering down power plants during drought reinforces the need to consider all

types of water consumption occurring as both a direct result of power production (cooling

waters) and indirect consumption after water has left the plant (forced evaporation). In order to

accurately represent the water consumption occurring at power plants, all forms of water

consumption, including forced evaporation, should be incorporated into the Water Resource Policy Act of 2009 currently under consideration by the state government.

Plans to add air emissions controls to existing power plants need to account for their impact on water consumption. Similarly siting decisions for new power plants need to estimate water needs particularly in drought prone areas. Placing new power plants in locations with already limited water resources is irresponsible and doesn't reflect the importance of water for other uses, especially for local consumption (drinking water).

In general, it's time for North Carolina to rethink its water and energy policies. Water consumption by major withdrawers should be regulated more closely and paid permits should be required. Water supply location and other factors should be considered more closely before a new facility site is selected. Various forms of water use at power plants are often overlooked, especially forced evaporation, and so more independent studies should be performed to determine the actual amount of water power plants are consuming, both on-site and downstream.
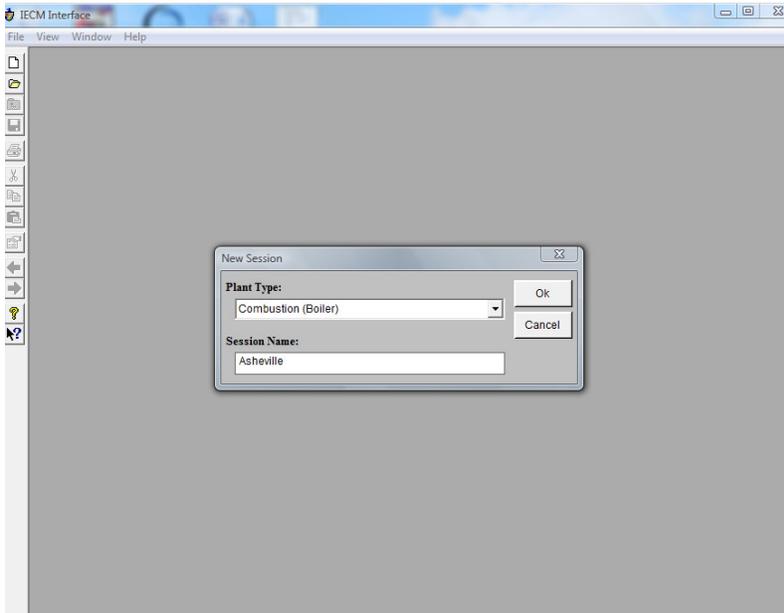
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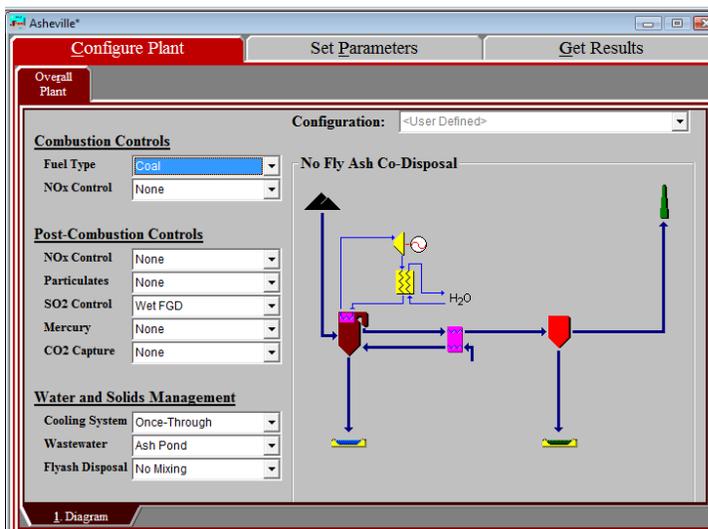12. **General Assembly of North Carolina.** *Water Resource Policy Act of 2009 (Senate Bill 907).* 2009.

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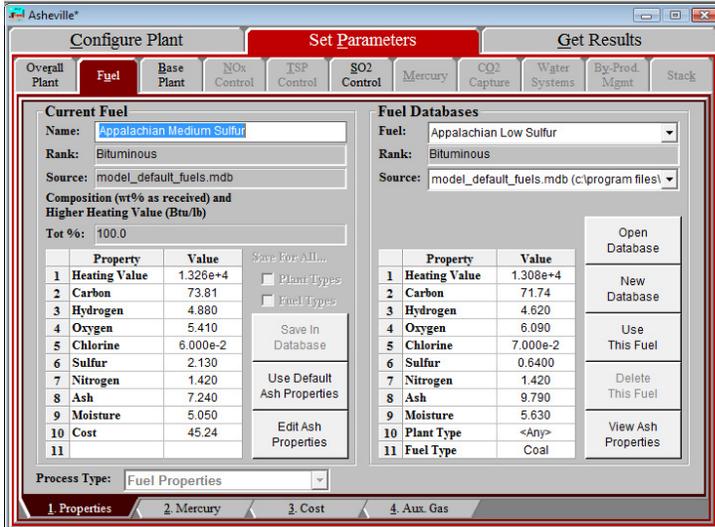
Appendix A – IECM

1) Select "New Session" button in upper left hand corner of screen (blank paper image). Select

Plant Type (Combustion Boiler) and type in name of plant under Session Name (Asheville).
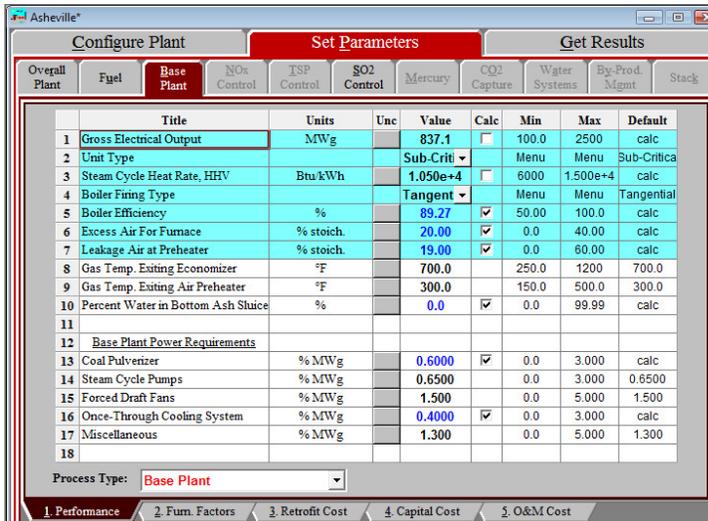

2) Under Configure Plant, Overall Plant tab, the fuel type (coal), cooling system (Once-

Through), and emissions controls (SO2 Control and CO2 Capture) are input into the model.

3) Under Set Parameters, Fuel tab, the fuel type is input (Appalachian Medium Sulfur).

4) Under Set Parameters, Base Plant tab, the gross electrical output (#1) value is changed to the nameplate capacity of the specific plant (from eGRID). Then the steam cycle heat rate, HHV (#3) value is changed to the plant nominal heat rate of the specific plant (from eGRID).

4) Under Get Results, O&M Cost tab, the cost of water used for scrubber or carbon capture is listed in millions of dollars per year. The operations and maintenance cost can then be converted to water use in millions of gallons per year.

Asheville*

Configure Plant	Set Parameters	Get Results

Overall Plant	Fuel	Base Plant	NOx Control	TSP Control	SO2 Control	Mercury	CO2 Capture	Water Systems	By-Prod. Mgmt	Stack

	Variable Cost Component	O&M Cost (M$/yr)		Fixed Cost Component	O&M Cost (M$/yr)
1	Reagent	3.018	1	Operating Labor	2.287
2			2	Maintenance Labor	1.753
3	Steam	0.2245	3	Maintenance Material	2.629
4	Solid Waste Disposal	2.846	4	Admin. & Support Labor	1.212
5	Electricity	6.401	5	Total Fixed Costs	7.881
6	Water	3.325e-2	6		
7	Total Variable Costs	12.52	7		
8			8		
9			9		
10			10		
11			11		
12			12		
13			13		
14			14		
15			15	Total O&M Costs	20.40

Process Type: Wet FGD   Costs are in Constant 2007 dollars.

1. Diagram	2. Flue Gas	3. Bypass	4. Capital Cost	5. O&M Cost	6. Total Cost